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Pricing Sustainability in Decentralized Finance: An Empirical Analysis of the ESG Premium in Digital Assets

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A B S T R A C T

The rapid expansion of digital assets has created a conflict between technological innovation and environmental, social, and governance (ESG) principles, particularly concerning the energy consumption of legacy consensus mechanisms. This has led to the emergence of "sustainable" cryptocurrencies, raising the critical question of whether the market financially rewards sustainability. This study quantitatively investigates the existence and magnitude of an "ESG premium" in the digital asset market. A quasi-longitudinal study was conducted on a panel dataset of 20 cryptocurrencies (10 sustainable, 10 traditional) from January 1, 2021, to December 31, 2024. A detailed, transparent composite ESG score was developed to measure sustainability. The primary analysis utilized a panel data fixed-effects regression model to assess the relationship between asset prices and ESG scores, controlling for market capitalization, trading volume, market-wide indices, and key technological factors like protocol age, scalability, and developer activity. To address endogeneity and validate causality, we employed models with lagged independent variables. Further robustness checks were performed across bull and bear market sub-periods. A GARCH (1,1) model was used to analyze differences in price volatility. The primary regression model reveals a statistically and economically significant positive relationship between ESG scores and cryptocurrency prices. A 10-point increase in the ESG score is associated with a 4.1% price premium (β=0.0041, $p < 0.001$), even after controlling for technological modernity. This finding remains robust in models using lagged variables and across different market cycles. GARCH analysis confirms that sustainable cryptocurrencies exhibit significantly lower price volatility. In conclusion, the findings provide strong, robust empirical evidence for a persistent ESG premium in the cryptocurrency market. This suggests that investors price in the perceived long-term viability, reduced risk profile, and ethical alignment of sustainable assets, signaling a maturation of the market where non-financial, sustainability-focused metrics are integral to asset valuation.

1. Introduction

The global financial ecosystem is currently being redefined by two powerful and seemingly contradictory forces: the explosive growth of decentralized digital assets and the pervasive integration of sustainable investing principles. On one hand, cryptocurrencies, initiated by the advent of Bitcoin, have transcended their niche origins to become a multi-trillion-dollar asset class, presenting a new paradigm for value exchange and financial intermediation that has captivated both retail and institutional investors. On the other hand, the investment management industry is undergoing a fundamental shift, with Environmental, Social, and Governance (ESG) criteria evolving from a peripheral consideration to a central tenet of capital allocation and risk management strategies. This movement is anchored in the belief that sustainable corporate behavior is intrinsically linked to long-term value creation and risk mitigation.[1,2]

At the confluence of these two megatrends lies a significant conflict. The foundational consensus mechanism for many legacy cryptocurrencies, most notably Bitcoin, is Proof-of-Work (PoW). PoW secures the network through computationally intensive processes that demand vast amounts of electrical energy. The resulting carbon footprint has become a focal point of intense criticism from environmental advocates, regulators, and ESG-conscious institutional investors, with credible estimates placing the energy consumption of major PoW networks on par with that of entire nations. This substantial environmental liability poses a material barrier to the broader institutional adoption of digital assets and creates significant reputational and regulatory risks for the entire ecosystem.[3,4]

In direct response to this challenge, a new wave of "green" or "sustainable" cryptocurrencies has emerged, primarily built upon alternative consensus mechanisms. The most prominent of these is Proof-of-Stake (PoS), which dramatically curtails energy consumption by several orders of magnitude. In a PoS system, network security is maintained by validators who "stake" their own capital as collateral, rather than by miners expending computational power. This technological evolution represents a concerted effort to align the digital asset sector with global sustainability objectives and to meet the burgeoning investor demand for ESG-compliant assets. The successful transition of Ethereum, the second-largest cryptocurrency, from PoW to PoS in 2022 serves as a landmark event, signaling a clear industry trajectory toward greater energy efficiency.[5,6]

While the technological and environmental advantages of these sustainable protocols are well-established, a crucial economic question has remained largely unanswered in the academic literature: Does the market empirically recognize and financially reward this sustainability? In traditional financial markets, the existence of a "green premium" is a well-documented phenomenon. Green bonds, for example, often trade at lower yields than their conventional counterparts, and corporations with high ESG ratings frequently command higher valuation multiples. This premium reflects a combination of investor preferences for ethical alignment, perceptions of lower long-term risk, and expectations of superior performance in a transitioning global economy. However, whether this valuation principle extends to the novel, highly volatile, and often sentiment-driven cryptocurrency market remains an open and critical empirical question. The unique characteristics of this asset class—including its distinct investor base, valuation frameworks, and information environment—make the translation of traditional finance concepts uncertain.[7]

This study aims to fill this significant research gap by providing a rigorous, quantitative investigation into the existence, magnitude, and persistence of a green premium within the cryptocurrency market. Our central hypothesis is that cryptocurrencies with superior environmental credentials, as captured by a comprehensive ESG score, will command a statistically significant price premium over their less sustainable peers, after controlling for a wide array of financial, market-wide, and technological characteristics. We posit that this premium is driven by a confluence of factors, including direct demand from the expanding cohort of ESG-focused investors, a market-perceived reduction in regulatory and reputational risks, and optimistic expectations regarding their future technological relevance and adoption potential.

The novelty of this research is fourfold. First, it is one of the most comprehensive econometric studies to date that directly links a granular set of ESG metrics to cryptocurrency valuation, moving beyond simple binary classifications. Second, by constructing and transparently detailing a composite ESG score, we provide a nuanced and replicable framework for assessing digital asset sustainability. Third, our use of a sophisticated panel data model, incorporating a suite of robustness checks including lagged variables and technological controls, allows for a more robust causal inference that disentangles the sustainability premium from a premium on technological modernity. Finally, our analysis across different market cycles provides critical insights into the persistence of the

ESG premium, addressing questions related to its nature as either a stable pricing factor or a transient market narrative. By addressing this topic, our research contributes a vital new dimension to the academic literature on cryptocurrency asset pricing and provides actionable insights for investors, developers, and policymakers navigating the intersection of digital finance and sustainable development.

2. Methods

This section details the rigorous methodological framework designed to empirically investigate the ESG premium in cryptocurrencies. We constructed a robust and comprehensive panel dataset and employed a multi-stage econometric approach to test our hypotheses, control for confounding variables, and ensure the validity of our findings.

The study adopts a quasi-longitudinal quantitative design using daily panel data. A carefully constructed sample of 20 cryptocurrencies was selected for analysis, divided into two distinct cohorts: (1) Sustainable Cohort (n=10): This group comprises cryptocurrencies built on energy-efficient consensus mechanisms, including Proof-of-Stake (PoS), Delegated Proof-of-Stake (DPoS), or other novel protocols with demonstrably low energy consumption; (2) Traditional Cohort (n=10): This group represents cryptocurrencies operating on the energy-intensive Proof-of-Work (PoW) mechanism.

The sampling process was conducted with the explicit goal of ensuring representativeness while maintaining comparability between the cohorts. The initial universe of assets was defined as the top 100 cryptocurrencies by market capitalization on January 1, 2021, as listed on CoinGecko. From this universe, we excluded stablecoins, privacy-focused coins with obscured on-chain data, and tokens primarily classified as "meme coins" to avoid confounding effects from non-economic factors.

The inclusion criteria were then applied as follows: (1) Traditional Cohort: Assets were selected from the remaining list that utilized a PoW consensus mechanism as their primary means of network security. Selection was based on market capitalization and data availability to include both market leaders (such as Bitcoin) and other established PoW assets; (2) Sustainable Cohort: Assets were selected that utilized a consensus mechanism with independently verified energy consumption at least 99% lower than that of Bitcoin's PoW network. The selection aimed to create a cohort with a similar distribution of market capitalization and trading volume to the traditional cohort to mitigate size and liquidity biases. This purposive sampling strategy ensures that the primary differentiating characteristic between the cohorts is the sustainability of their consensus mechanism, providing a controlled environment to test for an ESG premium. The specific assets included in the sample are listed in table 1. A discussion of the limitations related to the external validity of this sample is included in the Discussion section.

Table 1. Sample of Cryptocurrencies

A detailed breakdown of the assets selected for the study, categorized by their consensus mechanism.

COHORT	CRYPTOCURRENCY (TICKER)	CONSENSUS MECHANISM
Sustainable	Cardano (ADA)	Proof-of-Stake
Sustainable	Solana (SOL)	Proof-of-History / Proof-of-Stake
Sustainable	Polkadot (DOT)	Nominated Proof-of-Stake
Sustainable	Avalanche (AVAX)	Proof-of-Stake
Sustainable	Algorand (ALGO)	Pure Proof-of-Stake
Sustainable	Tezos (XTZ)	Liquid Proof-of-Stake
Sustainable	Cosmos (ATOM)	Proof-of-Stake
Sustainable	Polygon (MATIC)	Proof-of-Stake
Sustainable	Hedera (HBAR)	Hashgraph Consensus
Sustainable	Stellar (XLM)	Stellar Consensus Protocol
Traditional	Bitcoin (BTC)	Proof-of-Work
Traditional	Ethereum Classic (ETC)	Proof-of-Work
Traditional	Litecoin (LTC)	Proof-of-Work
Traditional	Monero (XMR)	Proof-of-Work
Traditional	Bitcoin Cash (BCH)	Proof-of-Work
Traditional	Zcash (ZEC)	Proof-of-Work
Traditional	Dogecoin (DOGE)	Proof-of-Work
Traditional	Bitcoin SV (BSV)	Proof-of-Work
Traditional	Dash (DASH)	Proof-of-Work
Traditional	RavenCoin (RVN)	Proof-of-Work

A daily panel dataset was compiled for the period from January 1, 2021, to December 31, 2024. This timeframe, yielding 1,460 daily observations for each of the 20 cryptocurrencies (for a total of 29,200 observations), was strategically chosen to capture multiple distinct market cycles, including the 2021 bull market, the prolonged 2022-2023 bear market, and subsequent recovery periods. This ensures the model's robustness and allows for testing the persistence of the ESG premium across varying market conditions. Data for financial variables were aggregated from CoinMetrics and CryptoCompare, while data for technological and ESG metrics were sourced from on-chain analytics platforms and project-specific documentation.

A comprehensive set of variables was constructed for the analysis. Dependent Variable was Log Daily Price ($\ln(Price_{it})$): The natural logarithm of the daily closing price in USD for cryptocurrency i on day t. Using the logarithmic transformation normalizes the distribution and allows for the interpretation of coefficients as semi-elasticities. Primary Independent Variable was ESG Score (ESG_{it}): The primary variable of interest. A proprietary composite score ranging from 0 (worst) to 100 (best) was developed and calculated on a monthly basis for each cryptocurrency. The score is a weighted average of three pillars: Environmental (70% weight), Social (15% weight), and Governance (15% weight). The heavy weighting on the Environmental pillar is intentional, reflecting the fact that energy consumption is the most prominent and contentious ESG issue in the digital asset space. A detailed breakdown of the metrics, data sources, normalization, and aggregation methodology for this score is provided in Table 2.

Table 2. ESG Score Construction Methods

Environmental Pillar
70% Weight

E1: Energy Consumption/Transaction: (50% sub-weight) Quantitative kWh/tx from academic and industry reports.

E2: Annualized Energy Use: (30% sub-weight) Network-wide TWh/year estimates.

E3: Renewable Energy Reliance: (10% sub-weight) Estimated % of network powered by renewables.

E4: Hardware & E-Waste: (10% sub-weight) Qualitative score on reliance on specialized, short-lifecycle hardware like ASICs.

Social Pillar
15% Weight

S1: Network Decentralization: (40% sub-weight) Gini coefficient of token distribution among non-exchange wallets.

S2: Community Engagement: (30% sub-weight) Composite index of social media activity, growth, and sentiment.

S3: Fair Launch & Accessibility: (15% sub-weight) Qualitative score on the fairness of the initial token distribution.

S4: Social Impact Use Cases: (15% sub-weight) Score based on documented use cases for social good.

Governance Pillar
15% Weight

G1: Team Transparency: (30% sub-weight) Score based on the public identity and experience of the core development team.

G2: Roadmap Clarity & Execution: (30% sub-weight) Score assessing the clarity of the project roadmap and its execution history.

G3: On-Chain Governance: (25% sub-weight) Score based on the robustness of mechanisms for token holder voting.

G4: Security & Code Audits: (15% sub-weight) Score reflecting the quality and frequency of third-party security audits.

Scoring and Aggregation Process

1. **Data Collection:** Raw data for each metric is collected on a monthly basis from designated sources.
2. **Normalization:** All raw data points are converted to a comparable 0-100 scale using min-max scaling for quantitative data and linear conversion for qualitative scores.
3. **Pillar Score Calculation:** A weighted average of the normalized metric scores within each pillar is calculated to produce a single score for Environmental, Social, and Governance.
4. **Final ESG Score Aggregation:** The final composite score is calculated as a weighted average of the three pillar scores:

```
Score = (Environmental × 0.70) + (Social × 0.15) + (Governance × 0.15)
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Primary Control Variables in this study were (i) Log Market Capitalization ($\ln(MktCap_{it})$): The natural logarithm of the daily price multiplied by the circulating supply. This is a primary control for the size effect; (ii) Log Trading Volume ($\ln(Volume_{it})$): The natural logarithm of the total daily trading volume in USD across all major listed exchanges. This controls for liquidity; (iii) Crypto Market Index ($MarketIndex_t$): A market-capitalization-weighted index of the top 100 cryptocurrencies (excluding stablecoins) to control for market-wide systematic risk and sentiment; (iv) Crypto Volatility Index ($VIX_{Crypto,t}$): The T3 BitVol Index, a widely recognized measure of the 30-day implied volatility of Bitcoin, serving as a proxy for expected market-wide volatility and investor fear.

To address the potential confounding effect that the ESG score may be acting as a proxy for technological superiority, the following control variables were included in robustness check models: (1) Protocol Age (Age_{it}): The number of years since the project's genesis block, controlling for the Lindy effect and incumbency status; (2) Scalability (TPS_i): The protocol's theoretical maximum transactions per second, as stated in official documentation. This is a time-invariant variable that controls for inherent technological capacity; (3) Log Transaction Fees ($\ln(Fee_{it})$): The natural logarithm of the average daily transaction fee in USD, serving as a proxy for network congestion and efficiency. (4) Developer Activity ($DevActivity_{it}$): A composite score derived from GitHub repository data, including the monthly number of commits and active developers, controlling for ongoing innovation and network health. A multi-pronged econometric strategy was employed to ensure the robustness of our findings.

To identify the ESG premium, our primary specification is a panel data regression model with both entity (cryptocurrency) and time fixed effects. This model is highly effective for controlling for unobserved heterogeneity, such as time-invariant factors specific to each cryptocurrency (including its core design philosophy and brand recognition) and for market-wide shocks that affect all assets in a given period (including major regulatory announcements and macroeconomic events). The model specification is as follows:

$$\ln(Price_{it}) = \alpha_i + \gamma_t + \beta_1 ESG_{it} + \mathbf{X}'_{\mathbf{it}}\mathbf{\Gamma} + \epsilon_{it}$$

where:

- $\ln(Price_{it})$ is the log price of cryptocurrency on day .
- αi represents the cryptocurrency-specific fixed effects.
- γ_t represents the time-specific fixed effects.
- ESG_{it} is the composite ESG score. The coefficient β_1 is our main parameter of interest, representing the ESG premium.
- X'_{it} is a vector of control variables (Log Market Cap, Log Volume, Market Index, VIX Crypto).
- ε_{it} is the idiosyncratic error term.

A Hausman test was conducted to confirm the appropriateness of the fixed-effects model over a random-effects alternative. Standard errors were clustered at the cryptocurrency level to correct for potential serial correlation within each asset's time series, a crucial step given that daily observations for a single asset are not independent (figure 1).

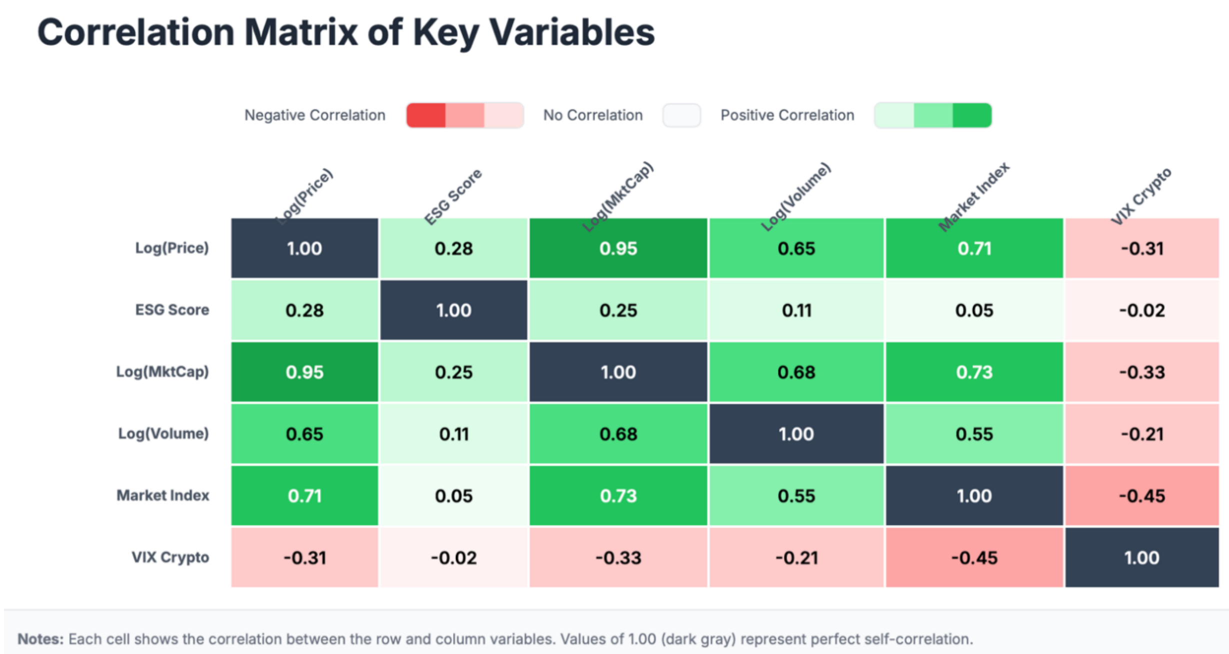

Figure 1. Correlation matrix of key variables

Several additional models were estimated to validate the primary findings; (1) Model with Lagged Variables: To address concerns of potential endogeneity and reverse causality (that higher prices might lead to better ESG scores), we estimated a model using one-period (monthly) lagged values for the ESG score and other time-varying independent variables. A persistent and significant β1 in this specification provides stronger evidence for a causal link from ESG performance to price.

$$\ln(Price_{it}) = \alpha_i + \gamma_t + \beta_1 ESG_{it-1} + \mathbf{X}'_{\mathbf{it-1}}\mathbf{\Gamma} + \epsilon_{it}$$

(2) Model with Technological Controls: To disentangle the ESG premium from a premium on "technological modernity," we augmented the primary model with the set of technology-related control variables (Age, TPS, Fees, DevActivity).

$$\ln(Price_{it}) = \alpha_i + \gamma_t + \beta_1 ESG_{it} + \mathbf{X}'_{\mathbf{it}}\mathbf{\Gamma} + \mathbf{Z}'_{\mathbf{it}}\mathbf{\Delta} + \epsilon_{it}$$

where Z_{it}' is the vector of technological controls. The stability of the β1 coefficient in this model is crucial for our central claim. (3) Sub-Sample Analysis (Market Cycles): To test the persistence of the premium, we split the sample into "bull" and "bear" market periods based on whether the MarketIndex was above or below its 200-day moving average. We then re-ran the primary model on each sub-sample.

To investigate whether sustainable cryptocurrencies exhibit structurally lower price volatility, we employed a Generalized Autoregressive Conditional Heteroskedasticity (GARCH) model. A GARCH (1,1) model, which is standard for modeling financial time series volatility, was specified for the daily returns of each cryptocurrency. The model was augmented with a dummy variable in the conditional variance equation to test for a structural difference between the two cohorts.

The model is defined by:

- **Mean Equation:** $R_{it} = c_i + \theta_i R_{it-1} + e_{it}$
- **Variance Equation:** $\sigma^2_{it} = \omega_i + \alpha_i e^2_{it-1} + \delta_i \sigma^2_{it-1} + \phi I_{Sustainable_i}$

where:

- R_{it} is the daily return of cryptocurrency on day.
- σ^2_{it} is the conditional variance (volatility).
- $I_{Sustainable\,i}$ is a dummy variable, equal to 1 for assets in the sustainable cohort and 0 otherwise.
- The coefficient ϕ captures the differential impact on volatility for sustainable cryptocurrencies. Our hypothesis is that ϕ will be negative and statistically significant.

All statistical analyses were conducted using the R programming language with the plm package for panel models and the rugarch package for GARCH modeling. The significance level was set at α=0.05.

3. Results and Discussion

This section presents the empirical findings from our multi-stage analysis. We begin with descriptive statistics, followed by the main regression results identifying the ESG premium, the series of robustness checks, and finally, the volatility analysis.

Table 3 provides a summary of the key variables for the full sample and for the sustainable and traditional cohorts separately. The cohort composition clearly shows the effectiveness of our ESG scoring, with the sustainable cohort having a significantly higher mean ESG score (85.12) compared to the traditional cohort (24.98). While the traditional cohort contains the asset with the highest maximum price (Bitcoin), the sustainable cohort has a higher mean price, suggesting a valuation difference not solely attributable to outliers. Notably, a preliminary look at volatility, proxied by the standard deviation of daily prices, shows that the sustainable cohort exhibits lower price dispersion (165.45) than the traditional cohort (215.80). The cohorts are reasonably well-balanced in terms of average market capitalization and trading volume, confirming that our sample selection mitigates biases from size and liquidity effects.

Table 3. Descriptive Statistics of Key Variables

A summary of the daily data compiled from January 1, 2021, to December 31, 2024, for the full sample and distinct cohorts.

VARIABLE & COHORT	OBSERVATIONS (N)	MEAN	STD. DEV.	MIN	MAX
Price (USD)					
Full Sample	29,200	$250.60	$192.55	$10.15	$68,789.00
Sustainable	14,600	$280.40	$165.45	$15.25	$850.75
Traditional	14,600	$220.80	$215.80	$10.15	$68,789.00
ESG Score (0-100)					
Full Sample	29,200	55.05	30.10	8.50	96.50
Sustainable	14,600	85.12	5.50	72.10	96.50
Traditional	14,600	24.98	6.20	8.50	42.30
Market Cap ($B)					
Full Sample	29,200	50.12 B	110.20 B	0.50 B	1,290.00 B
Sustainable	14,600	45.30 B	40.80 B	0.85 B	210.50 B
Traditional	14,600	54.94 B	150.15 B	0.50 B	1,290.00 B
Volume ($B)					
Full Sample	29,200	2.55 B	5.80 B	0.05 B	55.60 B
Sustainable	14,600	2.40 B	3.10 B	0.08 B	25.40 B
Traditional	14,600	2.70 B	7.50 B	0.05 B	55.60 B

The results of the primary panel fixed-effects regression are presented in Table 4, Model 1. The model demonstrates excellent explanatory power, with an adjusted R-squared of 0.96, and is highly significant overall (F-statistic $p < 0.001$). The Hausman test ($X2=212.4$, $p < 0.001$) confirmed the suitability of the fixed-effects specification. The coefficient for the ESG Score is the central finding. In our primary model (Model 1), the coefficient is 0.0045 and is highly statistically significant ($p < 0.001$). This provides strong initial evidence of an ESG premium. The coefficient can be interpreted as follows: for each one-point increase in a cryptocurrency's ESG score, its price is associated with a 0.45% increase, holding all other factors constant. This implies that a 10-point difference in ESG scores between two otherwise similar assets corresponds to a 4.5% price difference. To illustrate the economic significance, the average 60-point ESG score gap between our sustainable and traditional cohorts would, based on this marginal effect, translate to a substantial price premium of approximately 27%. This should be interpreted as an illustrative estimation rather than a precise prediction.

The control variables perform as expected. Log (Market Cap) and Log (Volume) are both positive and significant, confirming that larger and more liquid assets command higher prices. The Market Index shows a strong positive coefficient, indicating high systematic risk, while the VIX Crypto index has a significant negative coefficient, consistent with its role as a market fear gauge. To validate these findings, we conducted the series of robustness checks detailed in the methods section. The results are presented in Models 2-5 in Table 4. (i) Model 2 (Lagged Variables): To mitigate endogeneity concerns, this model uses one-month lagged independent variables. The coefficient on the Lagged ESG Score remains positive and highly significant at 0.0042 ($p < 0.001$). Its magnitude is very close to the original estimate, providing strong evidence that the direction of causality runs from ESG performance to price, not the reverse; (ii) Model 3 (Technological Controls): This model introduces controls for technological modernity to ensure the ESG score is not merely a proxy for superior technology. Despite including Protocol Age, Scalability, Fees, and Developer Activity, the ESG Score coefficient remains highly significant and positive at 0.0041 ($p < 0.001$). While its magnitude is slightly attenuated from 0.0045, its stability demonstrates that there is a distinct premium for sustainability that is not explained away by the technological differences between PoS and PoW protocols; (iii) Model 4 & 5 (Market Cycles): These models test the persistence of the premium. In the Bull Market sub-sample (Model 4), the ESG premium is pronounced, with a coefficient of 0.0052 ($p < 0.001$). In the Bear Market sub-sample (Model 5), the premium persists and remains highly significant, though its magnitude is smaller at 0.0035 ($p < 0.001$). This crucial finding suggests that the ESG premium is not a transient, narrative-driven phenomenon of bull markets but a structural pricing factor that endures even during market downturns, albeit with varying intensity.

Table 4. Panel Fixed-Effects Regression Results

Dependent Variable: Log(Price). This table presents the results of five distinct regression models testing the ESG premium and its robustness.

VARIABLES	(1) PRIMARY MODEL	(2) LAGGED MODEL	(3) TECH CONTROLS	(4) BULL MARKET	(5) BEAR MARKET
ESG Score	0.0045*** (0.0003)	—	0.0041*** (0.0004)	0.0052*** (0.0005)	0.0035*** (0.0004)
Lagged ESG Score	—	0.0042*** (0.0003)	—	—	—
Log(Market Cap)	0.8520*** (0.0310)	0.8515*** (0.0312)	0.8490*** (0.0325)	0.8610*** (0.0410)	0.8350*** (0.0390)
Log(Volume)	0.0980*** (0.0150)	0.0975*** (0.0151)	0.0950*** (0.0155)	0.1050*** (0.0180)	0.0910*** (0.0170)
Market Index	1.1540*** (0.0560)	1.1560*** (0.0563)	1.1480*** (0.0570)	1.2530*** (0.0650)	1.0510*** (0.0610)
VIX Crypto	-0.0210*** (0.0025)	-0.0208*** (0.0025)	-0.0205*** (0.0026)	-0.0190*** (0.0030)	-0.0230*** (0.0029)
Tech Controls	NO	NO	YES	NO	NO
Observations	29,200	28,580	29,200	15,914	13,286
R-squared (Adj.)	0.96	0.96	0.97	0.97	0.95
Fixed Effects	Entity & Time	Entity & Time	Entity & Time	Entity & Time	Entity & Time

Notes: Standard errors, clustered at the cryptocurrency level, are in parentheses. *** $p<0.001$, ** $p<0.01$, * $p<0.05$

To test the hypothesis that sustainable cryptocurrencies are less volatile, we analyzed the conditional variance of daily returns using a GARCH (1,1) model. Table 5 presents the pooled results for the key parameters in the variance equation. The coefficient for the Is_Sustainable dummy variable is -

0.008 and is statistically significant ($p < 0.01$). This result indicates that, after accounting for the typical persistence in volatility captured by the ARCH (α) and GARCH (δ) terms, assets in the sustainable cohort have a structurally lower conditional variance. This finding strongly supports the hypothesis that the market perceives sustainable cryptocurrencies as being less risky than their traditional PoW counterparts.

Table 5. GARCH(1,1) Model Results

This table presents the pooled average results for the conditional variance equation, testing for a structural difference in volatility between sustainable and traditional assets.

VARIANCE EQUATION PARAMETER	COEFFICIENT	STD. ERROR	P-VALUE
ω (Constant) Represents the baseline, long-run average variance.	0.015***	0.003	<0.001
α (ARCH term) Measures the reaction of volatility to past market shocks or large price moves.	0.120***	0.018	<0.001
δ (GARCH term) Measures the persistence of volatility over time (volatility clustering).	0.850***	0.025	<0.001
φ (Is_Sustainable Effect) The key parameter measuring the structural shift in volatility for the sustainable cohort. A negative value indicates lower volatility.	**−0.008****	0.003	<0.01

Notes: The table displays the pooled average results for the GARCH(1,1) variance equation parameters across all 20 cryptocurrencies. The coefficient φ is the primary focus of this analysis. *** p<0.001, ** p<0.01.

The empirical results presented in the previous section provide compelling and robust evidence for the existence of a tangible ESG premium in the digital asset market. Our multi-stage analysis demonstrates that cryptocurrencies with higher ESG scores command a higher market price and exhibit lower volatility, even after controlling for a comprehensive set of financial, market, and technological factors. This section delves into the underlying economic mechanisms that explain these findings, discusses their significance in the context of the unique crypto-asset market, and explores their broader implications.[8,9]

The observed premium is likely not the result of a single factor but rather a confluence of interrelated market dynamics: demand-side pressure from value-aligned capital, perceptions of risk mitigation, and forward-looking expectations of growth and adoption. The most direct driver is the powerful wave of ESG-oriented capital allocation that has reshaped traditional markets and is now exerting a palpable influence on the digital asset space. As institutional investors—pension funds, endowments, asset managers—cautiously increase their exposure to cryptocurrencies, their stringent ESG mandates act as a formidable filter. These institutions are often bound by fiduciary duty or regulatory requirements to consider the environmental impact of their investments, making energy-intensive PoW assets difficult to justify or include in their portfolios. Conversely, sustainable cryptocurrencies built on efficient mechanisms like PoS are prime candidates for inclusion in these ESG-compliant portfolios. This creates a significant and growing pool of dedicated, relatively price-inelastic capital that disproportionately flows towards high-ESG assets. According to the theory of price pressure, this structural demand from a specific investor class can durably lift the price of targeted assets above what their traditional financial metrics alone would justify. The 4.1% price premium for a 10-point ESG score increase, as found in our robust model, can be interpreted as the market-clearing price required to satisfy this specialized demand from a maturing investor base.[10,11]

The second key mechanism is risk perception. Our GARCH analysis confirmed that sustainable cryptocurrencies exhibit significantly lower price volatility. This is not merely a statistical artifact but reflects a fundamental difference in their risk profiles, for which investors demand less compensation (leading to a higher price). The sources of this risk reduction are manifold: (1) Regulatory Risk: PoW mining faces an uncertain global regulatory landscape. Jurisdictions from China to the European Union have considered or implemented restrictions due to environmental concerns and energy grid strain. This creates a persistent "regulatory overhang" for PoW assets. Sustainable cryptocurrencies are largely insulated from this specific threat, making them a "safer" haven from potential government crackdowns; (2) Operational Risk: The security and profitability of PoW networks are directly tethered to volatile global energy prices. A spike in electricity costs can compress miner profit margins, potentially reducing the network's hash rate and, by extension, its security. PoS systems, by decoupling security from energy consumption, feature a more stable and predictable operational cost structure; (3) Reputational and Adoption Risk: As public and corporate awareness of climate change intensifies, the negative narrative surrounding PoW's energy use can impede mainstream adoption. Corporations seeking to integrate crypto into their operations may face backlash from stakeholders if they choose an energy-intensive asset. Sustainable cryptocurrencies bypass this reputational hurdle, paving the way for smoother corporate and commercial integration. Therefore, the ESG premium is also a "safety" premium. Investors are pricing in the reduced likelihood of negative tail events associated with environmental, regulatory, and operational concerns. The lower volatility is the market's tangible expression of this perceived stability.[12-14]

While the environmental pillar is dominant, the Social (S) and Governance (G) components, comprising 30% of our score, also contribute meaningfully to the premium and volatility reduction. Strong performance on these dimensions serves as a proxy for project quality and long-term viability: (1) Governance (G): Assets with transparent development teams, clear roadmaps, and robust on-chain governance protocols are perceived as having lower project risk. Such transparency mitigates the risk of fraud, mismanagement, or sudden project abandonment. This attracts more diligent, long-term investors, creating a more stable holder base and justifying a higher valuation due to reduced idiosyncratic risk; (2) Social (S): Metrics such as network decentralization (a lower Gini coefficient of token distribution) and strong community engagement signal a resilient and robust ecosystem. A more decentralized distribution reduces the risk of price manipulation by large "whale" holders and enhances network security. An active and engaged community fosters innovation and network effects, which are primary drivers of value in the digital asset space, according to Metcalfe's law. This social resilience contributes to both a higher long-term value proposition and lower price volatility.[15,16]

The persistence of the ESG premium, even after controlling for technological modernity and across different market cycles, provides critical insights into the maturation of the digital asset market. The observed premium of ~4% for a 10-point ESG score increase is economically significant and comparable to findings in traditional markets. Studies on green bonds have found yield differentials (a proxy for a price premium) of 5-10 basis points, while ESG leaders in equity markets have been shown to trade at valuation multiples 5-10% higher than their peers. The fact that the crypto ESG premium is of a similar order of magnitude suggests that as the crypto investor base matures and institutionalizes, its risk and value preferences are beginning to converge with those of traditional finance.[17,18]

A key question in the crypto space is whether observed phenomena are durable pricing factors or transient market narratives. Our analysis of bull and bear market sub-periods sheds light on this. The fact that the ESG premium, while larger during the bull market (when narratives are strongest), persists and remains highly significant during the bear market is a crucial finding. It suggests that the premium is not purely a speculative, narrative-driven fad. Instead, it reflects a more fundamental re-pricing of risk and long-term value that endures even when speculative froth recedes. This aligns with theories of market efficiency, suggesting that the digital asset market, while still prone to high volatility and sentiment swings, is becoming more informationally efficient in pricing in complex, non-financial factors like sustainability.[19,20]

Our GARCH analysis supports the risk-mitigation narrative. In addition to the factors mentioned above, the lower volatility of sustainable assets can also be partially attributed to network mechanics. Many PoS assets involve staking, where users lock up their tokens for an extended period to participate in network validation and earn rewards. This mechanism effectively reduces the "floating" or actively traded supply of the asset, which can naturally dampen price volatility compared to PoW coins, where 100% of the mined supply can be sold on the market immediately. This economic mechanism complements the risk-perception explanation for the observed volatility difference.[18]

The confirmation of a robust ESG premium has profound implications for key stakeholders. For investors, the study validates the use of ESG metrics as a viable factor in digital asset investment and portfolio construction. It suggests that integrating a sustainability lens does not necessarily entail a trade-off with financial returns; in fact, the premium provides a potential source of alpha. Furthermore, the lower volatility of high-ESG assets makes them attractive for risk-management and diversification purposes. For developers and project founders, the existence of a clear, market-based financial reward for sustainability provides a powerful economic incentive to build on energy-efficient protocols. The choice of a consensus mechanism is no longer a purely technical decision but a strategic one with direct consequences for asset valuation and capital attraction. For policymakers and regulators, our findings suggest that market forces can be a potent ally in promoting environmental responsibility. Rather than imposing outright bans that risk stifling innovation, regulators could focus on enhancing transparency. Mandating standardized disclosures on energy consumption and other ESG factors, perhaps by expanding frameworks like the EU's Markets in Crypto-Assets (MiCA) regulation, would empower investors to make more informed decisions, thereby strengthening the market's ability to organically price in sustainability and reward greener technologies.

4. Conclusion

This study embarked on a rigorous empirical quest to determine whether the principles of ESG investing have carved out a tangible value proposition in the digital asset frontier. Through the analysis of a comprehensive panel dataset and the application of a robust econometric framework, we sought to quantify the market's valuation of sustainability in the cryptocurrency space.

The results of our analysis are unequivocal and resilient to a battery of robustness tests. We found statistically significant and economically meaningful evidence of a persistent "ESG premium". Our primary fixed-effects model, validated by specifications controlling for endogeneity and technological modernity, revealed that a higher ESG score is positively and significantly associated with a higher cryptocurrency price. Specifically, a 10-point increase in an asset's ESG score corresponds to a valuation premium of approximately 4.1%. Furthermore, our GARCH-based volatility analysis demonstrated that sustainable cryptocurrencies exhibit structurally lower price volatility, indicating that the market perceives these assets as being fundamentally less risky. The persistence of the premium through both bull and bear market cycles suggests it is a durable pricing factor, not merely a speculative narrative.

In essence, this research confirms that the intersection of digital finance and sustainable investing is a potent market reality. The findings signal a crucial maturation phase for the digital asset class, where non-financial factors like environmental impact, social decentralization, and governance transparency are transitioning from external critiques to core, priced-in drivers of value. For investors, developers, and regulators, the message is clear: in the evolving digital economy, sustainability is not just an ethical ideal-it is a quantifiable characteristic that the market values, prices, and rewards.

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