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The Relationship Between The Energy Mix Used in Bitcoin Mining and The Market Performance of Bitcoin as a Financial Asset: Market Return, Price Volatility, and GHG Emissions

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Abstract: Bitcoin's Proof-of-Work mechanism is energy intensive, exceeding the electricity consumption of a medium-sized country. As the adoption accelerates, it become a concern. Most studies analyzed its energy consumption, emissions, and price in isolation. This study examines the relationship between the energy consumption and energy mix of Bitcoin and its market performance, moderated by quality of regulation, using a time-series of secondary data from reputable resources e.g. Cambridge Bitcoin Electricity Consumption Index,, the Worldwide Governance Indicators, etc. Regression analyses are employed to test the hypotheses. Eight of nine null hypotheses failed to reject. However, energy consumption was found to have a significant positive relationship with market return. It is, however, likely that this finding captures shared underlying drivers of Bitcoin's price and its energy consumption, as well as possible reverse causality. Energy mix was found to have no significant effect on the three alternative outcomes, aligned with the fungibility of Bitcoin. Furthermore, regulatory was found not to significantly moderate also likely due to the narrow variation in the Indonesia's scores during the study period. The study identified that markets do not reward sustainable mining with a market premium, implying that the transition towards renewable-powered mining in Indonesia requires more policy intervention.

Keyword: Bitcoin, Energy Consumption, Market, Indonesia.

INTRODUCTION

Bitcoin is now the largest cryptocurrency and one of the most influential digital assets in contemporary market markets. However, Bitcoin, despite expanding acceptance, is controversial due to the immense energy consumption of its Proof-of-Work (PoW) consensus mechanism. The electricity consumption is also close to that of several medium-sized countries in a year, which has sparked worries over its environmental, climate, and sustainability impacts. Awareness of Bitcoin's environmental impact has garnered attention from governments, investors, regulators, and sustainability advocates alike. Although many previous studies investigated the energy consumption, carbon emissions, and market performance of Bitcoin, little empirical evidence is available on whether the energy mix of Bitcoin affects market performance.

This research closes three key gaps. First, past research has analysed environmental effects and not market performance. Second, very limited studies identify the impact of renewable and non-renewable energy composition on the return and volatility of the Bitcoin market. Third, few studies have examined whether governance quality and supportive regulatory frameworks provide a moderating effect on these relationships. Indonesia provides a relevant context for this investigation. Although Indonesia possesses substantial renewable energy potential through geothermal, hydro, and solar resources, coal still accounts for approximately 62% of its energy mix. At the same time, cryptocurrency adoption continues to increase rapidly. This study investigates: (1) Whether Bitcoin energy consumption significantly affects market and sustainability performance ; (2) Whether Bitcoin energy mix significantly affects market and sustainability performance ; (3) Whether regulatory quality moderates the relationship between energy mix market and sustainability performance, hence the result can be used to proposed strategic implications for regulators, miners, investors, and energy providers.

METHOD

In this article, the relation between Energy Consumption and Energy Mix for Bitcoin activities and Market Returns, Price Volatility and GHG Emissions are discussed. It employs time-series data from January 2020 to December 2025. The limitations of this study are the data availability, where most of the data related with Bitcoin—like market return, price volatility, GHG emissions—are measured in a global fashion (not by country) along with the Indonesia World Governance Index (WGI) data which does not show any rise or fall and Indonesia's current mining scale, which is the amount of available data, some of which comes from credible sources in the forms of graphical data meaning it is required to extract the data and to apply a best-guess estimation model as also used in the Cambridge Bitcoin Electricity Index. Because Bitcoin is still relatively new, what's currently happening could be not 100% open. From the variables above, there are 9 (nine) null hypotheses that will be tested one by one as follows:

Table 1. Hypothesis Null

No	Code	Correlation Tested
1	*H1a*	*There is no significant relationship between Bitcoin's energy consumption and its market return ($\beta = 0; p \geq 0.05$).*
2	*H1b*	*There is no significant relationship between Bitcoin's energy consumption and its price volatility ($\beta = 0; p \geq 0.05$).*
3	*H1c*	*There is no significant relationship between Bitcoin's energy consumption and its GHG / carbon emissions ($\beta = 0; p \geq 0.05$).*
4	*H2a*	*There is no significant relationship between Bitcoin's energy mix (renewable share) and its market return ($\beta = 0; p \geq 0.05$).*
5	*H2b*	*There is no significant relationship between Bitcoin's energy mix (renewable share) and its price volatility ($\beta = 0; p \geq 0.05$).*
6	*H2c*	*There is no significant relationship between Bitcoin's energy mix (renewable share) and its GHG / carbon emissions ($\beta = 0; p \geq 0.05$).*
7	*H3a*	*The quality of supportive regulatory frameworks (WGI) does not significantly moderate the relationship between Bitcoin's energy mix and its market return ($\beta\_interaction = 0; p \geq 0.05$).*
8	*H3b*	*The quality of supportive regulatory frameworks (WGI) does not significantly moderate the relationship between Bitcoin's energy mix and its price volatility ($\beta\_interaction = 0; p \geq 0.05$).*
9	*H3c*	*The quality of supportive regulatory frameworks (WGI) does not significantly moderate the relationship between Bitcoin's energy mix and its GHG / carbon emissions ($\beta\_interaction = 0; p \geq 0.05$)..*

As such, the study will extensively draw on secondary data extracted from reliable journals and literature from credible data sources / institution such as Cambridge, the World Bank — and more. This means that the validation of the data must take place before data processing - it happens with a stationary test. A heteroscedasticity test is then applied after processing. Stationarity test is a test that is done to verify that time series data have a constant mean and variance for the entire observation period and avoid spurious regression to estimate the relationships. The heteroscedasticity test was performed to check the level of residual variance. If heteroscedasticity exists the resulting standard error, t-statistic and p-value may be biased and will result in wrong estimates of the significance of the variable. Stationarity test is very important because it avoids spurious regression because we used monthly time series data with 72 observations for each part of the study. The heteroscedasticity test is used to check that the statistical inferences made by the OLS and Moderated Regression Analysis models are correct.

The study regards Energy Consumption and Energy Mix (% Renewable Energy) as Independent Variables and Market Return, Price Volatility, and GHG Emissions as Dependent Variables, with Regulatory Quality (WGI) as Moderated Variable. The Analysis Techniques applied were Quantitative Analytic (Descriptive Statistics, Multiple Regression (OLS), Moderated Regression Analysis (MRA)) and Qualitative Analysis (Stakeholder Analysis, SWOT Analysis, International Benchmarking) producing Strategic Recommendation Development for Stakeholders.

RESULTS AND DISCUSSION

Preliminary Tests

Before conducting quantitative testing, all variables, both independent and dependent variables, were tested for stationary to ensure that the time series data had a stable mean and variance throughout the observation period, with the following results.

Table 2. Preliminary Test

No	Variable	Type of Variable	Stationary Test	Remark
1	Market Return (%)	Dependent	Stationary	Data ready to use
2	Bitcoin Price (USD)	Dependent	Non-stationary	Data modified into Price Volatility
3	GHG Emission (MtCO2e)	Dependent	Non-stationary	Data modified into GHG Emission Growth
4	Energy Consumption (TWh)	Independent	Non-stationary	Data modified into Energy Consumption Growth
5	Energy Mix (%)	Independent	Stationary	Data ready to use
6	Price Volatility (%)	Dependent	Stationary	Data ready to use
7	Energy Consumption Growth (%)	Independent	Stationary	Data ready to use
8	World Government Index (%)	Moderated	N/A	Failed to test since the Index is on yearly data

Source: STATA Code for Data Processing (2026)

Quantitative Analysis

a. Descriptive Analysis

Table 3. Descriptive Statistic

Variable	N	Mean	Std. Dev.	Min	Maks.
Market Return (%)	71	5,149	18,873	-37,833	54,255
Price Volatility (%)	69	15,664	7,876	2,327	35,840
Energy Consumption Growth (%)	71	1,642	6,626	-23,636	21,053
Energy Mix (renewable proportion)- (%)	72	0,465	0,077	0,370	0,560
GHG Emission Growth (%)	71	1,600	5,352	-11,626	16,894
WGI (%)	72	0,452	0,016	0,423	0,471

Variable	N	Mean	Std. Dev.	Min	Maks.
COVID-19 (dummy)	72	0,556	0,500	0,000	1,000
Bitcoin Price (USD)	72	48.186,11	32.248,75	6.400	119.000

Source: STATA Code for Data Processing (2026)

Details statistics of all the variables used in this study are shown in Table 2. Bitcoin Market Return during the observation period shows wide fluctuations, with an average monthly return of 5.15% and 18.87% standard deviation. The returns vary between -37.83% and 54.26%, highlighting the extreme volatility of cryptocurrency markets. It can be said that Price Volatility is also moderately high averaging around 15.66% of volatility between 2.33% and 35.84%, each meaning that Bitcoin market risk has been variable with time. Bitcoin Price also exhibits a significant spread as it moves from a minimum of USD 6,400 to a maximum of USD 119,000, on average, USD 48,186. Both Energy Consumption Growth and GHG Emission Growth have an average monthly growth of 1.64% and 1.60%, respectively, with substantial change, according to the explanation. The Renewable Energy Mix shows a mean value of 46.5% between 37.0% and 56.0%, indicating a slow, yet relatively small change in the proportion of alternative sustainable energy components in Bitcoin mining.

Meanwhile, the Regulatory Quality indicator (WGI) has a very small span, ranging only between 0.423 and 0.471 with a standard deviation of 0.016. This small dispersion might be an explanation of the small moderating effect shown by the following regression analysis. The dummy variable for COVID-19 has a mean value of 0.556, which means that more than half the period of observation was affected by pandemic-related economic conditions.

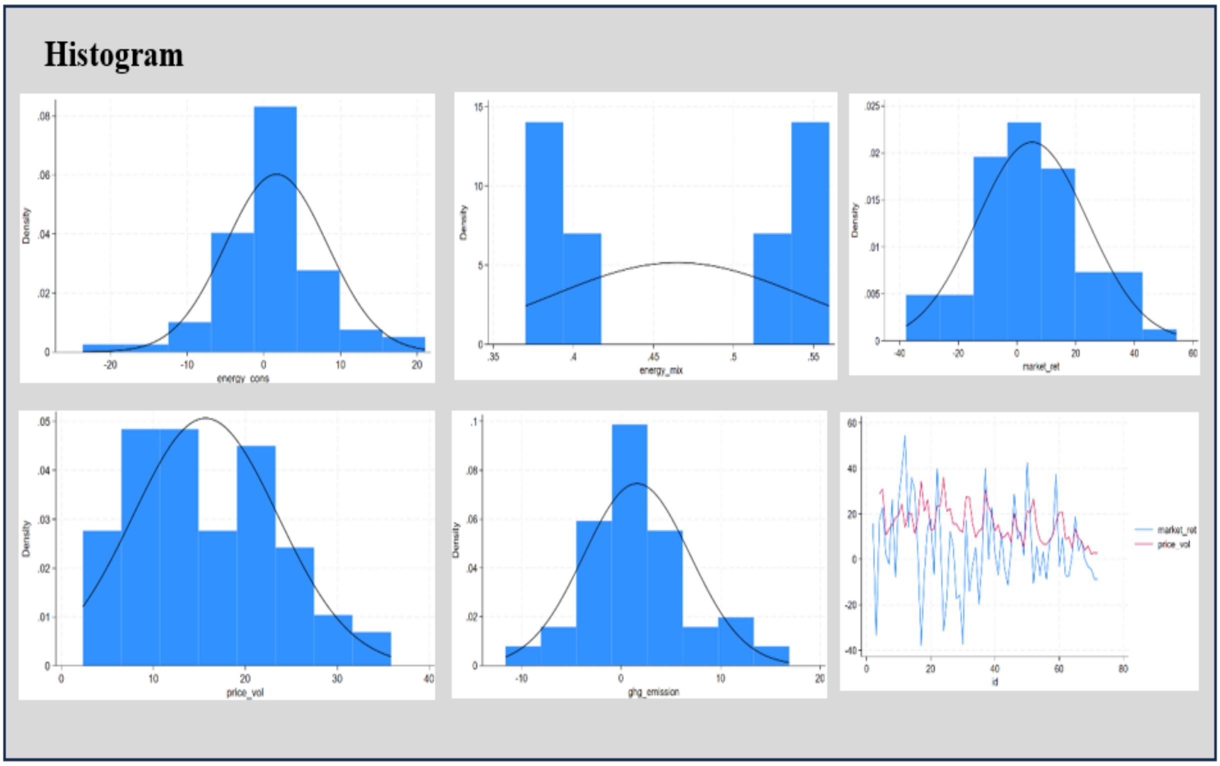

Figure 1. Descriptive Statistic Graphic

(Source: Stata 2026)

b. Inferential Statistics – Multiple Regression Analysis

Below is the result and analysis of the Multiple Regression:

Table 4. Multiple Regression Analysis

Independent Variable	Market Return	Price Volatility	GHG Emission Growth
Energy Consumption Growth	1,011 (p=0,011)*	-0,101 (p=0,514)	0,071 (p=0,535)
Energy Mix	98,232 (p=0,162)	14,495 (p=0,619)	-8,236 (p=0,675)
N	70	68	71
R-squared	0,350	0,409	0,286
Adj. R-squared	0,169	0,238	0,091
Prob > F	0,0393	0,0102	0,1506

Note: sign indicates significance at p<0.05.

Source: Results of data processing with STATA (2026)

From the Multiple Regression Data Result, it is shown that Energy Consumption and Market Return have positive and significant relation - 1% increase in energy consumption = 1.011% increase in return on market. H_0 is rejected as the coefficient is 1.011 (p = 0.011 (<0.05), so H_0 was not considered. On the contrary, it is evidenced that between Energy Consumption has no significant effect on price volatility [coefficient is −0.101 (p = 0.514 (>0.05)]. this observation fits in to many articles on Bitcoin, which have pointed out speculation and macroeconomic factors drive more Bitcoin volatility, Gkillas et al., 2022; Sakurai & Kurosaki, 2025. This is coherent with the position that the consumption-emissions dependence is not mechanical, but rather the product of energy content and mining site (Stoll et al., 2019), that there is no statistically significant association [The coefficient is 0.071 (p = 0.535 (> 0.05), so H_0 is fail to reject].

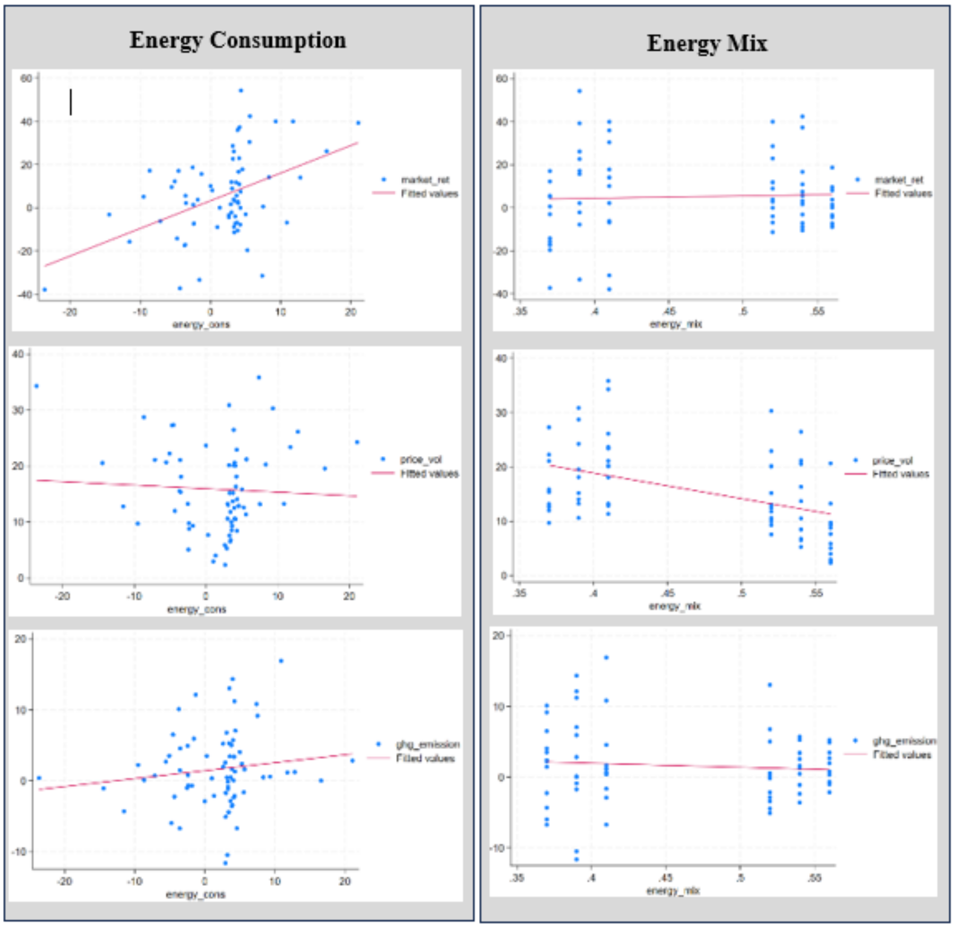

Figure 2. Multiple Regression Graphic

(Source: Stata 2026)

The Multiple Regression Data Result is also evidenced that the composition of renewable energy does not influence market returns, as predicted by the fungibility argument (Sapkota and Grobys, 2020; Hosseini et al., 2025). The coefficient is 98.232, p = 0.162 (>0.05), thus H_0 is fail to reject. Neither do the The energy-mix effect on volatility is insignificant as we can see that the coefficient is 14.495; p = 0.619 (> 0.05), H_0 is fail to reject. Between energy mix and emissions weakened. There is no significant relationship, also seen as a rebound effect (Jevons Paradox) as the direct link. H_0 is fail to reject (the coefficient is −8.236, p = 0.675 (> 0.05)).

c. Inferential Statistics – Moderated Regression Analysis

Below is the result and analysis of the Moderated Regression:

Table 5. Moderated Regression Statistic

Independent Variable	Market Return	Price Volatility	GHG Emission Growth
Energy Mix × WGI (interaction)	1.192,564 (p=0,633)	−1.274,365 (p=0,213)	114,379 (p=0,875)
Energy Consumption Growth	1,009 (p=0,012)*	−0,098 (p=0,524)	0,070 (p=0,543)
N	70	68	71
R-squared	0,353	0,427	0,286

Note: sign indicates significance at p<0.05.

Source: Results of data processing with STATA (2026)

No significant moderating effect of Regulatory Quality (WGI) was found on the relationship between Energy Mix and any of the dependent variables, including Market Return (p = 0.633), Price Volatility (p = 0.213), and GHG Emissions (p = 0.875). The insignificant results may be explained by the limited variation of Indonesia's WGI during the study period (0.423–0.471). Nevertheless, Energy Consumption remained significantly associated with Market Return across all model specifications.

Heteroscedasticity Test

In order to check for possible heteroscedasticity and to verify the assumption of constant error variance (homoscedasticity) prior to interpretation of the estimates of the six different models, a test for heteroscedasticity was performed. The test for heteroscedasticity of the error variance within the six models is the Breusch-Pagan test (also referred to as the Cook-Weisberg test) and the White test. The null hypothesis (H0) of both tests is equal to homoscedasticity. The results of the test for the six different models are presented in Table 5.

Table 6. Heteroscedasticity Test Results

Model (Related Variable)	Breusch-Pagan (Prob>chi2)	White (Prob>chi2)	Conclusion
Market Return	0,0778	0,4438	Homoscedasticity
Price Volatility	0,0696	0,4429	Homoscedasticity
GHG Emission	0,1361	0,4442	Homoscedasticity
Market Return (moderated)	0,0778	0,4438	Homoscedasticity
Price Volatility (moderated)	0,0696	0,4429	Homoscedasticity
GHG Emission (moderated)	0,1361	0,4442	Homoscedasticity

Source: Stata 2026

Prob > chi2 values shown in Table 4.2 for all models are greater than 0.05, i.e. values for the Breusch-Pagan test (from 0.0696 to 0.1361) and the White test (from 0.4429 to 0.4442). Thus, the null hypothesis H0 of no heteroscedasticity cannot be rejected for all models. Therefore, the assumption of constant error variance is met with the conclusion being reliable for the decision on the research question. Some values of the Breusch-Pagan test are close to the threshold of 0.07-0.08 but are safely rejected by the corresponding values of the White test, which are well above 0.05.

Table 7. Summary of Hypothesis Testing Decisions

Code	Correlation Tested	p-value	Test Result
H1a	Energy Consumption -> Market Return	0,011	H0 rejected (significant)
H1b	Energy Consumption -> Price Volatility	0,514	H0 failed to reject
H1c	Energy Consumption -> GHG Emission	0,535	H0 failed to reject
H2a	Energy Mix -> Market Return	0,162	H0 failed to reject
H2b	Energy Mix -> Price Volatility	0,619	H0 failed to reject
H2c	Energy Mix -> GHG Emission	0,675	H0 failed to reject
H3a	WGI moderation -> Market Return	0,633	H0 failed to reject
H3b	WGI moderation -> Price Volatility	0,213	H0 failed to reject
H3c	WGI moderation -> GHG Emission	0,875	H0 failed to reject

Source: Stata 2026

Qualitative Analysis

a. Stakeholder Analysis

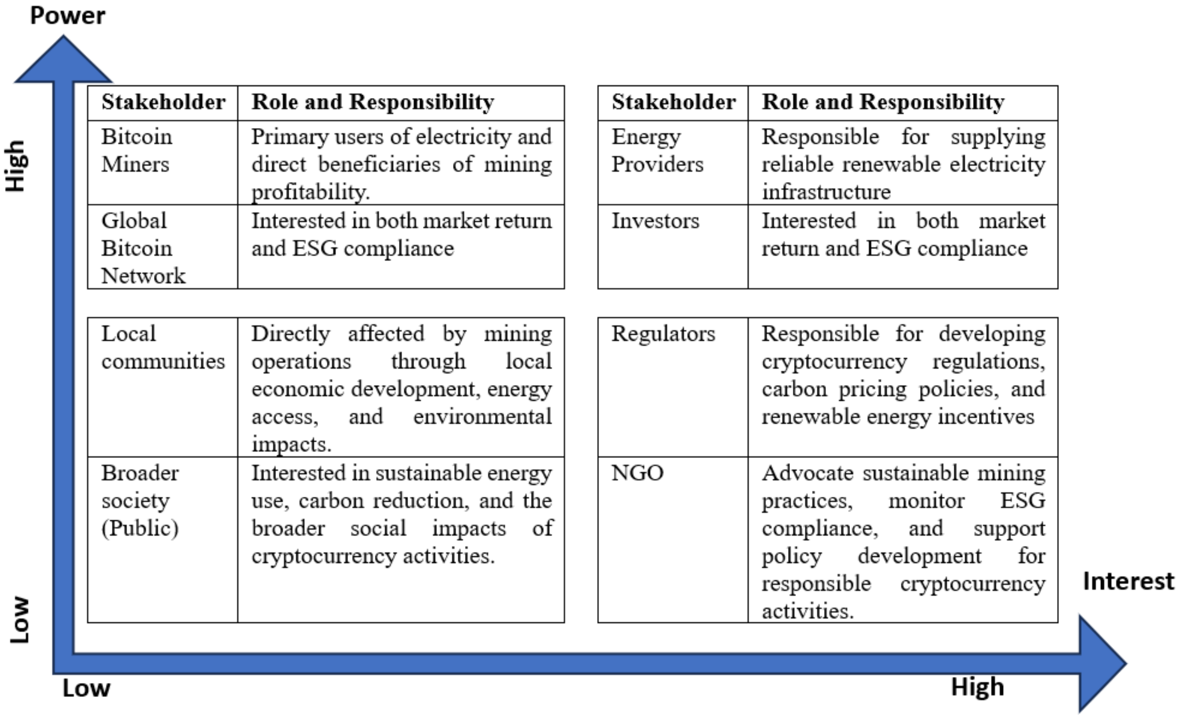

Figure 3. Stakeholder Mapping

Stakeholder mapping data shows that sustainable Bitcoin mining development involves a number of stakeholders with different interests and roles, such as investors, miners, community members and the global Bitcoin network (Bitcoin miners and the blockchain network). However, it is the task of energy providers to provide a steady and enduring power supply. Conversely, regulators have a strategic role to play in designing policy frameworks and renewable energy incentives, and systems to mitigate the environmental burden associated with Bitcoin mining activities. The sustainability of Bitcoin mining in addition to economic impacts is influenced by social and environmental issues besides the economic aspects. Local communities bear the brunt of the social, economic and environmental consequences of mining activities and the wider society cares about energy consumption, cut carbon emissions and national sustainability goal reaching. Non-governmental organizations have, therefore, an integral role as independent actors, as responsible mining participants, to spur responsible mining, review ESG compliance and to assist in implementation of sustainable policy initiatives. The results show that the development of sustainable Bitcoin mining is not only market and technical driven but also depends upon effective stakeholder collaboration.

b. SWOT Analysis

Strengths	Weaknesses
• Abundant renewable energy resources (geothermal, hydro, solar). • Growing cryptocurrency adoption and digital economy. • Strategic location in Southeast Asia. • Potential alignment with Indonesia's NZE 2060 agenda.	• Energy mix remains heavily dependent on coal. • Limited renewable infrastructure for large-scale mining operations. • Lack of specific regulations governing Bitcoin mining activities. • Higher electricity costs compared to leading mining hubs.
Opportunities	**Threats**
• Development of renewable-powered Bitcoin mining hubs. • Attraction of ESG-focused investors and green financing. • Monetization of stranded renewable energy resources. • Growing demand for sustainable digital assets.	• High Bitcoin price volatility and market uncertainty. • Regulatory restrictions on cryptocurrency activities. • Competition from established mining countries (USA, Norway, Iceland). • Carbon taxes and environmental compliance costs.

Figure 4. SWOT Mapping

According to the SWOT analysis, the potential for establishing a sustainable Bitcoin mining ecosystem is enormous in Indonesia, bolstered by the presence of plentiful renewable energy resources, a developing digital economy, and Indonesia's commitment to the 2060 Net Zero Emissions (NZE) target. The national energy mix is still dominated by coal, renewable energy infrastructure is limited, and there are no specific regulations around Bitcoin mining. However, increasing investor interest in ESG-based investments and prospects of exploiting under-optimal renewable energy sources also provide opportunities for green energy-oriented Bitcoin mining centres. Yet with Bitcoin price volatility, regulatory uncertainty, global competition, and the potential implementation of carbon pricing policies, these types of industries could be hampered. For this reason, clearer policy support and a more rapid energy transition will be required to push Bitcoin mining's competitiveness and the country towards a more sustainable future in Indonesia.

CONCLUSION

We study and analyse the interactions and results of energy consumption and regulatory quality on market and environmental performance of Bitcoin and the mix of energy for the 2020–2025 period. The study results demonstrate that only energy consumption has a positive and significant relationship with return, while energy mix does not show any association with market return, price volatility, or the growth in greenhouse gas emissions. In addition, regulatory quality (as assessed by the Worldwide Governance Indicators (WGI)) had no moderating effect between energy mix and any of the dependent variables. These results suggest that network activity growth and mining intensity are considered the market's most important factors and are worth more over the sustainability of the energy sources used. In other words, the market has not seen an adequate market premium for sustainable Bitcoin mining yet. For this reason, transitioning to renewable energy in Bitcoin mining should be promoted through policy with a stronger focus on incentives as opposed to market mechanisms.

DISCUSSION

The results from the research contribute to literature on digital asset sustainability by demonstrating that increasing the use of renewable energy in Bitcoin mining has not directly translated into improved market performance. This is consistent with Bitcoin fungibility, where the market doesn't distinguish between Bitcoin that is mined with renewable energy and fossil-based energy. This is the reason why market incentives alone cannot compel move towards sustainable mining approaches. For the Indonesian context, the research shows that creating a sustainable Bitcoin mining industry will require cooperation of regulators, energy companies, investors and industry members. The enormous promise of renewables is a strategic opportunity, but regulatory certainty, green energy infrastructural development, and policies that link digital economy targets to the national decarbonisation agenda and the 2060 Net Zero Emissions target remain required.

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