West Science Social and Humanities Studies
Vol. 03, No. 10, October 2025, pp. 1491-1504

How do Sustainability-Linked Lending, Fintech-ESG Partnership, and Dynamic Carbon Pricing impact the value of renewable energy projects in Central Java?

Ari Purwanti[1], Paramita Andiani[2], Ilham Akbar Bunyamin[3]
[1] Universitas Gunadarma
[2,3] Universitas Nusa Putra

Article Info

Article history:

Received Oct, 2025
Revised Oct, 2025
Accepted Oct, 2025

Keywords:

Sustainability-Based Financing
Fintech–ESG Partnership
Dynamic Carbon Pricing
Project Value
Renewable Energy

ABSTRACT

This study investigates how sustainability-based financing, fintech–ESG partnerships, and dynamic carbon pricing influence the value of renewable energy projects in Central Java, Indonesia. Using a quantitative approach with 130 respondents from financial institutions, project developers, and government agencies, data were collected through a Likert-scale questionnaire and analyzed using Structural Equation Modeling with Partial Least Squares (SEM-PLS 3). The results reveal that all three constructs significantly and positively affect renewable project value, with dynamic carbon pricing showing the strongest direct effect. Furthermore, dynamic carbon pricing mediates the relationships between sustainability-based financing and project value, as well as between fintech–ESG partnerships and project value, indicating that adaptive carbon mechanisms enhance the economic and environmental performance of renewable investments. The findings highlight the synergistic role of financial innovation, digital transparency, and carbon market policies in strengthening the sustainability and competitiveness of renewable energy projects. This study contributes theoretically by integrating Stakeholder Theory, Dynamic Capabilities, and Environmental Economics into a unified framework for sustainable project valuation, and offers practical insights for policymakers and investors in optimizing green finance and carbon pricing strategies across Indonesia's energy transition agenda.

Corresponding Author:

Name: Ari Purwanti
Institution: Universitas Gunadarma
Email: aripurwanti@staff.gunadarma.ac.id

1. INTRODUCTION

The transition toward renewable energy has become a central pillar of sustainable development, particularly in emerging economies such as Indonesia. Central Java, as one of the provinces with abundant solar, hydro, and biomass potential, plays a strategic role in supporting the national target of achieving net-zero emissions by 2060. However, the realization of renewable energy projects in the region often encounters structural challenges—ranging from limited access to sustainable financing, fragmented technological adoption, to volatile regulatory incentives such as carbon pricing. Indonesia's lower-middle-income status and limited budgets pose significant challenges in attracting international finance for renewable energy projects [1]. In this context, innovative financial mechanisms such as green bonds and blended finance can help mobilize the necessary capital for renewable energy investments [2]. Policy inconsistencies and regulatory barriers also hinder the adoption of renewable energy in Indonesia [2], making the strengthening of environmental governance through clear and consistent policies crucial to facilitate the integration of renewable energy into the national energy grid (Syabriyana, 2024). Furthermore, the adoption of digital technologies can enhance the efficiency and reliability of renewable energy systems [2], while digital platforms can facilitate better coordination among stakeholders and improve the management of renewable energy projects [3]. Thus, the integration of financial innovation, environmental governance, and digital technology is essential to overcome these structural challenges and enhance the economic value and long-term viability of renewable energy investments in Central Java, enabling the region to fully leverage its abundant renewable resources in alignment with Indonesia's net-zero emission goals.

Sustainability-based financing has become a key mechanism to support projects aligned with environmental, social, and governance (ESG) principles through instruments such as green bonds, sustainability-linked loans, and blended finance that reduce risk while rewarding environmental performance. Studies highlight that sustainable capital improves project bankability and attracts private investors, though regions like Central Java still face information asymmetry and weak risk assessment in renewable energy financing. Green bonds are essential for channeling funds into environmentally friendly projects, aligning with global sustainability goals like the UN SDGs [4], and they enhance financial sustainability by offering a reliable way to finance renewable energy and sustainable infrastructure, despite challenges such as greenwashing and regulatory inconsistencies [4]. Fintech–ESG collaborations offer solutions by enabling peer-to-peer funding, automating ESG reporting, and enhancing transparency through blockchain and AI-driven analytics [5], while decentralized finance (DeFi) democratizes access to finance and enables micro-investments in sustainability projects crucial for regions with limited financial infrastructure [5]. Nevertheless, despite the potential of sustainable finance, regulatory uncertainties and the absence of standardized ESG criteria continue to pose significant barriers [6]. Stakeholder collaboration and the development of innovative financial products are therefore vital for overcoming these challenges and accelerating green energy adoption in Indonesia [6].

Dynamic carbon pricing, as a market-based policy instrument, has gained traction as a means to internalize the cost of carbon emissions and incentivize low-carbon technologies. Unlike static schemes, it adjusts to market and policy conditions, providing more responsive signals that influence investment behavior. In Indonesia, the gradual implementation of carbon trading and carbon tax frameworks under Presidential Regulation No. 98/2021 has created new dynamics in renewable energy valuation. The interaction between carbon pricing mechanisms and financial innovations such as sustainable finance and fintech–ESG partnerships can reshape project risk–return profiles, though empirical insights on this linkage remain limited. This study addresses the gap by examining how sustainability-based financing, fintech–ESG partnerships, and dynamic carbon pricing affect renewable energy project value in Central Java. Using a quantitative approach with 130 respondents—including project managers, financial analysts, and policy stakeholders—data were collected via a Likert-scale questionnaire and analyzed through Structural Equation Modeling (SEM-PLS 3). Central Java serves as a representative case of Indonesia's renewable transition, balancing ambitious policies with financial and infrastructural constraints. The study contributes theoretically by expanding the financial–technological–environmental integration model; empirically by providing data-driven evidence of their combined effects on project value; and practically by offering insights for policymakers, investors, and financial institutions to strengthen green finance instruments and digital ESG ecosystems.

2. LITERATURE REVIEW

2.1 Sustainability-Based Financing

Sustainability-based financing is a pivotal mechanism in the transition to a low-carbon economy, integrating environmental, social, and governance (ESG) principles to achieve both financial returns and sustainable outcomes. This approach aligns with Stakeholder Theory and the Resource-Based View, emphasizing value creation for all stakeholders and leveraging ESG-oriented financial resources as strategic assets. Sustainable finance channels investments into renewable energy, clean technology, and sustainable infrastructure, catalyzing progress toward a low-carbon economya [7], [8]. Financial instruments such as green bonds and sustainability-linked loans mobilize capital for environmentally friendly projects, promoting energy efficiency and biodiversity conservation [8], [9]. By integrating ESG criteria, sustainable finance enhances transparency, accountability, and long-term value creation, addressing global challenges like climate change and social inequalities [10], [11]. However, emerging economies face regulatory barriers, market fragmentation, and a lack of investor confidence, limiting the adoption of green bonds and ESG investments [9]. High transaction costs and limited ESG data further hinder the implementation of sustainable finance frameworks, and in Indonesia, despite efforts by the Financial Services Authority (OJK) to promote sustainable finance, regional impacts—particularly in renewable energy projects—remain underexplored [9]. Lessons from India and Brazil show that tailored policies and public–private partnerships can unlock the potential of sustainable finance, while initiatives such as Indonesia's Green Taxonomy 2.0 and sustainability reporting guidelines are steps toward strengthening its regional effectiveness [9].

2.2 Fintech–ESG Partnerships

The integration of financial technology (fintech) with Environmental, Social, and Governance (ESG) principles is reshaping sustainable finance by leveraging digital innovation to enhance transparency, accountability, and inclusivity in financial ecosystems. Applications such as blockchain-based green bonds, AI-driven ESG analytics, and crowdfunding for renewable energy improve financial access and governance, supporting the global transition to sustainable investment [12]–[14]. Through the lens of Dynamic Capabilities Theory, fintech–ESG collaboration strengthens an organization's ability to adapt to environmental and technological changes while reducing information asymmetry and boosting investor confidence. This integration accelerates green capital flows and refines impact measurement—critical for valuing renewable energy projects [12], [14]. Fintech platforms further promote transparency through real-time data and automated ESG verification, foster financial inclusion via peer-to-peer lending that connects small renewable projects with ESG-focused investors, and enhance investment efficiency and governance quality [10], [13]. Nonetheless, challenges persist, including regulatory ambiguity, cybersecurity risks, and interoperability issues between fintech and ESG systems [12], [14].

2.3 *Dynamic Carbon Pricing*

Dynamic carbon pricing, as a flexible market-based mechanism, plays a vital role in promoting renewable energy investments by adjusting carbon prices in response to market conditions, technological progress, and policy shifts. This adaptability enhances the competitiveness of clean technologies over fossil fuels, improving project valuation and attracting green investments. Globally, carbon pricing has gained widespread adoption, with 46 countries implementing frameworks that collectively cover about 22% of global GHG emissions [15]. The Real Carbon Price Index serves as a benchmark for guiding investment decisions, helping investors manage regulatory risks and support the shift toward low-carbon technologies [16]. In Indonesia, the institutionalization of carbon pricing through Presidential Regulation No. 98/2021 and the pilot Emissions Trading Scheme (ETS) underlines the nation's commitment to sustainable development by driving renewable energy investment and reducing fossil fuel dependency [17]. The approach is tailored to local industrial capacities, emphasizing key sectors such as Industrial Processes and Product Use (IPPU). Nonetheless, implementation faces obstacles, including economic distribution concerns, political resistance, and the need for international policy alignment [18]. Despite these challenges, carbon pricing remains a cornerstone of Indonesia's strategy to achieve carbon neutrality and advance sustainable industrial transformation [17], [18], though the interaction between dynamic pricing, sustainability-based financing, and fintech-driven ESG partnerships still warrants further exploration.

2.4 *Renewable Energy Project Value*

The value of renewable energy projects is multifaceted, encompassing financial returns, operational efficiency, social benefits, and environmental impact, all shaped by a firm's ability to integrate financial, technological, and strategic resources alongside external factors such as policy incentives and market access. In Central Java, project valuation is influenced by the region's diverse energy portfolio and regulatory dynamics, where innovative financing models, ESG performance, and structured risk management play critical roles in enhancing project value. Innovative financing mechanisms such as green bonds, crowdfunding, and blockchain-based systems help mitigate financial and technical risks, improve scalability, and attract investment toward renewable solutions, while local financing schemes strengthen investor confidence and community engagement [19]. Superior ESG performance contributes to higher financial returns and reduced risks, emphasizing the importance of embedding ESG and Enterprise Risk Management (ERM) into investment strategies to bolster profitability and investor trust [20]. Comprehensive evaluation frameworks like the Triple Bottom Line and ESG Performance Index further enable stakeholders to assess both financial and non-financial outcomes, ensuring that renewable energy projects generate sustainable economic, environmental, and social value [21].

2.5 *Theoretical Framework and Hypothesis Development*

Based on the literature, the relationships among sustainability-based financing, fintech–ESG partnerships, and dynamic carbon pricing can be framed within an integrated theoretical model that combines Stakeholder Theory, Dynamic Capabilities Theory, and Environmental Economics. Sustainability-based financing is expected to positively influence project value by ensuring long-term capital stability and reducing investment risk, while fintech–ESG partnerships enhance project value through efficiency gains, transparency, and improved accountability in both financial and environmental reporting. Dynamic carbon pricing contributes by increasing the profitability of low-emission technologies and reinforcing long-term policy certainty, thereby elevating project valuation. Furthermore, dynamic carbon pricing serves a mediating role, strengthening the link between sustainable financing and project value by amplifying the financial attractiveness of sustainability-oriented investments. Overall, this conceptual framework highlights that the synergistic interaction of financial, technological, and environmental instruments collectively shapes the economic viability and sustainability performance of renewable energy projects in Central Java.

3. METHODS

3.1 Research Design

This study employed a quantitative explanatory design to analyze the causal relationships among sustainability-based financing, fintech–ESG partnerships, dynamic carbon pricing, and the value of renewable energy projects in Central Java. The quantitative approach was selected to empirically validate theoretical linkages between variables through hypothesis testing using Structural Equation Modeling with Partial Least Squares (SEM-PLS 3). This method was chosen because it effectively evaluates direct, indirect, and mediating effects within complex models containing multiple latent constructs and is suitable for small to medium sample sizes. The analytical framework integrates financial, technological, and environmental perspectives, drawing upon Stakeholder Theory [22], Dynamic Capabilities Theory [23], and Environmental Economics Theory [24] has the conceptual foundation for hypothesis development and model testing.

3.2 Population and Sample

The population of this research comprised stakeholders involved in renewable energy projects across Central Java Province, including project developers, financial institutions, government agencies, and sustainability officers. Respondents were required to have at least two years of experience in project management, financing, or regulatory oversight related to renewable energy. A purposive sampling technique was used to ensure the inclusion of participants with relevant expertise, resulting in 130 valid responses—meeting the minimum requirement for SEM-PLS analysis as recommended by [25], which suggests a sample size of at least ten times the number of indicators for the most complex construct. The respondent composition included 42% from financial institutions, 33% from renewable project management firms, 15% from government and regulatory bodies, and 10% from consultancy or technology service providers, ensuring a comprehensive representation of Central Java's renewable energy ecosystem.

3.3 Data Collection and Analysis

Data were collected between April and June 2025 through a structured questionnaire distributed both online and offline. The instrument, adapted from validated scales in previous studies, consisted of five sections: respondent profile, sustainability-based financing, fintech–ESG partnerships, dynamic carbon pricing, and project value indicators. Each item was measured using a five-point Likert scale (1 = strongly disagree to 5 = strongly agree). A pilot test with 20 respondents confirmed that all items achieved Cronbach's alpha values above 0.70, indicating internal consistency and clarity. Data analysis was conducted using SEM-PLS 3.0 in two stages: the measurement model (outer model) tested validity and reliability through factor loading, AVE, and CR, while the structural model (inner model) evaluated path coefficients, t-statistics, R^2, f^2, and predictive relevance (Q^2). Bootstrapping with 5,000 resamples at a 5% significance level was applied to assess hypothesis significance and model robustness.

4. RESULTS AND DISCUSSION

4.1 Respondent Profile

The data collection process for this study was conducted between April and June 2025, targeting stakeholders actively engaged in renewable energy projects across Central Java Province. Using a purposive sampling technique, only individuals with relevant expertise and decision-making authority in financing, management, or regulation were selected. A total of 150 questionnaires were distributed both online and through direct coordination meetings with renewable energy associations and regional energy offices, resulting in 130 valid responses after screening for completeness and consistency—an effective response rate of 86.7%. Data quality checks, including the Mahalanobis distance test and Harman's single-factor test, confirmed the absence of bias and outliers, validating the dataset for further Structural Equation Modeling–Partial Least Squares (SEM-PLS) analysis. The respondents represented diverse sectors within the renewable energy ecosystem: 42.3% from financial institutions, 33.1% from project developers, 15.4% from government and regulatory agencies, and 9.2% from consultants and technology service providers. This sectoral composition accurately reflects Central Java's Penta Helix ecosystem, illustrating the interconnected roles of government, business, finance, academia, and technology in advancing sustainable energy development.

The demographic analysis revealed that 62.3% of respondents were male and 37.7% female, with the majority (43.8%) aged between 35 and 44 years—typically middle-management professionals responsible for financial and strategic decisions. Over half (53.1%) held a bachelor's degree, while 46.9% possessed postgraduate qualifications (Master's or Doctorate), underscoring the respondents' advanced educational background. In terms of professional experience, nearly 70% had more than six years of involvement in renewable energy, financing, or ESG-related projects, with an average experience of 8.4 years, indicating strong domain expertise and reliable responses. Geographically, respondents represented ten regencies and cities across Central Java, including Semarang, Banyumas, Cilacap, Magelang, and Klaten, covering both urban and rural renewable energy zones. Semarang City served as the financial and policy hub, while areas like Banyumas and Magelang focused on micro-hydro, solar, and biomass innovations. This broad geographic and institutional distribution enhances the validity and generalizability of the study's findings across Central Java's diverse renewable energy landscape.

4.2 Measurement Model Evaluation (Outer Model)

The measurement model evaluation was conducted to assess the validity and reliability of the reflective constructs before testing the hypothesized relationships within the structural model. This process ensures that all latent variables—Sustainability-Based Financing (SBF), Fintech–ESG Partnerships (FEP), Dynamic Carbon Pricing (DCP), and Project Value (PV)—are accurately represented by their corresponding indicators. Using SmartPLS 3.0, the analysis examined convergent validity, discriminant validity, and reliability to confirm the robustness of the measurement model. Convergent validity was established by evaluating the correlation among indicators measuring the same construct, with criteria set at factor loadings (λ) ≥ 0.70 and Average Variance Extracted (AVE) ≥ 0.50. All items successfully met these thresholds, indicating that the measurement items effectively captured the intended latent constructs, as summarized in Table 1.

Table 1. Convergent Validity Results

Construct	Indicator Code	Loading (λ)	AVE	Status
Sustainability-Based Financing (SBF)	SBF1	0.812	0.716	Valid
	SBF2	0.874		
	SBF3	0.835		
	SBF4	0.867		
Fintech–ESG Partnerships (FEP)	FEP1	0.803	0.684	Valid
	FEP2	0.859		
	FEP3	0.816		
	FEP4	0.841		
Dynamic Carbon Pricing (DCP)	DCP1	0.821	0.698	Valid
	DCP2	0.868		
	DCP3	0.828		
	DCP4	0.845		
Project Value (PV)	PV1	0.831	0.735	Valid
	PV2	0.873		
	PV3	0.849		
	PV4	0.870		

The results presented in Table 1 indicate that all constructs in the measurement model—Sustainability-Based Financing (SBF), Fintech–ESG Partnerships (FEP), Dynamic Carbon Pricing (DCP), and Project Value (PV)—demonstrate strong convergent validity. Each indicator loading (λ) exceeds the minimum threshold of 0.70, confirming that the observed variables are highly correlated with their respective latent constructs and effectively measure the intended dimensions. The Average Variance Extracted (AVE) values for all constructs also surpass the recommended cutoff of 0.50, with SBF (0.716), FEP (0.684), DCP (0.698), and PV (0.735), indicating that more than 68% of the variance in the indicators is explained by the underlying construct. These results validate that each construct possesses adequate internal consistency and convergent representation, ensuring that the items used in the questionnaire reliably capture the theoretical concepts of sustainable financing, fintech–ESG collaboration, dynamic carbon pricing, and project value. Therefore, the model satisfies the convergent validity requirement and is suitable for further analysis in the structural model stage.

The reliability analysis was conducted to evaluate the internal consistency of all constructs using Cronbach's Alpha (α) and Composite Reliability (CR). Following the criteria suggested by Hair et al. (2021), reliability is established when both α and CR values exceed 0.70. As shown in the results, all constructs demonstrated strong reliability, with Cronbach's Alpha values ranging from 0.852 to 0.879 and Composite Reliability values between 0.901 and 0.920. Specifically, Sustainability-Based Financing (SBF) recorded α = 0.867 and CR = 0.913, Fintech–ESG Partnerships (FEP) α = 0.852 and CR = 0.901, Dynamic Carbon Pricing (DCP) α = 0.864 and CR = 0.910, and Project Value (PV) α = 0.879 and CR = 0.920. These results confirm that all indicators consistently measure their respective constructs and exhibit high internal stability, providing strong confidence in the reliability of the data and its suitability for further structural model analysis.

1. Discriminant Validity

Discriminant validity was evaluated to determine whether each construct in the model is empirically distinct from the others. Two statistical approaches were applied: the Fornell–Larcker criterion and the Heterotrait–Monotrait Ratio (HTMT). Based on the Fornell–Larcker criterion, the square root of the Average Variance Extracted (AVE) for each construct must exceed its correlations with other constructs. As shown in the results, the diagonal values (√AVE) for Sustainability-Based Financing (0.846), Fintech–ESG Partnerships (0.827), Dynamic Carbon Pricing (0.836), and Project Value (0.857) are all greater than their inter-construct correlations. This finding satisfies the Fornell–Larcker criterion, confirming that each construct measures a unique theoretical concept and does not exhibit multicollinearity with other constructs.

The results of the Heterotrait–Monotrait Ratio (HTMT) further reinforce this conclusion. Following the guideline proposed by [26], discriminant validity is established when HTMT values are below 0.90. All construct pairs in this study meet this criterion, with values ranging from 0.683 to 0.729, indicating clear empirical distinction among the variables. These consistent results from both the Fornell–Larcker and HTMT tests confirm that Sustainability-Based Financing, Fintech–ESG Partnerships, Dynamic Carbon Pricing, and Project Value represent separate constructs, ensuring the discriminant validity and robustness of the measurement model.

2. Multicollinearity Test

Before proceeding to the structural model analysis, multicollinearity among independent constructs was examined using the Variance Inflation Factor (VIF), where values below 5.0 indicate the absence of multicollinearity (Hair et al., 2021). The results show that Sustainability-Based Financing (SBF) recorded a VIF of 2.214, Fintech–ESG Partnerships (FEP) 2.145, and Dynamic Carbon Pricing (DCP) 2.362—all well below the established threshold. These findings confirm that no multicollinearity exists among the predictor constructs, ensuring that the independent variables are not excessively correlated and that the estimated path coefficients in the subsequent structural model remain stable and reliable.

4.3 Structural Model Evaluation (Inner Model)

The structural model (inner model) evaluation was conducted to analyze the causal relationships among the latent variables—Sustainability-Based Financing (SBF), Fintech–ESG Partnerships (FEP), Dynamic Carbon Pricing (DCP), and Project Value (PV)—in order to determine whether the theoretical framework proposed in Chapter 3 is supported by empirical data collected from 130 respondents. Using SmartPLS 3.0, the analysis employed a bootstrapping procedure with 5000 subsamples to estimate the significance of path coefficients and assess the strength of relationships between constructs. This stage was crucial to validate whether the hypothesized links among financial, technological, and environmental dimensions were statistically meaningful in explaining project value within the renewable energy ecosystem of Central Java.

Before hypothesis testing, the model's overall quality and predictive power were examined through several fit indices. The Standardized Root Mean Square Residual (SRMR) value of 0.064 indicated a good model fit (<0.08), while the Normed Fit Index (NFI) of 0.918 confirmed acceptable structural alignment (≥0.90). The R^2 value for Project Value (0.673) revealed that 67.3% of its variance is explained by SBF, FEP, and DCP, demonstrating strong explanatory capability. Similarly, $R^2 = 0.558$ for Dynamic Carbon Pricing showed that more than half of its variance is accounted for by SBF and FEP. The predictive relevance (Q^2) value of 0.359 (>0) further indicated high model robustness and accuracy in forecasting dependent variables. Collectively, these results confirm that the structural model possesses strong validity, predictive strength, and empirical support for hypothesis testing.

Table 2. Hypothesis Testing

Hypothesis	Path Relationship	Path Coefficient (β)	t-value	p-value	Result
H1	SBF → PV	0.312	4.852	0.000	Supported
H2	FEP → PV	0.298	4.225	0.000	Supported
H3	DCP → PV	0.341	5.097	0.000	Supported
H4	SBF → DCP → PV	0.106	3.072	0.002	Supported
H5	FEP → DCP → PV	0.094	2.883	0.004	Supported

The results presented in Table 2 confirm that all hypothesized relationships in the structural model are statistically significant and empirically supported. The direct effect of Sustainability-Based Financing (SBF) on Project Value (PV) is positive and significant (β = 0.312, t = 4.852, p = 0.000), indicating that sustainable financing mechanisms enhance renewable energy project valuation through improved capital stability and reduced investment risk. Similarly, Fintech–ESG Partnerships (FEP) exert a strong positive influence on project value (β = 0.298, t = 4.225, p = 0.000), highlighting that the integration of digital financial platforms with ESG principles increases efficiency, transparency, and investor confidence. The effect of Dynamic Carbon Pricing (DCP) on project value is also significant (β = 0.341, t = 5.097, p = 0.000), suggesting that adaptive carbon pricing mechanisms contribute directly to higher project valuations by improving the profitability and competitiveness of low-emission technologies.

Moreover, the mediation analysis demonstrates that Dynamic Carbon Pricing (DCP) serves as a significant intermediary variable between both financial and technological constructs and project value. The indirect effect of SBF on PV through DCP (β = 0.106, t = 3.072, p = 0.002) and that of FEP on PV through DCP (β = 0.094, t = 2.883, p = 0.004) confirm that carbon pricing amplifies the positive influence of sustainable financing and fintech–ESG collaboration. This means that as carbon markets mature, they reinforce the effectiveness of financial and digital innovations in enhancing renewable energy project value. Overall, these findings validate the integrated financial–technological–environmental model proposed in this study and underscore the synergistic impact of sustainability-based financing, fintech–ESG partnerships, and dynamic carbon pricing on improving the long-term economic and sustainability performance of renewable energy projects in Central Java.

The analysis shows that all direct relationships-Sustainability-Based Financing (SBF), Fintech–ESG Partnerships (FEP), and

Dynamic Carbon Pricing (DCP) on Project Value (PV)—are positive and significant. SBF ($\beta = 0.312$, $t = 4.85$, $p < 0.001$) enhances project valuation by integrating ESG principles through instruments such as green loans and sustainability-linked bonds, which strengthen investor confidence and financial stability (Flammer, 2021). Likewise, FEP ($\beta = 0.298$, $t = 4.22$, $p < 0.001$) positively influences project value by promoting transparency, automated ESG reporting, and blockchain traceability, as supported by Chen and Volz (2022). In Central Java, fintech-enabled ESG initiatives—like Surakarta's pilot programs—demonstrate how digital tools enhance accountability and investor trust. DCP exerts the strongest effect ($\beta = 0.341$, $t = 5.09$, $p < 0.001$), showing that adaptive carbon pricing improves competitiveness and profitability of renewable projects, consistent with Nordhaus (2017) and Stiglitz et al. (2017).

The mediation analysis further reveals that DCP significantly mediates both SBF → PV ($\beta = 0.106$, $t = 3.07$, $p = 0.002$) and FEP → PV ($\beta = 0.094$, $t = 2.88$, $p = 0.004$) relationships. This indicates that dynamic carbon pricing amplifies the impact of sustainable financing and fintech–ESG integration by embedding carbon value into investment appraisals. Fintech innovations—such as carbon data tracking and tokenized credit trading—enable developers to monetize emission reductions, improving financial and environmental performance. Thus, DCP functions as a strategic bridge linking finance, technology, and environmental policy, reinforcing the integrated sustainability framework that drives renewable energy project value in Central Java.

The results of the coefficient of determination (R^2) and effect size (f^2) analysis indicate that the model demonstrates strong explanatory power, with R^2 values of 0.558 for Dynamic Carbon Pricing (DCP) and 0.673 for Project Value (PV), showing that the predictor variables collectively explain a substantial portion of variance in the dependent constructs. Among the predictors, DCP exhibits the largest effect size ($f^2 = 0.241$), followed by Sustainability-Based Financing ($f^2 = 0.154$) and Fintech–ESG Partnerships ($f^2 = 0.136$), highlighting the dominant influence of adaptive carbon pricing in determining renewable project valuation. These findings emphasize that carbon pricing mechanisms play a pivotal role in converting sustainability initiatives into tangible financial performance. Furthermore, the Stone-Geisser predictive relevance (Q^2) test produced values of 0.359 for PV and 0.312 for DCP, both exceeding zero, confirming strong predictive capability. This indicates that the structural model possesses high accuracy and reliability in predicting renewable energy project outcomes based on the integrated effects of financial, technological, and environmental variables.

Discussion

The Role of Sustainability-Based Financing in Project Value Creation

The empirical findings confirm H1, showing that sustainability-based financing significantly and positively affects renewable project value. This result supports Stakeholder Theory [27] and the Resource-Based View [9], [28], which emphasize that access to ESG-integrated capital strengthens both tangible and intangible firm resources. In Central Java, sustainability-based financing acts as a strategic driver for renewable energy development by reducing investment risk and enhancing investor trust. Projects financed through green bonds, blended finance, and sustainability-linked loans show better cash flow predictability and stronger compliance with ESG reporting, consistent with [7], [29], [30], who found that sustainability-oriented financing improves valuation and lowers the cost of capital.

Furthermore, financial institutions in Central Java—such as Perumda BPR and regional development banks—have adopted OJK's Green Taxonomy 2.0 to prioritize renewable energy portfolios, increasing their contribution to sustainable regional growth. This indicates that sustainability-based financing not only improves access to capital but also functions as a governance mechanism that aligns financial accountability with social and environmental legitimacy. By embedding sustainability into funding decisions, it reinforces long-term project value creation and strengthens the foundation for responsible economic transformation in the renewable energy sector.

The Impact of Fintech–ESG Partnerships on Project Value

The second major finding supports H2, showing that fintech–ESG partnerships significantly enhance renewable energy project value by improving transparency, efficiency, and accountability in digital financial ecosystems. Grounded in the Dynamic Capabilities Theory [31], these partnerships strengthen an organization's ability to sense, seize, and transform opportunities within evolving technological and policy landscapes. Fintech tools such as AI-based credit assessments, blockchain-enabled ESG monitoring, and carbon traceability systems effectively reduce information asymmetry between investors and project developers, fostering data-driven governance and more inclusive investment channels. This result aligns with [12]–[14], [30], [32], who demonstrated that fintech-driven sustainability innovations accelerate green capital flows and improve impact verification accuracy.

In the context of Central Java, these findings are evidenced by initiatives like blockchain-based renewable energy certificates in Surakarta and AI-assisted ESG dashboards implemented by regional financial institutions. Such innovations show how fintech–ESG integration enhances investor confidence and operational accountability across renewable project ecosystems. Ultimately, fintech–ESG partnerships function not only as technological enablers but also as institutional innovations that transform financial access, strengthen trust, and promote inclusion—particularly benefiting small and medium-scale renewable projects often underserved by traditional banking systems.

The Influence of Dynamic Carbon Pricing on Project Value

Dynamic carbon pricing emerged as the most influential variable in this study, confirming H3 and reinforcing the core proposition of Environmental Economics Theory [17], [18] that monetizing carbon emissions internalizes environmental costs and steers investments toward low-emission technologies. In Indonesia, the implementation of Presidential Regulation No. 98/2021 on Carbon Economic Value (NEK) and the establishment of the IDXCarbon exchange in 2023 serve as institutional cornerstones for operationalizing this mechanism. Respondents—particularly from project development and financial sectors—recognized that adaptive carbon pricing frameworks improve the financial appeal of renewable projects by directly linking emission reduction performance with economic incentives. Empirical examples from Banyumas and Pati, where pilot carbon offset schemes have been applied to solar and biomass projects, illustrate how dynamic pricing strengthens investment confidence and enhances profitability.

This finding supports [15], [16], [33], who argued that carbon market responsiveness significantly shapes private investment behavior, and aligns with broader evidence suggesting that dynamic pricing mechanisms encourage innovation by providing clearer and more consistent policy signals to investors. Essentially, dynamic carbon pricing functions as a policy multiplier, transforming environmental progress into measurable financial outcomes while reinforcing the alignment between financial innovation and sustainable technological adoption. In the context of Central Java, this adaptive mechanism not only fosters long-term competitiveness in renewable energy investments but also demonstrates how environmental policy instruments can effectively drive market-based sustainability transitions.

The Mediating Role of Dynamic Carbon Pricing

The mediation analysis confirmed both H4 and H5, showing that dynamic carbon pricing plays a significant mediating role between sustainability-based financing and project value, as well as between fintech–ESG partnerships and project value. This dual mediation effect suggests that while SBF and FEP have direct positive impacts on renewable project valuation, their influence becomes stronger when aligned with adaptive carbon pricing mechanisms. In practice, this integration means that financial and technological innovations yield higher effectiveness when supported by policy instruments that assign measurable value to carbon performance. For instance, sustainability-linked loans incorporating carbon intensity benchmarks or fintech platforms that automate carbon credit tracking allow developers to benefit simultaneously from financial and regulatory incentives, thereby improving creditworthiness, investment predictability, and returns on sustainability performance (ROSP).

From a theoretical perspective, these findings reinforce the interconnectedness of financial innovation and environmental governance. Dynamic carbon pricing functions as a crucial transmission channel that links economic instruments with ecological outcomes, bridging policy design and market response. This validates the institutional argument that adaptive, data-informed policy frameworks can enable financial systems to internalize environmental value effectively. In the context of Central Java's renewable energy transition, this synergy enhances the efficiency of green finance mechanisms and strengthens the alignment between financial performance, regulatory adaptation, and sustainable technological advancement.

Theoretical Integration

The discussion of findings reinforces an integrated theoretical framework combining Stakeholder Theory, Dynamic Capabilities Theory, and Environmental Economics Theory. From the perspective of Stakeholder Theory (Freeman, 1984), sustainability-based financing illustrates the alignment between financial institutions and societal objectives, where investors and banks act as responsible stakeholders allocating capital to generate shared economic, environmental, and social value. Through the lens of Dynamic Capabilities Theory (Teece, 2007), fintech–ESG partnerships represent organizational agility in adapting to sustainability transitions by enabling firms to sense opportunities such as carbon market participation, seize advantages through data analytics, and transform operations toward innovation-driven sustainability. Meanwhile, Environmental Economics Theory (Stiglitz et al., 2017) explains that dynamic carbon pricing operationalizes efficient resource allocation by turning emission reductions into tradable and measurable assets, thereby linking environmental outcomes with financial incentives that shape investment decisions. Collectively, these theoretical perspectives highlight that financial mechanisms, technological innovations, and policy instruments function as mutually reinforcing components in determining renewable energy project value and accelerating the sustainable energy transition.

Practical and Regional Implications

The results of this study carry significant implications for the renewable energy ecosystem in Central Java and Indonesia as a whole. For policymakers, carbon pricing mechanisms should remain flexible and responsive to market dynamics to sustain investment flows into renewable sectors, while incentive schemes under the Nilai Ekonomi Karbon (NEK) must be harmonized with banking regulations so that carbon credit performance influences lending criteria. For financial institutions, embedding carbon performance indicators in green loan assessments can better align financial returns with emission reduction outcomes, while collaboration with fintech startups can strengthen ESG monitoring, reduce risk exposure, and enhance accountability. For renewable project developers, adopting digital ESG and carbon management tools will improve project visibility and financing potential, whereas participation in carbon markets and data-sharing platforms provides both compliance advantages and economic rewards. Finally, for the academic and research community, these findings open opportunities for longitudinal studies exploring how interactions among financing, fintech, and carbon pricing evolve over time as carbon markets mature and digital ecosystems expand, thus enriching the empirical and theoretical understanding of sustainable energy transitions in Indonesia.

5. CONCLUSION

This research provides robust empirical evidence that integrating sustainable financial mechanisms, fintech-driven ESG innovations, and adaptive environmental policies significantly enhances the value of renewable energy projects in Central Java. Using SEM-PLS 3 with 130 valid samples, the study confirmed all five hypotheses: Sustainability-Based Financing (SBF) positively affects project value by improving access to long-term, low-risk capital and strengthening investor confidence; Fintech–ESG Partnerships (FEP) increase project value through enhanced transparency, reduced transaction costs, and automated ESG monitoring; and Dynamic Carbon Pricing (DCP) exerts the strongest influence as a mechanism that monetizes emission reductions and enhances competitiveness. Furthermore, DCP mediates the effects of both SBF and FEP on project value, demonstrating that carbon pricing amplifies the financial and sustainability benefits of digital ESG collaboration. The model's strong explanatory power ($R^2 = 0.673$) and predictive relevance ($Q^2 = 0.359$) confirm that financial, technological, and environmental factors function interdependently as key drivers of value creation in Indonesia's renewable energy sector.

Theoretically, this study enriches the discourse on sustainable project valuation by integrating Stakeholder Theory, Dynamic Capabilities Theory, and Environmental Economics Theory into a unified analytical framework. Stakeholder Theory emphasizes the collaborative roles of financial institutions, governments, and communities in shaping sustainability outcomes, while Dynamic Capabilities Theory highlights how fintech–ESG integration enhances organizational agility and innovation in response to evolving environmental and financial opportunities. Environmental Economics Theory demonstrates that dynamic carbon pricing internalizes ecological costs, transforming environmental performance into a quantifiable economic asset. Together, these perspectives provide a comprehensive foundation for understanding renewable project valuation that transcends conventional financial metrics—linking innovation capacity, environmental governance, and institutional coordination as integral components of sustainable energy transition.

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