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Intelligent Control of Renewable Energy Systems and Resilient Supply Chain Finance Under Geopolitical Uncertainty: A Digital Integration Perspective

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Abstract: Background: The contemporary transition toward low-carbon development is no longer shaped by energy engineering alone. It is increasingly influenced by the interaction among renewable energy control systems, digital optimization methods, geopolitical risk, trade policy uncertainty, supply chain resilience, blockchain-enabled transparency, and the growing financialization of digital assets. The references provided for this study span renewable energy conversion control, maximum power point tracking, hybrid solar-wind systems, artificial intelligence-based optimization, supply chain risk classification, trade policy uncertainty, blockchain product passports, supply chain tokens, cryptocurrency dynamics, and connectedness modeling.

Objective: This article develops a publication-ready original research narrative, based strictly on the supplied references, to explain how renewable energy system intelligence and digitally mediated supply chain-financial mechanisms jointly shape resilient energy transitions under uncertainty.

Methodology: A text-based integrative research design was employed. The renewable energy literature was interpreted through the lenses of control architecture, maximum power extraction, hybrid system coordination, and soft-computing optimization. The finance and supply chain literature was interpreted through the lenses of risk transmission, geopolitical uncertainty, blockchain transparency, crypto-linked asset behavior, and dynamic connectedness. These streams were then synthesized into a common framework of techno-financial resilience.

Results: The analysis indicates that renewable energy performance depends not only on resource availability but also on adaptive digital control, especially in variable wind and solar conditions. At the same time, supply chains and energy-linked financial ecosystems are increasingly exposed to geopolitical shocks, trade uncertainty, and volatility spillovers. Blockchain-based transparency, tokenization, and digital asset interconnection offer new opportunities for traceability and financing, but they also introduce fresh channels of contagion and instability.

Conclusion: The study argues that a resilient clean-energy future requires simultaneous progress in three dimensions: intelligent renewable generation control, transparent and sustainable supply chain design, and sophisticated risk management for crypto-financial spillovers under geopolitical pressure. Energy transition resilience therefore emerges as a systems property located at the intersection of engineering control, digital infrastructure, and financial connectedness.

Keywords: Renewable energy control, MPPT, supply chain resilience, blockchain transparency, cryptocurrency connectedness, geopolitical risk, energy security.

Introduction: The global movement toward renewable energy and sustainable production has often been described as a technological transition, but the evidence now suggests that it is better understood as a systemic transition involving engineering, supply chains, financial markets, and digital infrastructure simultaneously. Solar and wind energy systems must operate efficiently under changing environmental conditions. Supply chains must remain reliable despite geopolitical disruptions, climate-related stress, and trade policy uncertainty. Financial systems increasingly interact with tokenized assets, cryptocurrencies, and blockchain-based platforms that influence investment behavior, transparency, and market sentiment. The references provided for this article make clear that these developments are not isolated. They increasingly belong to a common field of inquiry centered on resilience, adaptability, and digitally enabled coordination in uncertain environments (Baloch et al., 2016a; Tahir et al., 2018; Shahbaz et al., 2019; Viriyasitavat et al., 2021; Qin et al., 2023; Zhao et al., 2025).

Renewable energy systems occupy a central position in this transition because they lie at the intersection of climate mitigation, energy security, and technological modernization. Wind and solar systems are attractive not only because they reduce dependence on fossil fuels, but because they can be deployed across diverse scales and locations. Yet the engineering challenge is formidable. Wind velocity fluctuates, solar irradiance varies, partial shading affects photovoltaic output, and hybrid systems must balance intermittent sources against storage and backup requirements. As a result, the efficiency of renewable energy generation depends heavily on control intelligence rather than on hardware alone. This is why the literature reviewed here pays such close attention to digital control techniques, maximum power point tracking, fuzzy logic, neural optimization, and advanced system coordination (Kaloi et al., 2016; Kumar & Chatterjee, 2016; Tahir et al., 2018; Abdellatif et al., 2021; Abo-Khalil et al., 2021; Abdolrasol et al., 2021; Prasad et al., 2023).

The control problem is particularly evident in wind energy systems. Baloch et al. (2016a) discuss the current scenario of wind energy in Pakistan, highlighting both the promise and the structural challenges of wind development in an emerging economy. Kaloi et al. (2016) address active and reactive power control of doubly fed induction generators in wind energy conversion systems, emphasizing the importance of precise power management. Hussain et al. (2018), from the earlier formatted list provided in the conversation, along with Kumar and Chatterjee (2016), contribute to the understanding of maximum power tracking in wind systems, while Tahir et al. (2018) broaden the discussion to voltage source inverter control in renewable applications. Taken together, these studies show that renewable energy effectiveness depends not merely on resource potential, but on the ability of intelligent controllers to convert variable resource conditions into stable and optimized electrical output.

Solar systems present analogous challenges. Maximum power point tracking in photovoltaic systems has evolved from conventional incremental or perturbative approaches toward sophisticated intelligent controllers that respond more effectively to nonlinear and rapidly changing conditions. Abdellatif et al. (2021) demonstrate fuzzy logic control for photovoltaic MPPT, while Abo-Khalil et al. (2021) apply an opposition-based learning firefly algorithm under partial shading conditions. These references indicate that photovoltaic performance is increasingly treated as an optimization problem under uncertainty rather than a static engineering exercise. Prasad et al. (2023) extend this logic to a grid-tied multifunctional solar energy conversion system using a novel optimization-based control approach, again emphasizing that advanced power systems require real-time intelligence for reliable operation.

Hybrid renewable systems add a further layer of complexity. Solar-wind-battery-diesel configurations, isolated-site hybrid systems, and PV-wave-fuel cell integrations all require control frameworks that coordinate multiple technologies with different dynamic behaviors and intermittency patterns (Anowar et al., 2016; Jemaa et al., 2018; Belmili et al., 2017; Talaat et al., 2022 from the earlier conversation-provided list). Rezvani et al. (2015) also show the relevance of ANFIS and fuzzy logic for improving hybrid dynamic performance under fast-varying solar radiation and high wind speeds. These studies imply that resilience in renewable energy is not a simple matter of installing more capacity. It depends on whether system intelligence can maintain stability, optimize extraction, and accommodate variable environmental input.

Artificial intelligence and soft computing methods are therefore not peripheral tools in renewable energy research; they are increasingly central to system viability. Abdolrasol et al. (2021) review artificial neural network optimization techniques, revealing the breadth of intelligent methods now used in engineering optimization. This matters because renewable systems are inherently nonlinear and uncertain. Fuzzy logic, neural methods, evolutionary optimization, and hybrid intelligent controllers are appealing not because they are fashionable, but because conventional deterministic methods may struggle with the irregularities of real operating environments. Mhmood and Jumaa (2023), mentioned in the user’s reference-cleaning stage earlier in the conversation, compare soft-computing MPPT techniques with traditional incremental conductance under arbitrary environmental conditions, reinforcing the idea that intelligent control is increasingly a functional necessity rather than an optional enhancement.

Yet renewable energy engineering does not occur in an institutional or economic vacuum. Deployment, scaling, component sourcing, infrastructure coordination, and market integration all depend on supply chains. These supply chains are themselves exposed to a range of disruptions, including logistics bottlenecks, policy shocks, climate-related disturbances, commodity price volatility, and geopolitical instability. Shahbaz et al. (2019) provide a useful review-based classification of supply chain risks, suggesting that the field already recognizes the multidimensional character of uncertainty. Wang (2025) further emphasizes global supply chain resilience under trade uncertainties, while Feng et al. (2022) analyze trade policy and supply chain network equilibrium. Qin et al. (2023) bring climate and geopolitics into the supply chain sustainability discussion. These studies collectively indicate that energy transition planning must include not only technical generation efficiency but also robust supply chain design.

The geopolitical dimension is especially important. Caldara et al. (2020) show the economic effects of trade policy uncertainty, Jia et al. (2025) link geopolitical risk with metal prices and global supply chain pressure, Khan (2025) examines how supply chain and geopolitical risks threaten energy security, and Gao et al. (2025) analyze spillover effects of economic policy uncertainty through transnational supply chains. In a renewable energy context, this matters greatly because wind turbines, inverters, control systems, battery materials, and solar components often depend on globally distributed value chains. A supply chain shock is therefore not merely a procurement problem; it can become an energy security problem. This makes the traditional distinction between engineering reliability and geopolitical-economic stability increasingly untenable.

Alongside physical supply chain exposure, a second form of complexity has emerged through the digitalization and financialization of supply chains. Viriyasitavat et al. (2021) discuss cryptocurrency in the smart supply chain, while Canciani et al. (2024) examine blockchain product passports as tools for transparency. Yan et al. (2025) study the impact of blockchain application on supply chain alliances, and Shang and Chen, mentioned earlier in the conversation during reference preparation, connect supply chain transparency with corporate financial fraud. Zhao et al. (2025) relate supply chain sustainability to market competitiveness through ESG practices. Together, these works indicate that digital traceability and blockchain-based coordination are increasingly presented as mechanisms for improving supply chain governance, trust, and sustainability.

However, digitalization also creates new financial channels of risk transmission. The references include a substantial body of work on cryptocurrency volatility, connectedness, dynamic equicorrelation, cross-asset spillovers, stablecoins, tokenized real estate, healthcare tokens, NFTs, and supply chain tokens (Corbet et al., 2019; Bouri et al., 2021; Demiralay & Golitsis, 2021; Aloui et al., 2021; Long et al., 2022; Yousaf et al., 2023 from the earlier reference-cleaning stage; Abdullah et al., 2023; Chen & Yang, 2024; Adelopo & Luo, 2025; Mbarek & Msolli, 2025). This literature matters for the present study because digital assets are increasingly discussed not merely as speculative instruments but as components of broader economic and supply chain architectures. Once tokenization enters supply chain systems, the boundary between logistics transparency and asset-market volatility becomes blurred.

The methodological literature included in the references provides important clues about how these asset relationships should be interpreted. Engle (2002) introduced dynamic conditional correlation as a parsimonious approach to time-varying covariance structures. Engle and Kelly (2012) developed dynamic equicorrelation, which is especially useful for understanding broad comovement structures. Bollerslev and Wooldridge (1992) offer inference foundations for dynamic models with time-varying covariances, while Glosten et al. (1993) examine volatility-return asymmetry. These references are not incidental. They show that modern analysis of energy-financial risk, cryptocurrency markets, and connected asset systems increasingly depends on models capable of capturing evolving interdependence rather than static correlation. This is vital in the context of geopolitical shocks, where market relationships often intensify, reverse, or propagate unexpectedly.

The cryptocurrency and token literature reveals several important trends. Corbet et al. (2019) frame cryptocurrency as a financial asset through systematic analysis. Bouri et al. (2021) investigate return equicorrelation in the cryptocurrency market, while Demiralay and Golitsis (2021) focus on dynamic equicorrelations. Aloui et al. (2021) ask whether Islamic gold-backed cryptocurrencies are different, suggesting that not all digital assets behave alike. Long et al. (2022) study whether geopolitical risk is priced in cryptocurrency returns, Fang et al. (2024) examine geopolitical risk and crypto volatility directly, and Jin and Yu (2023), from the earlier reference list formatting stage, bring climate policy uncertainty into crypto volatility forecasting. Adelopo and Luo (2025) further analyze how cryptocurrency features determine volatility and comovement with stocks. These studies indicate that digital assets are increasingly entangled with macroeconomic, geopolitical, and policy environments rather than existing outside them.

This matters for sustainable energy transitions because investment ecosystems are changing. Renewable infrastructure can be influenced by investor sentiment, market liquidity, and broader risk-on/risk-off conditions. At the same time, blockchain-enabled supply chains and tokenized financing mechanisms promise greater traceability, faster settlement, and new participation models. Yet these same systems may be exposed to volatility spillovers, speculation, regulatory uncertainty, and contagion. The result is an emerging paradox: digital finance may strengthen supply chain transparency and innovation while also introducing a new layer of systemic fragility.

The literature gap addressed in this article lies precisely in this intersection. Existing references speak richly to renewable energy control, to supply chain risk and resilience, and to digital asset connectedness. What is less developed is an integrated account of how these domains interact as parts of a single resilience problem. Renewable energy scholars often emphasize technical optimization without fully integrating supply chain-financial uncertainty. Supply chain scholars often address risk and transparency without connecting them to the operational intelligence of renewable infrastructure. Financial connectedness scholars often analyze cryptocurrencies and tokenized assets without linking them back to energy transition systems, energy security, or hybrid supply chain architectures. The present article addresses this gap by placing these domains in dialogue.

The core argument advanced here is that resilient clean-energy systems require synchronized advancement in three layers. The first layer is engineering intelligence, including MPPT, fuzzy logic, AI optimization, inverter control, and hybrid system coordination. The second layer is supply chain resilience, including trade-policy awareness, geopolitical risk adaptation, transparency, sustainability, and network equilibrium management. The third layer is digital-financial governance, including blockchain adoption, tokenized asset interconnection, and dynamic risk modeling for cryptocurrencies and adjacent digital instruments. None of these layers is sufficient alone. A highly optimized renewable system may still fail economically if supply chains fracture or energy security is undermined by geopolitical shocks. A transparent blockchain supply chain may still be fragile if the underlying energy assets are poorly controlled or the financing environment is excessively volatile.

This article therefore develops an original, publication-ready research narrative based strictly on the provided references, with the aim of explaining how renewable energy control, supply chain risk, and digital-financial connectedness jointly shape resilience under uncertainty. The article proceeds by treating the references not as isolated topical clusters but as contributions to a broader systems theory of the energy transition. In this theory, energy generation, logistics, and finance are not sequential domains but mutually conditioning infrastructures.

METHODOLOGY

The methodology of this study was designed as an integrative, text-based original research synthesis using only the references supplied by the user. Because the instruction requires a publication-ready article without equations, figures, tables, or external evidence, the methodological approach is interpretive and analytical rather than computational. Nevertheless, it is structured and disciplined rather than impressionistic. The goal was to create a coherent research design capable of organizing a heterogeneous body of literature into a unified explanatory model of renewable energy resilience under digital, geopolitical, and financial uncertainty.

The first methodological step involved corpus segmentation. The reference set was divided into three principal clusters. The first cluster consisted of renewable energy engineering and control studies, including work on wind energy conversion systems, active and reactive power control, MPPT algorithms, fuzzy logic controllers, ANN-based optimization, grid-tied solar conversion, inverter control, and hybrid solar-wind or multi-source systems (Baloch et al., 2016a; Kaloi et al., 2016; Kumar & Chatterjee, 2016; Tahir et al., 2018; Abdellatif et al., 2021; Abo-Khalil et al., 2021; Abdolrasol et al., 2021; Jemaa et al., 2018; Prasad et al., 2023; Belmili et al., 2017; Rezvani et al., 2015; Anowar et al., 2016). The second cluster consisted of supply chain risk, resilience, transparency, sustainability, and trade-policy-related studies (Shahbaz et al., 2019; Feng et al., 2022; Qin et al., 2023; Canciani et al., 2024; Wang, 2025; Zhao et al., 2025; Gao et al., 2025; Jia et al., 2025; Khan, 2025). The third cluster consisted of cryptocurrency, tokenization, connectedness, and volatility literature, including both conceptual asset studies and methodological works on dynamic dependence (Corbet et al., 2019; Bouri et al., 2021; Demiralay & Golitsis, 2021; Aloui et al., 2021; Long et al., 2022; Abdullah et al., 2023; Urom et al., 2022, 2024; Ullah et al., 2024; Chen & Yang, 2024; Adelopo & Luo, 2025; Mbarek & Msolli, 2025; Engle, 2002; Engle &

Kelly, 2012; Bollerslev & Wooldridge, 1992; Glosten et al., 1993).

The second methodological step involved thematic coding within each cluster. In the renewable energy cluster, the studies were coded according to six subthemes: resource variability, power control, MPPT design, intelligent or soft-computing optimization, hybrid system coordination, and deployment-oriented hardware implementation. For instance, Kaloi et al. (2016) and Tahir et al. (2018) were coded under power control and converter intelligence; Kumar and Chatterjee (2016), Abdellatif et al. (2021), and Abo-Khalil et al. (2021) were coded under MPPT design; Abdolrasol et al. (2021) and Rezvani et al. (2015) were coded under AI and adaptive optimization; Jemaa et al. (2018), Belmili et al. (2017), and Anowar et al. (2016) were coded under hybrid coordination and isolated-site system integration. This coding made it possible to treat renewable energy intelligence as a layered engineering system rather than as a single technical function.

In the supply chain cluster, the studies were coded under risk typology, trade and geopolitical uncertainty, sustainability and ESG logic, blockchain-enabled transparency, and network resilience. Shahbaz et al. (2019) were particularly important as a foundational risk taxonomy reference. Caldara et al. (2020), Feng et al. (2022), Qin et al. (2023), Gao et al. (2025), Jia et al. (2025), and Khan (2025) were coded under macro-risk transmission and uncertainty effects. Canciani et al. (2024), Viriyasitavat et al. (2021), and Yan et al. (2025) were coded under digitalization and blockchain coordination. Zhao et al. (2025) and Wang (2025) were coded under sustainability-linked resilience and competitiveness. This coding framework was essential because it allowed the supply chain literature to be interpreted not just as a list of disruptions, but as a field concerned with governance and design responses.

In the cryptocurrency and token cluster, the studies were coded under asset identity, volatility and connectedness, geopolitical sensitivity, portfolio behavior, and tokenized supply chain interaction. Corbet et al. (2019) and Aloui et al. (2021) were coded under asset characterization. Bouri et al. (2021), Demiralay and Golitsis (2021), Chen and Yang (2024), and Adelopo and Luo (2025) were coded under dynamic connectedness and comovement. Long et al. (2022), Fang et al. (2024), and Ullah et al. (2024) were coded under geopolitical and macro-risk interaction. Abdullah et al. (2023), Urom et al. (2022, 2024), and Mbarek and Msolli (2025) were coded under tokenized asset spillovers and cross-asset connectedness. Viriyasitavat et al. (2021) and Canciani et al. (2024) formed a bridge between this cluster and the supply chain cluster by showing how digital assets and blockchain tools enter operational value-chain structures.

The third methodological step was conceptual abstraction across clusters. After thematic coding, the literature was interpreted through five higher-order concepts that cut across all clusters: adaptive optimization, uncertainty management, network interdependence, transparency and trust, and resilience under shock. Adaptive optimization was obvious in renewable control and MPPT design, but it also appeared in blockchain-enabled coordination and portfolio or risk-management logic in tokenized financial environments (Kumar & Chatterjee, 2016; Abdolrasol et al., 2021; Abo-Khalil et al., 2021; Viriyasitavat et al., 2021). Uncertainty management appeared in renewable intermittency, trade uncertainty, geopolitical volatility, and crypto return dynamics (Baloch et al., 2016a; Caldara et al., 2020; Fang et al., 2024; Khan, 2025). Network interdependence appeared in hybrid energy systems, global supply chain equilibrium, and financial connectedness across tokens and conventional assets (Belmili et al., 2017; Feng et al., 2022; Bouri et al., 2021; Abdullah et al., 2023). Transparency and trust emerged through blockchain product passports and the informational dimension of tokenized systems (Canciani et al., 2024; Yan et al., 2025). Resilience under shock unified the entire corpus.

The fourth methodological step was interpretive triangulation. A major proposition in the article was only advanced when supported by convergence across at least two clusters, and ideally across all three. For example, the claim that digital intelligence is now central to resilience was supported in the energy cluster by fuzzy logic, ANN, and optimization studies (Abdellatif et al., 2021; Abdolrasol et al., 2021; Prasad et al., 2023), in the supply chain cluster by blockchain transparency and digital coordination studies (Viriyasitavat et al., 2021; Canciani et al., 2024; Yan et al., 2025), and in the financial cluster by work on tokenized assets and dynamic connectedness (Mbarek & Msolli, 2025; Adelopo & Luo, 2025). Similarly, the claim that geopolitical uncertainty threatens system performance was triangulated through trade policy and macroeconomic references, energy security references, and crypto volatility references (Caldara et al., 2020; Qin et al., 2023; Khan, 2025; Long et al., 2022; Fang et al., 2024).

The fifth methodological step concerned the role of econometric references. The article does not estimate any model numerically, because the user requested a continuous text article based strictly on supplied references and without equations. However, the methodological references on dynamic conditional correlation, dynamic equicorrelation, time-varying covariance inference, and volatility-return asymmetry were used to define the analytical logic by which connectedness and spillovers are interpreted (Bollerslev & Wooldridge, 1992; Engle, 2002; Engle & Kelly, 2012; Glosten et al., 1993). In other words, these references were not included as decorative citations but as part of the conceptual toolkit. They justify the study's treatment of financial and tokenized asset behavior as dynamic, state-dependent, and sensitive to changing uncertainty regimes.

The sixth methodological step involved exclusion discipline. Because the reference set is broad, there was a risk of forcing unrelated subtopics into superficial unity. To avoid this, the analysis excluded lines of interpretation that were not sufficiently grounded in the references. For example, the article does not claim that any specific cryptocurrency should finance renewable grids, because the provided literature does not establish that direct causal pathway. It also does not claim that blockchain automatically solves supply chain governance, because the references point more toward enhancement potential than universal effectiveness. Likewise, it does not claim that fuzzy logic or ANN approaches are always superior to conventional controllers in every environment; instead, it interprets them as increasingly relevant under complexity and variability. This discipline was essential for credibility.

The seventh methodological step was the use of systems comparison rather than direct equivalence. Renewable control systems, supply chains, and crypto-financial markets are obviously distinct domains. The methodology did not collapse them into one object. Instead, it treated them as interconnected infrastructures within the broader energy transition. Renewable engineering generates electricity. Supply chains deliver materials, components, and operational continuity. Digital-financial systems influence transparency, risk pricing, and connectedness. This systems comparison allowed the article to explain interaction without erasing domain differences.

The eighth methodological step was argument sequencing. The article first establishes the engineering logic of renewable energy intelligence, then the structural logic of supply chain resilience, then the behavior of digital-financial connectedness, and only after that presents an integrated interpretation. This sequence was deliberate. It allows each domain to retain its own explanatory integrity before being positioned within a common resilience framework. In interdisciplinary writing, this sequencing reduces the risk of vague analogy and instead builds a layered explanatory structure.

The ninth methodological step involved citation density and placement. Because the instruction requires that every major claim be cited, references are distributed throughout the discussion rather than concentrated only at section ends. This is particularly important in long, interpretive passages where multiple claims are made about control design, uncertainty, supply chain fragility, or tokenized asset behavior. Dense citation supports traceability and helps ensure that synthesis remains demonstrably anchored in the source base.

Overall, the methodology of this study can be described as a structured integrative systems analysis. It is not a meta-analysis, not a narrative review in the loose sense, and not a speculative essay. It is a reference-bound research synthesis designed to reveal how renewable energy control, supply chain resilience, and digital-financial connectedness jointly shape system robustness in the context of energy transition uncertainty.

RESULTS

The analysis of the supplied literature yielded a set of interrelated findings that clarify how intelligent renewable energy control, supply chain resilience, and digital-financial connectedness interact in shaping sustainable development under uncertainty.

The first major finding is that renewable energy performance is decisively dependent on control intelligence rather than on resource availability alone. Wind and solar resources may be abundant in theory, but extraction efficiency and system stability depend on whether control architectures can continuously adapt to nonlinear and fast-changing operating conditions. Baloch et al. (2016a) show that wind energy prospects are inseparable from the technological and infrastructural conditions required to harness them. Kaloi et al. (2016) demonstrate that active and reactive power control in doubly fed induction generator systems is central to wind energy conversion performance. Kumar and Chatterjee (2016) reinforce this by showing that MPPT algorithms play a pivotal role in wind systems. The collective result is that renewable resource presence is only the starting point. Usable energy output is a function of control sophistication.

A second finding is that digital control has become the operational backbone of renewable energy conversion systems. Tahir et al. (2018) review voltage source inverter control techniques in renewable applications, indicating that conversion quality and energy interface performance are now tightly bound to digital control design. Abdellatif et al. (2021) show that fuzzy logic can enhance photovoltaic MPPT behavior, while Jemaa et al. (2018) demonstrate the feasibility of hardware implementation for fuzzy logic control in hybrid wind-solar systems. Prasad et al. (2023) take this further through a novel optimization-based control approach for multifunctional solar energy conversion systems. The result is clear: renewable energy systems increasingly behave as cyber-physical systems in which digital control intelligence is inseparable from electrical performance.

A third finding is that soft-computing methods have moved from experimental alternatives to practical contenders in renewable energy optimization. Fuzzy logic, artificial neural networks, ANFIS, and metaheuristic-enhanced control methods are repeatedly positioned in the literature as responses to uncertainty, intermittency, and nonlinearity (Rezvani et al., 2015; Abdellatif et al., 2021; Abdolrasol et al., 2021; Abo-Khalil et al., 2021). These approaches are not used merely because they are computationally sophisticated. Their appeal lies in their flexibility under variable environmental input, especially when conventional control methods may struggle with partial shading, wind-speed turbulence, or hybrid-source coordination. The practical implication is that future renewable deployment will likely depend on the growing integration of intelligent optimization into mainstream control practice.

A fourth finding is that hybrid renewable systems make systems coordination more important than component-level optimization alone. Belmili et al. (2017) address optimized control and sizing of standalone PV-wind systems, Anowar et al. (2016) implement fuzzy logic in a solar-wind-battery-diesel hybrid system, and Jemaa et al. (2018) study a hybrid wind-solar system in an isolated site. These references indicate that as systems become more diversified, performance depends less on the maximum efficiency of one source and more on the quality of interaction among sources, storage, backup, and control. This is a critical shift. It suggests that resilient renewable infrastructure is a coordination problem as much as a generation problem.

A fifth finding is that renewable energy engineering and energy security are increasingly linked through geopolitical and supply chain conditions. Khan (2025) explicitly analyzes how supply chain and geopolitical risks threaten energy security, while Jia et al. (2025) connect geopolitical risk with metal prices and global supply chain pressure. Qin et al. (2023) similarly show that climate and geopolitics create major challenges to sustainable development through the global supply chain. These findings imply that renewable energy systems cannot be evaluated solely at the device or controller level. Their resilience is partly determined by whether component supply, mineral access, logistics continuity, and policy stability remain intact. Energy transition vulnerability therefore lies not only in intermittency, but in cross-border economic and geopolitical exposure.

A sixth finding is that trade policy uncertainty operates as a transmission channel that can destabilize supply chain efficiency and therefore indirectly affect energy transition systems. Caldara et al. (2020) examine the broader economic effects of trade policy uncertainty. Feng et al. (2022) show how trade policy shapes global supply chain network equilibrium, and Gao et al. (2025) document spillover effects of US economic policy uncertainty through transnational supply chains. Lin et al. (2023), which the user previously provided during reference formatting, also reinforce that trade policy uncertainty affects supply chain efficiency. The integrated implication is that renewable and sustainable systems are embedded in policy-sensitive trade networks. Even highly efficient energy technologies may face implementation barriers if uncertainty distorts sourcing, costs, or cross-border coordination.

A seventh finding is that supply chain resilience has shifted from being primarily a logistics concern to becoming a strategic governance and competitiveness issue. Shahbaz et al. (2019) classify supply chain risks, but later references go further by linking resilience to competitiveness, sustainability, transparency, and strategic adaptability. Zhao et al. (2025) connect supply chain sustainability with firm market competitiveness through ESG practices. Wang (2025) focuses directly on enhancing global supply chain resilience under trade uncertainties. These studies suggest that resilience is no longer defined merely as the ability to recover from disruption. It increasingly includes the capacity to remain credible, competitive, and sustainable in the eyes of markets, regulators, and stakeholders.

An eighth finding is that blockchain and digital traceability are emerging as serious tools for supply chain transparency, not merely as conceptual experiments. Viriyasitavat et al. (2021) discuss cryptocurrency in smart supply chains, Canciani et al. (2024) analyze blockchain product passports, and Yan et al. (2025) examine the impact of blockchain on supply chain alliances. These references indicate that digital traceability mechanisms are increasingly being understood as infrastructural tools that can affect trust, coordination, and information flow within supply networks. This is especially important for renewable energy systems, where supply chain transparency may matter for sustainability certification, ESG compliance, ethical sourcing, and risk monitoring.

A ninth finding is that blockchain-enabled transparency does not eliminate risk but restructures it. The literature suggests that blockchain can improve traceability and alliance coordination, yet the simultaneous presence of cryptocurrency, tokenization, and dynamic asset connectedness research indicates that digitalization may also introduce new volatility channels (Viriyasitavat et al., 2021; Canciani et al., 2024; Mbarek & Msolli, 2025). The implication is that digital supply chains may become more observable and programmable while also becoming more financially networked. This creates a dual effect: improved transparency on one side, and increased exposure to token-linked market dynamics on the other.

A tenth finding is that cryptocurrencies and related digital assets are increasingly integrated into broader financial and macroeconomic connectedness structures, rather than behaving as isolated speculative novelties. Corbet et al. (2019) treat cryptocurrency as a financial asset in systematic terms. Bouri et al. (2021) and Demiralay and Golitsis (2021) show that cryptocurrency markets exhibit dynamic equicorrelation structures. Chen and Yang (2024) demonstrate asymmetric dynamic correlations between Bitcoin and stablecoins, while Adelopo and Luo (2025) show that specific crypto features affect volatility and co-movement with stocks. The result is that digital assets now behave as components of interconnected market systems whose internal and external correlations matter for portfolio and risk management.

An eleventh finding is that geopolitical risk is increasingly priced into digital asset markets. Long et al. (2022) ask whether geopolitical risk appears in the cross-section of cryptocurrency returns, while Fang et al. (2024) directly connect geopolitical risk with cryptocurrency volatility. Ullah et al. (2024) compare crypto and conventional assets under heightened geopolitical risk. These references collectively indicate that digital assets do not sit outside the geopolitical sphere. On the contrary, they are sensitive to global uncertainty, and perhaps in some contexts amplify or repackage it. This matters for energy-transition finance because tokenized or crypto-linked financing frameworks cannot be assumed to provide insulation from geopolitical turbulence.

A twelfth finding is that connectedness has expanded from cryptocurrencies in general to specialized token ecosystems linked to sectors and asset classes. Abdullah et al. (2023) study real estate tokens and REITs, Yousaf et al. (2023) from the earlier formatted set examine healthcare tokens and healthcare stocks, Urom et al. (2022, 2024) examine NFTs and their connectedness with conventional assets, and Mbarek and Msolli (2025) analyze supply chain tokens. This implies that tokenization is creating more specialized digital asset ecologies. The significance of this result is that future supply chain or sustainability-linked tokens may inherit the connectedness and spillover properties already visible in other token classes. Thus, tokenization may not only create operational utility; it may also create new vectors of portfolio contagion.

A thirteenth finding is that the econometric literature on time-varying correlation provides a conceptual foundation for understanding the instability of asset and risk relationships in these environments. Engle (2002) and Engle and Kelly (2012) show that correlation structures evolve over time rather than remaining static. Bollerslev and Wooldridge (1992) provide inference logic for time-varying covariances, while Glosten et al. (1993) demonstrate asymmetry between expected returns and volatility. When read alongside the cryptocurrency and supply chain-finance studies, these references support the conclusion that risk in digitally mediated energy-transition systems is dynamic, state-dependent, and potentially nonlinear. This is more than a methodological point. It means that static governance assumptions are likely to be inadequate.

A fourteenth finding is that renewable energy control intelligence and financial connectedness are structurally similar in one crucial respect: both are adaptive responses to volatility. In the engineering domain, MPPT, fuzzy logic, and ANN-based controllers respond to environmental volatility in wind and solar inputs (Kumar & Chatterjee, 2016; Abdellatif et al., 2021; Abo-Khalil et al., 2021). In the financial domain, dynamic correlation models, connectedness studies, and volatility analyses respond to market volatility and uncertainty spillovers (Engle, 2002; Bouri et al., 2021; Fang et al., 2024). This suggests that both domains are developing tools for managing instability, though one instability is physical-energy based and the other is financial-market based.

A fifteenth finding is that supply chain resilience increasingly depends on both material and informational transparency. Canciani et al. (2024) and Yan et al. (2025) show the role of blockchain in strengthening product and alliance transparency, while Zhao et al. (2025) connect sustainable supply chain practice with competitiveness. The implication is that resilient supply chains are not only those that reroute goods efficiently. They are also those that make their provenance, sustainability characteristics, and coordination structures legible to stakeholders. This is especially relevant for energy-transition sectors, where legitimacy often depends on environmental claims, sourcing practices, and policy alignment.

A sixteenth and most integrative finding is that sustainable energy transition resilience emerges from the interaction of three adaptive systems: intelligent engineering control, shock-aware supply chains, and dynamically monitored financial-digital linkages. None of the literature clusters alone is sufficient to explain the full system. Renewable energy studies explain how to extract and stabilize energy efficiently. Supply chain studies explain how resources, components, and strategic coordination remain viable under uncertainty. Cryptocurrency and token studies explain how digital-financial structures transmit or amplify volatility and interconnectedness. Together, they reveal a broader truth: clean-energy resilience is no longer a single-discipline outcome.

DISCUSSION

The findings of this study suggest that the contemporary energy transition should not be described narrowly as a substitution of fossil generation with renewable generation. Such a description is incomplete because it ignores the growing significance of digital intelligence, global supply chain fragility, and financial interdependence in shaping whether renewable systems actually perform reliably in practice. The broader and more accurate interpretation is that the energy transition is a coordinated systems transformation in which control algorithms, component supply, geopolitical stability, market connectedness, and digital governance jointly determine outcomes.

The first major issue for discussion is the meaning of optimization in renewable energy research. Much of the engineering literature reviewed here revolves around optimization: maximizing power output, improving tracking efficiency, coordinating hybrid systems, and enhancing control response under changing input conditions (Kaloi et al., 2016; Kumar & Chatterjee, 2016; Abdellatif et al., 2021; Abo-Khalil et al., 2021; Prasad et al., 2023). Yet this optimization is often interpreted too narrowly in practice. It is tempting to think of MPPT or inverter control as device-level performance enhancement with limited strategic significance. The references suggest otherwise. In renewable systems, small improvements in control quality may influence the economic viability of projects, the stability of isolated systems, the reliability of grid interaction, and the confidence of investors in renewable infrastructure. Optimization is therefore not merely technical fine-tuning. It is a pathway through which intermittency becomes governable and renewable resources become bankable.

A second discussion point concerns the rise of intelligent control methods. Fuzzy logic, ANN-based optimization, and hybrid soft-computing approaches appear repeatedly in the literature because renewable environments are inherently noisy and nonlinear (Rezvani et al., 2015; Anowar et al., 2016; Abdellatif et al., 2021; Abdolrasol et al., 2021). This development reflects a larger transition in engineering knowledge. Earlier systems often sought deterministic control solutions under relatively simplified assumptions. Modern renewable systems instead accept variability as endemic and attempt to work with it through adaptive intelligence. This is a meaningful epistemic shift. It signals that future energy infrastructure may depend less on rigid control certainty and more on computational flexibility.

However, one should be careful not to treat soft-computing methods as universally superior or inherently transformative in all contexts. The provided references strongly support their relevance, but not an unqualified victory over traditional approaches. Kumar and Chatterjee (2016) review both conventional and advanced MPPT algorithms, implying that each class retains situational value. Mhmood and Jumaa (2023), referenced earlier in the conversation, specifically frame their work as comparative. This suggests that the real scientific question is not "traditional versus intelligent" in the abstract, but which control architectures are appropriate under which environmental, computational, and operational conditions. Overstating the superiority of soft computing would flatten the nuanced landscape these studies actually reveal.

The discussion of hybrid systems leads to a third important point: resilience depends increasingly on coordination rather than isolated component excellence. An isolated-site hybrid system with solar, wind, battery, and diesel backup does not succeed simply because each component functions individually (Anowar et al., 2016; Jemaa et al., 2018). It succeeds when the control architecture manages transitions, balances inputs, and aligns generation with demand and storage behavior. This is a broader lesson that extends beyond hybrid microgrids. In modern infrastructure, resilience is more often about the quality of interaction among subsystems than the standalone perfection of any one part. That same principle appears later in this article in supply chains and financial connectedness.

A fourth issue concerns the material and geopolitical embeddedness of renewable technology. Policy discourse often speaks of renewable energy as though it were an autonomous solution to insecurity, but the supply chain literature complicates this view. Khan (2025) directly links supply chain and geopolitical risk to energy security. Jia et al. (2025) connect geopolitical risk with metal prices and global supply chain pressure. Gao et al. (2025) show uncertainty spillovers through transnational supply chains. These studies imply that renewable energy transitions inherit the vulnerabilities of the industrial systems on which they depend. If a wind turbine, inverter, battery, or photovoltaic module depends on internationally sourced inputs, then geopolitical uncertainty can become a hidden determinant of energy resilience. This does not weaken the case for renewables. It deepens it by showing that engineering ambition must be matched by strategic supply chain planning.

This leads naturally to the role of trade policy uncertainty. Caldara et al. (2020) and Feng et al. (2022) show that policy uncertainty can affect economic behavior and network equilibrium in meaningful ways. For sustainable energy systems, this means that resilience cannot be reduced to domestic generation capacity. A country or firm may invest in renewable assets, but still face implementation instability if global trade conditions disrupt components, pricing, maintenance access, or associated technologies. Thus, the energy transition is partly a problem of industrial policy and international economic governance, even when its most visible artifacts are engineering devices.

Supply chain resilience itself must therefore be reconsidered. Shahbaz et al. (2019) classify supply chain risks, which is a useful starting point, but the later literature moves further by connecting resilience to sustainability, transparency, alliance behavior, and market competitiveness (Canciani et al., 2024; Yan et al., 2025; Zhao et al., 2025). The implication is that resilient supply chains are not simply those that “bounce back” after disruptions. They are increasingly expected to be transparent, ethically legible, environmentally aligned, and strategically flexible. In the context of clean energy, this is particularly significant because stakeholders often judge renewable transitions not only by emissions reduction but by the integrity of the supporting value chain.

Blockchain-based product passports and related digital traceability tools therefore deserve serious attention. Canciani et al. (2024) present a model in which transparency is enhanced through blockchain-linked product information. Yan et al. (2025) show that blockchain may influence supply chain alliance structures. Viriyasitavat et al. (2021) imply that cryptocurrency-related mechanisms can augment smart supply chain operations. These studies suggest that blockchain is not important only because it enables tokens or speculative assets. It is important because it may serve as an infrastructure of trust. In fragmented and uncertain supply chains, trustworthy visibility can reduce asymmetry, support compliance, and potentially improve coordination. Yet this promise must be qualified. Transparency technologies do not automatically eliminate opportunism, cost constraints, or governance failures. Their effectiveness depends on adoption incentives, interoperability, and credible institutional integration.

The discussion becomes more complex when blockchain and tokenization are linked to financial volatility. Digital assets are often portrayed either as revolutionary innovations or as speculative distractions. The references support a more balanced interpretation. Corbet et al. (2019) treat cryptocurrency as a serious financial asset class for analysis. Bouri et al. (2021), Demiralay and Golitsis (2021), and Chen and Yang (2024) show that dynamic equicorrelation and asymmetric correlation structures matter within crypto ecosystems. Long et al. (2022), Fang et al. (2024), and Ullah et al. (2024) indicate that geopolitical risk affects crypto pricing and volatility. Adelopo and Luo (2025) show that asset features matter for dynamic volatility and co-movements. This means digital assets can no longer be treated as disconnected from broader market or political realities.

That insight matters profoundly for tokenized supply chain and sustainability-linked systems. Mbarek and Msolli (2025) study supply chain tokens specifically, while Abdullah et al. (2023) and Urom et al. (2022, 2024) show that tokenized or adjacent digital assets exhibit meaningful connectedness with other markets. The practical implication is that tokenization may create innovative financing and coordination channels, but it may also expose operational systems to new forms of market contagion. A token associated with a supply chain, logistics ecosystem, or sustainability initiative may carry symbolic and functional value, but it may also inherit volatility dynamics from the broader digital asset environment. This is a critical caution against naïve techno-financial optimism.

A further discussion point concerns the relationship between transparency and volatility. One might assume that more transparent systems are automatically more stable. The references suggest a more nuanced reality. Blockchain product passports may improve visibility and accountability (Canciani et al., 2024), and supply chain sustainability may strengthen competitiveness (Zhao et al., 2025). Yet tokenized assets and crypto-linked systems also reveal that greater digitalization can create faster and broader channels for information and shock transmission (Bouri et al., 2021; Mbarek & Msolli, 2025). Transparency, then, is not simply stabilizing. It can stabilize governance while simultaneously accelerating financial response. This duality deserves more attention in future research.

The methodological references to dynamic conditional correlation and dynamic equicorrelation deepen this interpretation. Engle (2002) and Engle and Kelly (2012) remind us that relationships among variables are not fixed. Correlation structures tighten, weaken, reverse, or cluster depending on broader conditions. When applied conceptually to the present study, this means that connectedness among digital assets, supply chain conditions, and geopolitical risk is not stable over time. During calm periods, tokenized systems may appear weakly linked to broader stress factors. During crises, those links may intensify sharply. A similar principle holds in renewable engineering, though expressed differently: a controller that performs acceptably in moderate conditions may become critically important in rapidly fluctuating environments. In both domains, performance and connectedness are regime-sensitive.

The question of energy security introduces yet another layer of complexity. Renewable energy is often framed as an antidote to geopolitical vulnerability because it can reduce dependence on imported fossil fuels. That claim is partly correct, but the literature reviewed here suggests it must be reformulated. Renewables may reduce one form of dependency while increasing sensitivity to others, such as metals, electronics, converter technologies, software intelligence, and advanced components embedded in global supply chains (Baloch et al., 2016a; Khan, 2025; Jia et al., 2025). Thus, renewable energy does not abolish energy security concerns. It transforms them. The new energy security challenge is not only access to fuel, but resilience of technology, materials, logistics, and control.

This transformed security environment has implications for investment and portfolio behavior as well. Digital assets, stablecoins, NFTs, and sector-linked tokens may increasingly interact with sustainability finance and alternative investment strategies. Ullah et al. (2024) show comparative investment analysis between crypto and conventional assets under geopolitical risk. Abdullah et al. (2023) and Urom et al. (2024) indicate that nontraditional digital assets are connected to broader asset systems. If renewable-energy-linked infrastructures or supply chain initiatives increasingly intersect with tokenized finance, then investors and policymakers must understand that they are not entering a frictionless transparency economy, but a connected, volatile, and regime-sensitive market ecology.

There are, of course, important limitations to the present study. The first is that it is based strictly on the references supplied and therefore does not introduce additional recent policy reports, regulatory studies, engineering datasets, or empirical market estimates beyond those sources. The second is that the literature spans several domains that are adjacent but not identical in purpose. Renewable control studies are highly technical, while supply chain and crypto-finance studies often work at more macro or econometric levels. The synthesis is therefore strongest at the conceptual and systems level rather than at the level of directly measured causal integration. A third limitation is that some topics, such as blockchain-enabled supply chain passports and tokenized asset ecosystems, remain relatively emergent and therefore may still be evolving in practice faster than the underlying literature can stabilize them. Even so, these limitations do not weaken the study’s core conclusion that the energy transition is increasingly a problem of integrated resilience.

Future research should proceed in several directions. On the engineering side, more work is needed on how intelligent MPPT and hybrid control systems perform under supply disruptions, cyber-dependency, or economically constrained operating environments. On the supply chain side, future studies should examine whether blockchain traceability measurably improves resilience under actual trade or geopolitical stress rather than only in design scenarios. On the financial side, the connectedness of supply chain tokens, ESG-linked digital assets, and infrastructure-related tokenization deserves much more attention, especially under periods of geopolitical escalation or policy uncertainty. Finally, interdisciplinary models that combine engineering performance, supply chain exposure, and financial spillovers could substantially improve how resilience is evaluated in sustainable energy systems.

The overarching implication of this article is that clean-energy transitions require a broader definition of system design. It is no longer enough to ask whether solar panels, wind converters, or MPPT algorithms are efficient. One must also ask whether the supply chains that support them are transparent and adaptable, whether the geopolitical context threatens their continuity, and whether the digital-financial instruments surrounding them amplify or absorb shocks. When these questions are asked together, the energy transition becomes visible not as a linear technological substitution, but as a multilayered socio-technical transformation requiring coordination across engineering, logistics, policy, and finance.

CONCLUSION

This article has developed a publication-ready, original research synthesis showing that renewable energy control, supply chain resilience, and digital-financial connectedness are not separate issues but interacting dimensions of sustainable development under uncertainty. Based strictly on the references provided, the study demonstrates that resilient energy transitions depend on adaptive intelligence at the generation level, strategic robustness in the supply chain, and sophisticated monitoring of financial and tokenized spillovers.

The renewable energy literature shows that wind and solar systems achieve meaningful efficiency only when supported by advanced control mechanisms, including active and reactive power control, MPPT logic, fuzzy systems, ANN-based optimization, and hybrid coordination strategies (Kaloi et al., 2016; Kumar & Chatterjee, 2016; Abdellatif et al., 2021; Abdolrasol et al., 2021; Prasad et al., 2023). The supply chain literature shows that these engineering systems are embedded in trade-sensitive, geopolitically exposed, and increasingly sustainability-oriented networks in which resilience is shaped by transparency, risk management, and strategic adaptation (Shahbaz et al., 2019; Caldara et al., 2020; Feng et al., 2022; Qin et al., 2023; Wang, 2025; Zhao et al., 2025). The cryptocurrency and token literature further reveals that digital asset ecosystems are dynamically connected, geopolitically sensitive, and increasingly relevant to tokenized supply chain or transparency frameworks, thereby adding new channels of both innovation and instability (Corbet et al., 2019; Bouri et al., 2021; Long et al., 2022; Abdullah et al., 2023; Fang et al., 2024; Mbarek & Msolli, 2025).

The central conclusion is that future energy resilience cannot be reduced to any one of these domains. A technically advanced renewable system may remain fragile if supply chains are opaque or geopolitically exposed. A transparent blockchain-based supply chain may remain fragile if it becomes entangled in volatile tokenized finance. A dynamic digital asset ecosystem may support innovation yet still undermine planning if connectedness and spillover risks are poorly understood. Therefore, real resilience lies in coordinating these layers rather than optimizing them in isolation.

This study argues, finally, that the clean-energy transition should be understood as a digitally mediated systems transformation. Its success depends on whether intelligent engineering, sustainable and transparent logistics, and financially aware governance evolve together. That is the essential lesson emerging from the references provided here, and it offers a strong conceptual foundation for future research on resilient energy systems in an age of geopolitical and digital uncertainty.

REFERENCES

1. Abdellatif, W. S. E., Mohamed, M. S., Barakat, S., & Brisha, A. (2021). A fuzzy logic controller based MPPT technique for photovoltaic generation system. International Journal on Electrical Engineering and Informatics, 13(2), 394–417. https://doi.org/10.15676/ijeei.2020.13.2.9
2. Abdolrasol, M. G. M., et al. (2021). Artificial neural networks based optimization techniques: A review. Electronics, 10(21), Article 2689. https://doi.org/10.3390/electronics10212689
3. Abdullah, M., Adeabah, D., Abakah, E. J. A., & Lee, C.-C. (2023). Extreme return and volatility connectedness among real estate tokens, REITs, and other assets: The role of global factors and portfolio implications. Finance Research Letters, 56, Article 104062. https://doi.org/10.1016/j.frl.2023.104062
4. Abo-Khalil, A. G., Alharbi, W., Al-Qawasmi, A. R., Alobaid, M., & Alarifi, I. M. (2021). Maximum power point tracking of PV systems under partial shading conditions based on opposition-based learning firefly algorithm. Sustainability, 13(5), Article 2656. https://doi.org/10.3390/su13052656
5. Adelopo, I., & Luo, X. (2025). How do cryptocurrency features determine their dynamic volatility and co-movements with stocks? Cogent Business & Management, 12(1), Article 2461732. https://doi.org/10.1080/23311975.2025.2461732
6. Aloui, C., Ben Hamida, H., & Yarovaya, L. (2021). Are Islamic gold-backed cryptocurrencies different? Finance Research Letters, 39, Article 101615. https://doi.org/10.1016/j.frl.2020.101615
7. Anowar, T., et al. (2016). Fuzzy logic implementation with MATLAB for solar-wind-battery-diesel hybrid energy system. Imperial Journal of Interdisciplinary Research, 2(5), 574–584.
8. Baloch, M. H., Kaloi, G. S., & Memon, Z. A. (2016a). Current scenario of the wind energy in Pakistan: Challenges and future perspectives. Energy Reports, 2, 201–210. https://doi.org/10.1016/j.egyr.2016.08.002
9. Baloch, M. H., Wang, J., & Kaloi, G. S. (2016b). A review of the state of the art control techniques for wind energy conversion system. International Journal of Renewable Energy Research, 6(4), 1276–1295.
10. Belmili, H., Boulouma, S., Boualem, B., & Fayçal, A. M. (2017). Optimized control and sizing of standalone PV-wind energy conversion system. Energy Procedia, 107, 76–84.

https://doi.org/10.1016/j.egypro.2016.12.134

11. Bollerslev, T., & Wooldridge, J. M. (1992). Quasi-maximum likelihood estimation and inference in dynamic models with time-varying covariances. Econometric Reviews, 11(2), 143–172. https://doi.org/10.1080/07474939208800229

12. Bouri, E., Vo, X. V., & Saeed, T. (2021). Return equicorrelation in the cryptocurrency market: Analysis and determinants. Finance Research Letters, 38, Article 101497. https://doi.org/10.1016/j.frl.2020.101497

13. Caldara, D., Iacoviello, M., Molligo, P., Prestipino, A., & Raffo, A. (2020). The economic effects of trade policy uncertainty. Journal of Monetary Economics, 109, 38–59. https://doi.org/10.1016/j.jmoneco.2019.11.002

14. Canciani, A., Felicioli, C., Severino, F., & Tortola, D. (2024). Enhancing supply chain transparency through blockchain product passports. In IEEE International Conference on Pervasive Computing and Communications Workshops (PerCom Workshops). https://doi.org/10.1109/PerComWorkshops59983.2024.10502429

15. Chen, K.-S., & Yang, J. J. (2024). Asymmetric dynamic correlations and portfolio management between Bitcoin and stablecoins. Applied Economics. https://doi.org/10.1080/00036846.2024.2408034

16. Corbet, S., Lucey, B., Urquhart, A., & Yarovaya, L. (2019). Cryptocurrency as a financial asset: A systematic analysis. International Review of Financial Analysis, 62, 182–199. https://doi.org/10.1016/j.irfa.2018.09.003

17. Demiralay, S., & Golitsis, P. (2021). On the dynamic equicorrelations in cryptocurrency market. Quarterly Review of Economics and Finance, 80, 524–533. https://doi.org/10.1016/j.qref.2021.04.002

18. Engle, R. (2002). Dynamic conditional correlation: A simple class of multivariate generalized autoregressive conditional heteroskedasticity models. Journal of Business & Economic Statistics, 20(3), 339–350. https://doi.org/10.1198/073500102288618487

19. Engle, R., & Kelly, B. (2012). Dynamic equicorrelation. Journal of Business & Economic Statistics, 30(2), 212–228. https://doi.org/10.1080/07350015.2011.652048

20. Fang, Y., Tang, Q., & Wang, Y. (2024). Geopolitical risk and cryptocurrency market volatility. Emerging Markets Finance and Trade, 60(14), 3254–3270. https://doi.org/10.1080/1540496X.2024.2343948

21. Feng, P., Zhou, X., Zhang, D., Chen, Z., & Wang, S. (2022). The impact of trade policy on global supply chain network equilibrium: A new perspective of product-market chain competition. Omega, 109, Article 102612. https://doi.org/10.1016/j.omega.2022.102612

22. Gao, J., Qin, Q., & Zhou, S. (2025). Spillover effects of US economic policy uncertainty on emerging markets: Evidence from transnational supply chains. Journal of International Financial Markets, Institutions and Money, 100, Article 102136. https://doi.org/10.1016/j.intfin.2025.102136

23. Glosten, L. R., Jagannathan, R., & Runkle, D. E. (1993). On the relation between the expected value and the volatility of the nominal excess return on stocks. Journal of Finance, 48(5), 1779–1801. https://doi.org/10.1111/j.1540-6261.1993.tb05128.x

24. Jemaa, A., Zarrad, O., Hajjaji, M. A., & Mansouri, M. N. (2018). Hardware implementation of a fuzzy logic controller for a hybrid wind-solar system in an isolated site. International Journal of Photoenergy. https://doi.org/10.1155/2018/5379864

25. Jia, Y., Liu, Y., & Taghizadeh-Hesary, F. (2025). The nexus among geopolitical risk, metal prices, and global supply chain pressure. Economic Analysis and Policy, 85, 1776–1789. https://doi.org/10.1016/j.eap.2025.02.003

26. Joshi, A., Wazid, M., & Goudar, R. H. (2015). An efficient cryptographic scheme for text message protection against brute force and cryptanalytic attacks. Procedia Computer Science, 48, 360–366. https://doi.org/10.1016/j.procs.2015.04.194

27. Kaloi, G. S., Wang, J., & Baloch, M. H. (2016). Active and reactive power control of the doubly fed induction generator based on wind energy conversion system. Energy Reports, 2, 194–200. https://doi.org/10.1016/j.egyr.2016.08.001

28. Khan, K. (2025). How do supply chain and geopolitical risks threaten energy security? Energy, 316, Article 134501. https://doi.org/10.1016/j.energy.2025.134501

29. Kumar, D., & Chatterjee, K. (2016). A review of conventional and advanced MPPT algorithms for wind energy systems. Renewable and Sustainable Energy Reviews, 55, 957–970. https://doi.org/10.1016/j.rser.2015.11.013

30. Long, H., Demir, E., Będowska-Sójka, B., Zaremba, A., & Shahzad, S. J. H. (2022). Is geopolitical risk priced in the cross-section of cryptocurrency returns? Finance Research Letters, 49, Article

103131. https://doi.org/10.1016/j.frl.2022.103131

31. Mbarek, M., & Msolli, B. (2025). Assessing linkages between supply chain tokens and other assets. Journal of Behavioral and Experimental Finance, 46, Article 101029. https://doi.org/10.1016/j.jbef.2025.101029

32. Memon, B., Baloch, M. H., Memon, A. H., Qazi, S. H., Haider, R., & Ishak, D. (2019). Assessment of wind power potential based on Raleigh distribution model. Engineering, Technology & Applied Science Research, 9(1), 3721–3725. https://doi.org/10.48084/etasr.2381

33. Prasad, D., Kumar, N., Sharma, R., Malik, H., Garcia Márquez, F. P., & Pinar-Pérez, J. M. (2023). A novel ANROA based control approach for grid-tied multifunctional solar energy conversion system. Energy Reports, 9, 2044–2057. https://doi.org/10.1016/j.egyr.2023.01.039

34. Qin, M., Su, C.-W., Umar, M., Lobonţ, O.-R., & Manta, A. G. (2023). Are climate and geopolitics the challenges to sustainable development? Economic Analysis and Policy, 77, 748–763. https://doi.org/10.1016/j.eap.2023.01.002

35. Rezvani, A., Izadbakhsh, M., & Gandomkar, M. (2015). Enhancement of hybrid dynamic performance using ANFIS for fast varying solar radiation and fuzzy logic controller in high speeds wind. Journal of Electrical Systems, 11(1), 11–26.

36. Shahbaz, M. S., Sohu, S., Khaskhelly, F. Z., Bano, A., & Soomro, M. A. (2019). A novel classification of supply chain risks: A review. Engineering, Technology & Applied Science Research, 9(3), 4301–4305. https://doi.org/10.48084/etasr.2781

37. Tahir, S., Wang, J., Baloch, M., & Kaloi, G. (2018). Digital control techniques based on voltage source inverters in renewable energy applications: A review. Electronics, 7(2), Article 18. https://doi.org/10.3390/electronics7020018

38. Ullah, M., Sohag, K., & Haddad, H. (2024). Comparative investment analysis between crypto and conventional financial assets amid heightened geopolitical risk. Heliyon, 10(9), Article e30558. https://doi.org/10.1016/j.heliyon.2024.e30558

39. Urom, C., Ndubuisi, G., & Guesmi, K. (2022). Dynamic dependence and predictability between volume and return of non-fungible tokens (NFTs): The roles of market factors and geopolitical risks. Finance Research Letters, 50, Article 103188. https://doi.org/10.1016/j.frl.2022.103188

40. Urom, C., Ndubuisi, G., & Guesmi, K. (2024). Global macroeconomic factors and the connectedness among NFTs and conventional assets. Research in International Business and Finance, 71, Article 102429. https://doi.org/10.1016/j.ribaf.2024.102429

41. Viriyasitavat, W., Hoonsopon, D., & Bi, Z. (2021). Augmenting cryptocurrency in smart supply chain. Journal of Industrial Information Integration, 21, Article 100188. https://doi.org/10.1016/j.jii.2020.100188

42. Wang, J. (2025). Enhancing global supply chain resilience under trade uncertainties. In Reference Module in Social Sciences. Elsevier. https://doi.org/10.1016/B978-0-443-28993-4.00140-2

43. Yan, J., et al. (2025). How does blockchain application impact on supply chain alliance? Technovation, 143, Article 103199. https://doi.org/10.1016/j.technovation.2025.103199

44. Zhao, Q., Wang, W., & Tao, Y. (2025). Supply chain sustainability and its impact on firm market competitiveness: A perspective based on ESG practices. International Review of Economics & Finance, 101, Article 104236. https://doi.org/10.1016/j.iref.2025.104236