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The Integration of Fintech in Energy Markets: Economic Benefits and Policy Considerations

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Abstract

This study investigates the impact of, financial technology (fintech) integration, on the efficiency, cost reduction, and, sustainability of energy markets, with a, particular focus on, Pakistan. Employing, the Technology-Organization-Environment, (TOE) framework, the research, explores how fintech, adoption, investment in, fintech, regulatory support, technological, infrastructure, and market transparency, influence key market, outcomes. A structured questionnaire, was distributed to professionals, and stakeholders in the, energy sector, yielding 320, responses. The analysis, conducted using, Structural Equation Modelling (SEM), in Smart PLS, reveals that fintech, adoption significantly, enhances market efficiency, while, investment in fintech and market, transparency contribute to, cost reduction. Regulatory, support and technological, infrastructure is crucial, for market efficiency, and sustainability, respectively. The, study underscores the, need for a balanced approach that, includes supportive regulatory, frameworks and robust, technological infrastructure to fully, leverage fintech's potential. The findings, offer valuable insights for, policymakers and energy, market participants, highlighting, the critical role of fintech in driving, economic benefits and addressing, market inefficiencies. Future, research should expand, to multiple countries to validate these findings and explore additional contextual factors.

Keywords: Fintech, energy markets, market efficiency, cost reduction, sustainability.

INTRODUCTION

The integration of financial technology (fintech) in energy markets is transforming the global energy landscape. According to the International Energy Agency (IEA), global investment in digital energy technologies reached $63 billion in 2020, driven by advancements in blockchain, AI, and IoT (IEA, 2021). A study by Davradakis and Santos (2019) highlighted that fintech applications could reduce transaction costs by up to 30%, improve market transparency, and enhance overall efficiency in energy markets. These technologies are enabling real-time data analysis and more efficient energy trading, thereby contributing to significant economic benefits worldwide. In Pakistan, the energy sector faces numerous challenges, including high transmission and distribution losses, frequent power outages, and a lack of investment in modern infrastructure. According to the Pakistan Economic Survey (2021) the country's

transmission and distribution losses stand at 17.7%, significantly higher than the global average of 8%. Furthermore, the World Bank (2020) reported that Pakistan experiences an annual economic loss of approximately $4.5 billion due to inefficiencies in the energy sector. These issues are exacerbated by limited adoption of fintech solutions, which could otherwise enhance market efficiency and transparency (Ediagbonya & Tioluwani, 2023; Murinde et al., 2022).

Market efficiency in energy markets refers to the extent to which market prices reflect all available information, a concept first defined by Fama (1970). In the context of fintech and energy markets, enhanced market efficiency is critical for reducing transaction costs and improving transparency. Cost reduction, as articulated by Coase (1993) in his theory of transaction costs, emphasizes the importance of minimizing costs associated with economic transactions. Sustainability in energy markets, a concept promoted by the Muñoz (2020), underscores the need for meeting current energy demands without compromising future generations' ability to meet theirs. In Pakistan, these factors are particularly pertinent given the high inefficiencies and economic losses.

If issues such as market efficiency, cost reduction, and sustainability are not addressed globally and within Pakistan, the consequences could be severe. Globally, a lack of market efficiency can lead to increased volatility and instability in energy prices, negatively impacting economic growth. In Pakistan, failure to reduce transaction costs and improve market efficiency can exacerbate the already significant economic losses and hinder sustainable development. Additionally, for the energy sector specifically, not leveraging fintech innovations could result in persistent inefficiencies, higher operational costs, and reduced investor confidence, further stalling the sector's growth and sustainability. Addressing these issues through fintech adoption is crucial for achieving both economic benefits and energy market resilience.

Adoption of fintech solutions is crucial for enhancing the operational efficiency of energy markets. Previous research by Allen et al. (2021) indicates that fintech innovations such as blockchain and smart contracts can significantly reduce the time and costs associated with energy transactions by automating processes and ensuring real-time data accuracy. For example, blockchain technology enables transparent and tamper-proof records of energy trades, which can help reduce fraud and increase trust among market participants. In Pakistan, where energy market inefficiencies contribute to substantial economic losses, widespread fintech adoption can streamline operations, reduce power outages, and ultimately lower transmission and distribution losses. Globally, improved fintech adoption can lead to more stable and efficient energy markets, fostering economic growth and sustainability.

Investment in fintech is essential for the development and implementation of advanced technological solutions. According to Malhotra and Malhotra (2023), firms that invest in fintech are better equipped to handle large volumes of transactions and can leverage big data analytics to optimize energy distribution and consumption. In Pakistan, increased investment in fintech can provide the necessary infrastructure to support digital energy platforms, which can facilitate more efficient energy trading and management. This can help address the country's high transmission and distribution losses by enabling better monitoring and control of the energy grid. On a

global scale, higher investment in fintech can drive innovation, leading to more resilient and adaptable energy markets that can respond swiftly to changes in supply and demand dynamics. Regulatory support plays a pivotal role in fostering an environment conducive to fintech innovations in the energy sector. Studies by the World Economic Forum (2018) show that clear and supportive regulatory frameworks can encourage the adoption of new technologies and ensure that they are integrated smoothly into existing systems. For instance, regulations that facilitate the use of decentralized energy trading platforms can enhance market transparency and efficiency. In Pakistan, stronger regulatory support can help overcome barriers to fintech adoption, such as lack of awareness and resistance to change. By creating a favorable regulatory environment, the government can encourage more companies to invest in and adopt fintech solutions, thereby improving the overall efficiency and sustainability of the energy market. Globally, harmonized regulatory frameworks can promote cross-border energy trading and integration, contributing to a more interconnected and efficient global energy market.

Robust technological infrastructure is fundamental for the successful implementation of fintech solutions in energy markets. Research by Zinakova (2020) highlights that countries with advanced technological infrastructure, such as high-speed internet and reliable electricity supply, are more likely to successfully integrate fintech innovations. In Pakistan, enhancing technological infrastructure can support the deployment of smart grids and IoT devices that provide real-time monitoring and management of energy resources. This can lead to significant reductions in transmission and distribution losses by allowing for immediate identification and rectification of issues. Globally, improving technological infrastructure can enable the widespread adoption of digital energy solutions, leading to more efficient and resilient energy systems capable of meeting increasing energy demands sustainably (Shabalov et al., 2021).

Market transparency is critical for ensuring fair and efficient energy markets. Transparency can be significantly enhanced through fintech solutions, as demonstrated by a study from the International Finance Corporation (2020), which found that blockchain and AI can provide greater visibility into market operations and reduce information asymmetry. In Pakistan, increasing market transparency can help combat issues such as corruption and inefficiencies in the energy sector. By providing clear and accessible information on energy transactions and market conditions, fintech can build trust among stakeholders and encourage more efficient market behavior. Globally, enhanced market transparency can lead to more competitive energy markets, reducing costs for consumers and fostering innovation and investment in the sector.

Addressing the factors mentioned above can have profound effects on both global and country-specific issues in the energy sector. By enhancing market efficiency through fintech adoption and investment, countries can reduce economic losses and improve energy reliability (Liu, Yao, et al., 2022). For Pakistan, this means a more stable energy supply, reduced economic burden from energy inefficiencies, and greater investor confidence in the energy market. Globally, resolving these issues can lead to more stable and interconnected energy markets, fostering economic growth and sustainability. Improving regulatory support and technological infrastructure can ensure that fintech innovations are effectively integrated into energy markets, leading to

better management of resources and reduction in operational costs (Lisha et al., 2023; Liu, Yao, et al., 2022). For Pakistan, this translates into lower transmission and distribution losses, and for the global market, it means a more resilient and adaptable energy system capable of meeting future energy demands. Finally, increasing market transparency can drive fairer and more efficient energy markets, reducing costs for consumers and encouraging innovation. This is particularly important for Pakistan, where market inefficiencies and corruption have long plagued the energy sector (Naveed et al., 2022). Globally, greater transparency can enhance market competitiveness and drive the development of sustainable energy solutions, contributing to global economic stability and environmental sustainability.

While fintech adoption has the potential to significantly improve energy market efficiency, it also comes with several challenges that can exacerbate existing issues if not managed properly. For example, the implementation of blockchain technology in energy markets requires substantial initial investment and technical expertise, which may be lacking in developing countries like Pakistan. A study by Lu (2019) found that the high costs and complexity associated with blockchain deployment can deter smaller firms from adopting these technologies, potentially leading to increased market concentration and reduced competition. Additionally, the integration of fintech solutions can raise cybersecurity concerns, as highlighted by Steinmetz et al. (2023), who noted that increased digitalization in the energy sector can make it more vulnerable to cyberattacks. These challenges can offset the benefits of fintech adoption, making it crucial to address them through appropriate policies and infrastructure improvements.

Investing in fintech is essential for technological advancements, but it also poses risks, particularly in terms of financial stability and market dynamics. According to Zhang (2022), excessive investment in fintech without proper regulatory oversight can lead to speculative bubbles and financial instability. In Pakistan, where financial markets are relatively underdeveloped, sudden and large-scale investments in fintech could disrupt existing market structures and create volatility (Yasin, 2023; Zhang, 2022). Moreover, the focus on fintech investment might divert resources from other critical areas, such as improving physical infrastructure and human capital in the energy sector. This diversion of resources can slow down overall development and exacerbate existing inefficiencies.

While supportive regulatory frameworks are crucial for fintech integration, overly stringent regulations can stifle innovation and limit the benefits of fintech. A study by Locatelli et al. (2021) emphasized that while regulations are necessary to ensure security and fairness, they can also create barriers to entry and slow down the adoption of new technologies. In Pakistan, regulatory frameworks are often slow to adapt to technological changes, which can lead to a lag in fintech adoption and its associated benefits (Ali & Abdullah, 2020). Furthermore, inconsistent regulations across different regions can create confusion and increase compliance costs for firms operating in multiple markets, thereby reducing overall market efficiency. Improving technological infrastructure is fundamental for fintech implementation, but it also poses significant challenges, particularly in resource-constrained environments. As highlighted by Jha and Bag (2019), upgrading technological infrastructure requires substantial financial and human resources, which may be scarce in developing

countries like Pakistan. The focus on technological infrastructure can also lead to a digital divide, where regions with better infrastructure benefit more from fintech solutions, while less developed areas lag behind. This divide can exacerbate existing inequalities and limit the overall impact of fintech on market efficiency and sustainability. Enhancing market transparency is beneficial, but it can also have unintended consequences. For instance, increased transparency can lead to information overload, making it difficult for market participants to process and act on available data effectively. A study by Dang et al. (2020) found that too much transparency can lead to market volatility as traders react to every piece of information, regardless of its significance. In Pakistan, where the energy market is already volatile, increased transparency without adequate market education and regulatory measures could lead to increased speculation and instability. Additionally, greater transparency can expose market inefficiencies and corruption, which, while beneficial in the long run, can create short-term disruptions and resistance from entrenched interests (Mcsparren, 2019).

The integration of fintech solutions into energy markets holds significant promise for improving efficiency, reducing costs, and enhancing sustainability (Nassiry, 2018). However, this study identifies several critical challenges and potential adverse effects associated with fintech adoption, investment, regulatory support, technological infrastructure, and market transparency. These factors, while pivotal for resolving issues related to market efficiency, cost reduction, and sustainability, can also exacerbate existing problems if not managed properly (Cochrane, 2021; Doh et al., 2019). In particular, the high costs of fintech implementation, risks of financial instability, regulatory lag, infrastructural constraints, and potential for increased market volatility pose significant obstacles. Therefore, the problem statement of this study is:

"To explore the dual-edged impact of fintech integration in energy markets, examining how key factors can both resolve and exacerbate existing inefficiencies, with a specific focus on the challenges faced by developing countries like Pakistan (Naz et al., 2024; Ullah et al., 2023). The study aims to provide a nuanced understanding of how fintech can be effectively harnessed to address market inefficiencies while mitigating potential risks and adverse effects." By addressing these challenges, this study seeks to contribute to the development of strategies that maximize the benefits of fintech in energy markets while minimizing the associated risks. This study differentiates itself from previous research through its unique methodology, which employs a comprehensive, multi-variable regression analysis using Smart PLS. Unlike earlier studies that often focused on singular aspects of fintech integration or relied on qualitative analyses, this research incorporates a robust conceptual framework that examines multiple interrelated factors affecting energy market efficiency. It also utilizes a large dataset from Pakistan to provide a country-specific perspective, addressing both global and local challenges in the fintech-energy nexus (Naz et al., 2024; Ullah et al., 2023).

The study finds that fintech adoption significantly improves market efficiency, reduces transaction costs, and enhances sustainability in the energy sector. Regulatory support and investment in fintech are identified as critical enablers for these benefits (Thomas, 2023). However, the study also highlights potential risks such as financial instability and increased market volatility if these factors are not managed properly. In Pakistan, improved technological infrastructure and market transparency were found to be particularly impactful in addressing the country's specific energy market inefficiencies

(Liu, Khan, et al., 2022). This study makes several key contributions to the existing body of knowledge. Firstly, it provides empirical evidence on the multifaceted impacts of fintech on energy markets, using a sophisticated analytical approach. This contrasts with prior research that often relied on theoretical models or case studies. Secondly, the study highlights the specific challenges and opportunities within the Pakistani context, offering insights that are directly relevant to developing countries facing similar issues.

For policymakers, the study underscores the importance of a balanced approach to fintech integration. It suggests that while fintech can drive significant improvements in market efficiency and sustainability, careful attention must be paid to regulatory frameworks and infrastructural investments to mitigate potential risks. Policies should encourage innovation while ensuring robust oversight to prevent financial instability and protect against cyber threats.

Practically, the study offers actionable insights for energy market participants. For instance, investing in fintech solutions like blockchain can streamline operations and reduce costs, but it should be accompanied by measures to enhance cybersecurity. Additionally, the research highlights the importance of fostering a supportive regulatory environment that encourages fintech adoption while addressing potential downsides. For the broader academic community, this study provides a framework for understanding the complex interplay between fintech innovations and energy market dynamics. It encourages further research into the specific mechanisms through which fintech can affe

THEORETICAL FRAMEWORK

Establishment and Definition of Key Outcomes

The core outcomes of interest in this study are market efficiency, cost reduction, and sustainability in energy markets. Market efficiency, first defined by Fama (1970), refers to the extent to which market prices reflect all available information. Enhanced market efficiency is critical for reducing transaction costs and improving transparency. Cost reduction, articulated by Coase (1993) in his theory of transaction costs, emphasizes the importance of minimizing costs associated with economic transactions. Sustainability in energy markets, promoted by the Muñoz (2020), underscores the need for meeting current energy demands without compromising future generations' ability to meet theirs.

Proxies for Key Outcomes

Market efficiency is measured using the Energy Market Efficiency Score (EMES), which evaluates the degree to which energy market operations reflect efficient allocation of resources and information transparency. High transaction costs and information asymmetry often lead to inefficiencies, as highlighted by a study from the International Finance Corporation (2020). Cost reduction is quantified through the Percentage Reduction in Transaction Costs (PRTC), which measures the decrease in costs associated with energy transactions due to technological and process improvements. High operational and transaction costs in energy markets hinder economic performance, as reported by Davradakis and Santos (2019). Sustainability is assessed using the Sustainability Score (SS), which evaluates the extent to

which energy market practices contribute to environmental sustainability and long-term viability. Unsustainable energy practices lead to environmental degradation and resource depletion, as discussed by Muñoz (2020).

Key Enablers of Outcomes

Fintech adoption, defined as the implementation of financial technologies such as blockchain, AI, and IoT in energy markets, is crucial for enhancing operational efficiency. Previous research by Allen et al. (2021) indicates that fintech innovations can significantly reduce the time and costs associated with energy transactions by automating processes and ensuring real-time data accuracy. For example, blockchain technology enables transparent and tamper-proof records of energy trades, which can help reduce fraud and increase trust among market participants. In Pakistan, where energy market inefficiencies contribute to substantial economic losses, widespread fintech adoption can streamline operations, reduce power outages, and ultimately lower transmission and distribution losses. Globally, improved fintech adoption can lead to more stable and efficient energy markets, fostering economic growth and sustainability.

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Regulatory support plays a pivotal role in fostering an environment conducive to fintech innovations in the energy sector. Studies by the World Economic Forum (2018) show that clear and supportive regulatory frameworks can encourage the adoption of new technologies and ensure that they are integrated smoothly into existing systems. For instance, regulations that facilitate the use of decentralized energy trading platforms can enhance market transparency and efficiency. In Pakistan, stronger regulatory support can help overcome barriers to fintech adoption, such as lack of awareness and resistance to change. By creating a favorable regulatory environment, the government can encourage more companies to invest in and adopt fintech solutions, thereby improving the overall efficiency and sustainability of the energy market. Globally, harmonized regulatory frameworks can promote cross-border energy trading and integration, contributing to a more interconnected and efficient global energy market.

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deployment of smart grids and IoT devices that provide real-time monitoring and management of energy resources. This can lead to significant reductions in transmission and distribution losses by allowing for immediate identification and rectification of issues. Globally, improving technological infrastructure can enable the widespread adoption of digital energy solutions, leading to more efficient and resilient energy systems capable of meeting increasing energy demands sustainably (Emon, 2023; Malhotra & Malhotra, 2023).

Market transparency is critical for ensuring fair and efficient energy markets. Transparency can be significantly enhanced through fintech solutions, as demonstrated by a study from the International Finance Corporation (2020), which found that blockchain and AI can provide greater visibility into market operations and reduce information asymmetry. In Pakistan, increasing market transparency can help combat issues such as corruption and inefficiencies in the energy sector. By providing clear and accessible information on energy transactions and market conditions, fintech can build trust among stakeholders and encourage more efficient market behavior. Globally, enhanced market transparency can lead to more competitive energy markets, reducing costs for consumers and fostering innovation and investment in the sector.

Addressing Problems Through Key Enablers

By focusing on these key enablers, the study aims to address significant problems highlighted in the energy markets. Fintech adoption, through technologies like blockchain and AI, can reduce transaction costs and improve market efficiency by providing accurate, real-time data and secure transaction records. Investment in fintech ensures that the necessary infrastructure and technological capabilities are in place, facilitating efficient energy trading and management. Regulatory support can create a conducive environment for fintech adoption, ensuring that new technologies are integrated smoothly and effectively. Enhancing technological infrastructure supports the deployment of advanced systems for real-time monitoring and management, reducing inefficiencies and losses. Finally, improving market transparency can reduce corruption and information asymmetry, leading to a more efficient and fair energy market. By addressing these areas, the study contributes to a more efficient, cost-effective, and sustainable energy market, benefiting both global and country-specific contexts. This holistic approach ensures that fintech solutions are not only adopted but also integrated in a way that maximizes their benefits while minimizing potential risks.

Technology-Organization-Environment (TOE) Framework

The Technology-Organization-Environment (TOE) framework, developed by Salmizi et al. (2022), provides a comprehensive lens for understanding the adoption and implementation of technological innovations within organizations. This framework posits that technological adoption is influenced by three critical contexts: technological, organizational, and environmental. The technological context encompasses the technical aspects of the technology itself, including its availability and characteristics (Emon, 2023). The organizational context refers to the internal structure, processes, and resources of the organization. The environmental context involves

external factors, such as regulatory environment, competition, and market conditions, that influence an organization's adoption of new technologies. The TOE framework plays a crucial role in explaining how market efficiency, cost reduction, and sustainability in energy markets are influenced by fintech adoption, investment in fintech, regulatory support, technological infrastructure, and market transparency. It helps understand how these variables interact within technological, organizational and environmental contexts to impact the efficiency and sustainability of energy markets. By examining the interdependencies among these contexts, the TOE framework provides a comprehensive perspective on how to achieve desired outcomes in energy markets through the integration of fintech (Chang et al., 2024).

The TOE framework elucidates that the successful adoption and integration of fintech in energy markets depend on the interplay of technological readiness, organizational capabilities, and supportive environmental conditions. Fintech adoption and investment in fintech, influenced by technological and organizational contexts, directly impact market efficiency by improving data accuracy and reducing transaction times. Regulatory support and market transparency, shaped by the environmental context, ensure that fintech solutions are integrated effectively, enhancing cost reduction and sustainability (Bayram et al., 2022; Emon, 2023). Thus, the TOE framework elucidates how technological, organizational and environmental factors collectively drive the efficiency, cost-effectiveness and sustainability of energy markets.

The dimensions of the TOE framework underpin the proposed relationships between fintech adoption, investment in fintech, regulatory support, technological infrastructure, market transparency, and the outcomes of market efficiency, cost reduction, and sustainability. The technological context, which includes the availability and characteristics of fintech solutions such as blockchain and AI, impacts the ease and extent of their adoption in energy markets, influencing market efficiency and cost reduction. The organizational context, including internal capabilities and resources like investment in fintech and technological infrastructure, determines the ability of organizations to integrate fintech solutions effectively, impacting market efficiency and sustainability. The environmental context, encompassing external factors such as regulatory support and market transparency, influences the broader environment in which fintech solutions are adopted, affecting their overall impact on market efficiency, cost reduction, and sustainability (Bayram et al., 2022; Chang et al., 2024; Emon, 2023).

HYPOTHESES DEVELOPMENT

Hypotheses Development and Research Model

Fintech adoption is expected to positively influence market efficiency in energy markets. This hypothesis is based on the premise that fintech solutions, such as blockchain and AI, provide real-time data and secure transaction records, reducing information asymmetry and improving market efficiency (Allen et al., 2021). Therefore, we propose the first hypothesis:

H1: Fintech adoption positively influences market efficiency in energy markets.

Investment in fintech is anticipated to positively influence cost reduction in energy markets. Higher investment in fintech enables the development and deployment of advanced technological solutions, optimizing energy distribution and consumption, thereby reducing transaction costs (Malhotra & Malhotra, 2023). Thus, our second hypothesis is:

H2: Investment in fintech positively influences cost reduction in energy markets.

Regulatory support is hypothesized to positively influence market efficiency in energy markets. Clear and supportive regulatory frameworks facilitate the adoption of new technologies, ensuring they are integrated smoothly and efficiently, enhancing market efficiency (World Economic Forum, 2018). Hence, we propose the third hypothesis:

H3: Regulatory support positively influences market efficiency in energy markets.

Technological infrastructure is expected to positively influence sustainability in energy markets. Robust technological infrastructure supports the deployment of smart grids and IoT devices, providing real-time monitoring and management of energy resources, leading to sustainable energy practices (Zinakova, 2020). Therefore, the fourth hypothesis is:

H4: Technological infrastructure positively influences sustainability in energy markets.

Market transparency is anticipated to positively influence cost reduction in energy markets. Improved market transparency reduces information asymmetry and corruption, fostering more efficient market behavior and reducing transaction costs (International Finance Corporation, 2020). Thus, the fifth hypothesis is:

H5: Market transparency positively influences cost reduction in energy markets.

The research model is designed to investigate the relationships between fintech adoption, investment in fintech, regulatory support, technological infrastructure, and market transparency, and their impacts on market efficiency, cost reduction, and sustainability in energy markets. The constructs of the research model include fintech adoption, investment in fintech, regulatory support, technological infrastructure, and market transparency. Fintech adoption refers to the degree to which energy market participants are implementing fintech solutions. Investment in fintech pertains to the amount of financial resources allocated to developing and deploying fintech technologies. Regulatory support measures the extent of government policies and regulations facilitating fintech adoption. Technological infrastructure assesses the quality and availability of technological resources supporting fintech implementation. Market transparency evaluates the level of visibility and accessibility of market operations and transactions.

Methods

This section focuses on the empirical analysis of the study. First, a survey questionnaire is developed based on the existing literature. Second, we describe the data collection process and demographic characteristics. Third, relevant techniques for data analysis are introduced.

Questionnaire Design

A structured questionnaire was designed using a Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The questionnaire was developed based on insights from several key studies to ensure validity and reliability. The constructs and their respective items were adapted from the following studies:

- **Fintech Adoption**: Items were adapted from Venkatesh et al. (2003) in their Unified Theory of Acceptance and Use of Technology (UTAUT).
- **Investment in Fintech**: Questions were based on the work of Chau and Tam (1997), which explores organizational investment in technology.
- **Regulatory Support**: Items were derived from studies by Zhu et al. (2006) on the impact of regulatory frameworks on technology adoption.
- **Technological Infrastructure**: The constructs were adapted from Iacovou et al. (1995), focusing on technological readiness.
- **Market Transparency**: Items were influenced by the research of Kim and Prabhakar (2004) on trust and transparency in market transactions.

The questionnaire included items specifically tailored to measure market efficiency, cost reduction, and sustainability within the energy market context.

Data Collection and Sample Population

Data collection was conducted through an online survey distributed to professionals and stakeholders in the energy sector. The sample population consisted of individuals involved in the adoption and implementation of fintech solutions within energy markets. A total of 500 surveys were distributed, and 320 completed responses were received, yielding a response rate of 64%. The demographic characteristics of the respondents included a diverse range of roles within the energy sector, such as energy traders, regulatory officials, and technology providers, ensuring a comprehensive perspective on the issues being studied.

The survey responses were collected over a period of two months. The data were then cleaned and prepared for analysis, with incomplete or inconsistent responses being excluded from the final dataset. The demographic data revealed that 60% of the respondents were male, and 40% were female. The majority of respondents (70%) had over five years of experience in the energy sector, and 30% had less than five years of experience. This demographic diversity provided a robust dataset for analyzing the impacts of fintech on energy market efficiency, cost reduction, and sustainability.

Data Analysis Techniques

Relevant techniques for data analysis included Structural Equation Modeling (SEM) using Smart PLS, which allows for the examination of complex relationships between observed and latent variables. The measurement model was first evaluated for reliability and validity using Cronbach's alpha (α), Average Variance Extracted (AVE), and Composite Reliability (CR). Convergent validity was assessed through item loadings, with values above 0.70 considered acceptable. By employing these rigorous data collection and analysis methods, the study ensures robust and reliable findings, providing valuable insights into the integration of fintech in energy markets.

Common Method Bias

Common method bias continues to be a key concern for social researchers. In PLS-SEM, we can measure common method bias through the variance inflation factor (VIF) (Kock, 2020), which should be equal to or lower than 3.3. In our study, the value of VIF is between 1.683 and 2.1, indicating that common method bias is not a significant issue in our analysis.

Measurement Model

To check the reliability and validity of constructs used in this study, we performed four sets of necessary tests: internal consistency, convergent validity, and discriminant validity (Hair et al., 2019; Sarstedt et al., 2021). We assessed these validities by analyzing Cronbach's alpha (α), factor loadings, composite reliability (CR), and average variance extracted (AVE). The findings of the CFA confirm that all factor loadings are above the minimum level of 0.7. The minimum value for α is 0.7, which shows that the data has internal consistency (Dahri et al., 2019; Manley et al., 2021; Sarstedt et al., 2021). The value of CR for all constructs is above 0.8, while the value of AVE for all constructs is above 0.5. Therefore, the outcomes show reasonable convergent validity, as illustrated in Table 1. The discriminant validity confirms whether the construct measures are different from other constructs or not (Hair et al., 2019; Sarstedt et al., 2021). As shown in Table 3, the square root of the AVE is higher than the correlation between variables, which demonstrates reasonable discriminant validity.

Table 1.
Convergent Validity of Measurement Model

Constructs	Items	Loading	α	AVE	CR
Fintech Adoption	FA1	0.78	0.82	0.60	0.84
	FA2	0.80			
	FA3	0.75			
Investment in Fintech	IF1	0.81	0.85	0.63	0.86
	IF2	0.83			
	IF3	0.77			
Regulatory Support	RS1	0.79	0.80	0.58	0.82
	RS2	0.76			
	RS3	0.74			
Technological Infrastructure	TI1	0.82	0.83	0.61	0.85
	TI2	0.79			
	TI3	0.78			
Market Transparency	MT1	0.80	0.84	0.65	0.87
	MT2	0.85			
	MT3	0.78			

Structural Model

In order to evaluate our hypotheses, we examine the estimated path coefficients of the structural model. The results of the study model are shown in Figure 2. Fintech adoption has a positive effect on market efficiency, supporting H1 ($\beta = 0.313$, $p < 0.001$). Likewise,

investment in fintech has a positive effect on cost reduction, supporting H2 (β = 0.452, p < 0.001). Regulatory support has a positive effect on market efficiency, supporting H3 (β = 0.144, p < 0.01). Technological infrastructure has a positive effect on sustainability, supporting H4 (β = 0.381, p < 0.001). Finally, market transparency has a positive effect on cost reduction, supporting H5 (β = 0.289, p < 0.01).

Table 3.
Measurement Model and Discriminant Validity

Constructs	FA	IF	RS	TI	MT
FinTech Adoption (FA)	0.775				
Investment in Fintech (IF)	0.483	0.793			
Regulatory Support (RS)	0.412	0.506	0.761		
Technological Infrastructure (TI)	0.451	0.478	0.472	0.782	
Market Transparency (MT)	0.394	0.422	0.438	0.401	0.806

Blindfolding Procedure

We used the blindfolding procedure to evaluate the relevance of exogenous variables and the model's performance. This sample reuse procedure helps in assessing the predictive relevance of the model. The blindfolding procedure indicated that the model has satisfactory predictive relevance, with Q^2 values above zero for all endogenous constructs, suggesting that the model has good explanatory power for the dependent variables. By following these rigorous analysis methods, we ensure that the study provides reliable and valid insights into the integration of fintech in energy markets, contributing to our understanding of how these technologies can enhance market efficiency, reduce costs, and promote sustainability.

Discussion and Implications

The empirical analysis provided robust insights into the relationships between fintech adoption, investment in fintech, regulatory support, technological infrastructure, market transparency, and the key outcomes of market efficiency, cost reduction, and sustainability in energy markets. The findings align with the Technology-Organization-Environment (TOE) framework, confirming the significant role of technological, organizational, and environmental factors in influencing these outcomes.

Table 4.
Structural Model Results (Hypothesis Testing)

Hypothesis	Relationship	Std Beta	Std Error	t-value	Decision	Q^2	R^2
H1	Fintech Adoption -> Market Efficiency	0.313	0.045	6.956	Supported	0.27	0.54
H2	Investment in Fintech -> Cost Reduction	0.452	0.038	11.895	Supported	0.32	0.48
H3	Regulatory Support -> Market Efficiency	0.144	0.050	2.880	Supported	0.27	0.54
H4	Technological Infrastructure -> Sustainability	0.381	0.042	9.071	Supported	0.29	0.46
H5	Market Transparency -> Cost Reduction	0.289	0.049	5.898	Supported	0.32	0.48

DISCUSSION OF FINDINGS

The analysis reveals that fintech adoption significantly enhances market efficiency ($\beta = 0.313$, $p < 0.001$). This supports the notion that integrating fintech solutions like blockchain and AI can improve real-time data accuracy and secure transaction records, thereby reducing inefficiencies. This finding is consistent with Allen et al. (2021), which highlighted the role of fintech in improving market transparency and operational efficiency.

Investment in fintech shows a strong positive influence on cost reduction ($\beta = 0.452$, $p < 0.001$). This suggests that higher investment in fintech enables the deployment of advanced technological solutions, optimizing energy distribution and consumption, and thus lowering transaction costs. This aligns with Malhotra and Malhotra (2023), which emphasized the cost-saving potential of fintech investments in the energy sector. Regulatory support also positively affects market efficiency ($\beta = 0.144$, $p < 0.01$). Supportive regulatory frameworks facilitate the adoption and smooth integration of new technologies, enhancing overall market efficiency. This finding is in line with the World Economic Forum (2018), which highlighted the importance of regulatory support in promoting technology adoption.

Technological infrastructure has a significant positive impact on sustainability ($\beta = 0.381$, $p < 0.001$). Robust technological infrastructure supports the deployment of smart grids and IoT devices, providing real-time monitoring and management of energy resources, which leads to sustainable energy practices. This corroborates the findings of Zinakova (2020), which emphasized the role of technological infrastructure in enabling efficient energy management. Market transparency significantly influences cost reduction ($\beta = 0.289$, $p < 0.01$). Enhanced transparency reduces information asymmetry and corruption, fostering more efficient market behavior and reducing transaction costs. This supports the International Finance Corporation (2020) findings, which highlighted the benefits of transparency in reducing costs and improving market operations.

IMPLICATIONS FOR POLICY AND PRACTICE

For policymakers, the study underscores the importance of fostering a conducive environment for fintech integration in energy markets. Regulatory frameworks should support innovation while ensuring robust oversight to prevent financial instability and protect against cyber threats. Policies encouraging investment in fintech and technological infrastructure are crucial for achieving efficiency and sustainability in the energy sector. Practically, energy market participants should invest in fintech solutions like blockchain and AI to streamline operations and reduce costs. However, these investments should be complemented by measures to enhance cybersecurity. Furthermore, fostering a supportive regulatory environment is essential for encouraging fintech adoption while addressing potential downsides. For the academic community, this study provides a comprehensive framework for understanding the complex interplay between fintech innovations and energy market dynamics. It encourages further research into the specific mechanisms through which fintech can affect different aspects of energy markets and offers a model for other researchers to build upon. By addressing these key areas, the study contributes to a more efficient, cost-effective, and sustainable energy market, benefiting both global and country-specific contexts. The findings provide actionable insights for

enhancing market efficiency, reducing costs, and promoting sustainable energy practices through the strategic integration of fintech solutions.

MODEL PERFORMANCE AND PREDICTIVE RELEVANCE

Using the blindfolding procedure, we evaluated the relevance of exogenous variables and the model's performance. The Q^2 values for all endogenous constructs were above zero, indicating satisfactory predictive relevance. The R^2 values, which indicate the proportion of variance explained by the model, were robust, showing that the model has good explanatory power for the dependent variables. By employing rigorous analysis methods, this study ensures reliable and valid insights into the integration of fintech in energy markets, contributing significantly to our understanding of how these technologies can enhance market efficiency, reduce costs, and promote sustainability.

CONCLUSION

The primary problem this study aimed to investigate is the dual-edged impact of fintech integration in energy markets, specifically focusing on how key factors such as fintech adoption, investment in fintech, regulatory support, technological infrastructure, and market transparency influence market efficiency, cost reduction, and sustainability. The study sought to address both global and country-specific challenges, with a particular emphasis on the energy sector in Pakistan. To explore these relationships, we formulated several hypotheses based on the Technology-Organization-Environment (TOE) framework. The hypotheses posited that fintech adoption, investment in fintech, regulatory support, technological infrastructure, and market transparency would positively influence market efficiency, cost reduction, and sustainability in energy markets.

A structured questionnaire was designed using a Likert scale ranging from 1 (strongly disagree) to 7 (strongly agree). The survey was distributed to professionals and stakeholders in the energy sector, including energy traders, regulatory officials, and technology providers. Out of 500 distributed surveys, 320 completed responses were received, yielding a response rate of 64%. The empirical analysis employed Structural Equation Modeling (SEM) using Smart PLS to examine the relationships between the constructs. The results indicated that fintech adoption positively influences market efficiency ($\beta = 0.313$, $p < 0.001$), investment in fintech positively influences cost reduction ($\beta = 0.452$, $p < 0.001$), regulatory support positively influences market efficiency ($\beta = 0.144$, $p < 0.01$), technological infrastructure positively influences sustainability ($\beta = 0.381$, $p < 0.001$), and market transparency positively influences cost reduction ($\beta = 0.289$, $p < 0.01$).

The key findings of the study demonstrate that integrating fintech solutions can significantly enhance market efficiency, reduce transaction costs, and promote sustainability in energy markets. These results confirm the hypotheses and align with previous research, providing empirical evidence on the multifaceted impacts of fintech. The contribution of this study is multifaceted. Theoretically, it extends the TOE framework to the context of energy markets, offering a comprehensive understanding of how technological, organizational, and environmental factors interact to influence market outcomes. The study provides a robust model for examining

the integration of fintech in energy markets, highlighting the critical roles of regulatory support and technological infrastructure. Practically, the study offers actionable insights for energy market participants and policymakers. For energy market participants, the findings underscore the importance of investing in fintech solutions to streamline operations and reduce costs. Policymakers are encouraged to foster a supportive regulatory environment that facilitates fintech adoption while addressing potential risks such as financial instability and cybersecurity threats. Enhancing technological infrastructure is also crucial for enabling efficient energy management and promoting sustainable practices.

Despite its contributions, the study has several limitations. First, the data were collected from a single country, Pakistan, which may limit the generalizability of the findings to other contexts. Future research could expand the scope to include multiple countries and compare the impacts of fintech integration across different regulatory and technological environments. Second, the study relied on self-reported data, which may be subject to response biases. Future studies could incorporate objective measures of market efficiency, cost reduction, and sustainability to validate the findings. Furthermore, while the study highlights the positive impacts of fintech integration, it also acknowledges potential challenges such as high implementation costs, financial instability, and cybersecurity risks. Addressing these challenges requires a balanced approach that combines technological innovation with robust regulatory frameworks and infrastructure investments. In conclusion, this study provides valuable insights into the role of fintech in enhancing market efficiency, reducing costs, and promoting sustainability in energy markets. By addressing the key factors influencing these outcomes, the study offers practical and theoretical contributions that can guide future research and policy-making in the energy sector.

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