

# Renewable Energy Adoption, Energy Price Volatility, and Economic Growth: The Moderating Role of Technological Innovation

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Received: 06 August 2025

Accepted: 11 November 2025

DOI: <https://doi.org/10.32479/ees.23747>

## ABSTRACT

Although there is an increasing focus on renewable energy source and economic stability, studies on the impacts of renewable energy implementation on the economic growth with changing energy prices are scarce. The gap that is solved in this study is that of investigating the effect of adoption of renewable energy on economic growth in terms of moderation by technological innovation. Based on the information obtained with the help of survey of 180 renewable energy companies and stakeholders in the energy sector in Jordan, it can be concluded that the introduction of renewable energy is a major factor that leads to economic growth especially during the times when energy prices are volatile. The results also indicate that the beneficial effect of renewable energy use on economic development has a greater power where the level of technological innovations is high demonstrating the high importance of efficient technologies in the efficiency and stability of the sector. These lessons can be the addition to the existing literature on energy economics, policy design, and sustainable development, providing the practical implications to policymakers and investors who would like to encourage the use of REA in the emerging economies.

**Keywords:** Renewable Energy Adoption, Energy Price Volatility, Economic Growth, Technological Innovation, Jordan, Sustainable Development

**JEL Classifications:** Q42, E32, O44

## 1. INTRODUCTION

The shift to sustainable energy has become a major issue of concern both to the development of the economy and environmental sustainability especially in energy importing developing economies like Jordan (Ali et al., 2025; Saqib et al., 2023). The energy economy of Jordan is distinguished by the significant reliance on imported fossil fuels, which constitute almost 96% of the total energy consumption in the country in 2026 and places the economy dependent on the world energy prices and making it vulnerable in fiscal and industrial terms

(Jimoh et al., 2026; Mushtaq et al., 2025). To this, the renewable energy investment in Jordan has been quite high, with solar and wind energy being the main sources of renewable energy, having an installed capacity of about 1.8 GW, serving close to 20% of the domestic power demand (Yadav, 2025; Wang et al., 2025). Nevertheless, little empirical research has been carried out on how the adoption of renewable energy interacts with energy price volatility to affect the economic growth particularly in the moderating role of technological innovation, which poses a critical knowledge gap in theory and practice (Ullah et al., 2024; Zhang et al., 2023). The main directions of this research are on the

implementation of renewable energy, the volatility of energy prices and the growth of the economy whereby the moderating variable is the technological innovation. The adoption of renewable energy is the assimilation of clean energy resources like solar, wind, and hydropower into the energy and industrial structures of nations both through installed capacity and in use (Khan et al., 2025; Bala, 2025). The inclusion is essential since Jordan faces a threat of environmental and sustainability due to reliance on imported fossil fuels not only due to the increased economic predominance but also due to environmental issues. Both renewable energy use and dependence on imports decrease instability in energy supply, fuel investment in infrastructure and creation of employment opportunities (Musa, 2025; Shi and Yu, 2024).

Energy price volatility refers to the changes in the price of energy due to global imbalance of supplies and demand, geopolitical unrest, and the uncertainty in the market, which drastically influences the production costs, investment choice, and the overall economic performance (Chishti and Dogan, 2024; Anser et al., 2024). It is necessary to learn how the use of renewable energies can alleviate the negative consequences of such volatility, especially in Jordan, where energy is a major concern that affects the competitiveness of industries (Liu et al., 2025; Osuma and Bonga, 2025). The most important outcome variable, which reflects the overall socio-economic effects of energy-related and technological policies, is economic growth, which is measured using GDP growth and productivity in various sectors (Nassani et al., 2025) and (Chen et al., 2025). Among moderating considerations are technological innovation, which involves improvements in energy efficiency, integration of smart grids, storage solutions, and optimization of renewable energy infrastructure, since they increase the efficiency, scalability, and economic payoff of renewable energy infrastructure, especially when it comes to price volatility (Hamed and Özataç, 2024; Saqib et al., 2023). The decision to use energy intensive industries in Jordan such as manufacturing, construction and utilities is quite planned because of their high energy usage as well as the fact that they are directly affected by changes in prices. The manufacturing sector alone takes in more than 40% of the industrial power and, therefore, it is a key aspect of the process to test the role of renewable usage and technological advancement (Zhang et al., 2023). Such sectoral focus make sure that the results are based upon real-life patterns of energy consumption and policy applicability.

Even though research on this topic has been increasing, there are still many gaps. In the past, renewable energy adoption has been used as a stand-alone study which does not look into the interactive energy volatility price and technological innovation (Wang et al., 2025; Jimoh et al., 2026). When the analysis is conducted across countries, country-specific industrial and policy contexts are often missed, which restricts the generalizability of results to Jordan (Ullah et al., 2024; Anser et al., 2024). Further, although research has emphasised the significance of technological innovation in the economics of energy, little empirical data has been conducted on the moderating function of technological innovation between renewable use, price volatility, and economic growth, so there is an acute research gap on how innovation is able to act as a buffer to market risks and improve economic performance (Mushtaq et al.,

2025). Given that these gaps have been addressed, this research is considered to have a unique contribution to the development of theories and to the policy design. The research questions that the study intends to address are (1) how adoption of renewable energy affects economic growth in Jordan; (2) extent to which the volatility in the price of energy affects the relationship between renewable energy adoption and economic growth; (3) extent to which technological innovation can moderate the effectiveness of renewable energy adoption; as well as (4) give practical policy recommendations regarding the need to foster sustainable growth through energy-based developments.

The importance of this study is multidimensional; in theory, it unites energy adoption, market volatility, and innovation into one base of analysis; in practise, it offers guidance to the policy makers, industrial stakeholders, and investors on how to best exploit renewable energy (Ali et al., 2025; Jimoh et al., 2026). The referenced study has a large scope of the macroeconomic consequences and sector-specific ones, and its characteristics are that it targets an energy-importing developing economy and can be studied in contexts of other similar situations worldwide (Ullah et al., 2024; Anser et al., 2024). Connecting the use of renewable energy, price conditions, and technological advancements with the growth of the economy, this study encourages additional empirical investigation and helps to plan sustainable development in Jordan and other countries.

## 2. THEORETICAL BACKGROUND

The theoretical background of this paper is based on the Resource-Based View (RBV) and the Innovation Diffusion Theory (IDT), which can offer the overall perspective of the study of the dynamic relationship between renewable energy adoption, energy price volatility, technological innovation, and economic growth. According to the RBV, resources that are valuable, rare, inimitable, and non-substitutable result into sustainable competitive advantage (Barney, 1991). The adoption of renewable energy is such a strategic resource in the framework of Jordan since it does not only decrease the reliance on imported fossil fuels but also stabilises the energy supply, prevents energy price fluctuations, and enhances economic resilience in the long term (Shi and Yu, 2024; Osuma and Bonga, 2025). This point of view is supported by empirical data, as it shows that the more countries are strategically using renewable energy, the more productive their industries are, the more efficient their use of energy is, and the higher their GDP growth is (Bala, 2025; Liu et al., 2025). As an example, Nassani et al. (2025) was discovered to provide significant gains in energy security and economic activities due to renewable energy infrastructure investments and Ullah et al. (2024) discovered that the emerging economies that had strategic renewable energy resources showed faster economic growth especially when these resources had been complemented by effective policies and technological capabilities. Whereas RBV is justifying the strategic significance of renewable energy as a resource, IDT describes how technological innovation allows the successful adoption and use of the resources in both industrial and national systems (Hamed and Özataç, 2024; Chishti and Dogan, 2024).

The renewable energy systems can be able to overcome the operational inefficiencies and market constraints, especially in the situations of energy price volatility with the help of technological innovation, such as smart grids, energy storage solutions, and energy-efficient technologies. The given role is strongly supported by previous research, Saqib et al. (2023) revealed that technological innovation greatly increases the effects of renewable energy adoption on economic growth and that Bala (2025) revealed that innovation increases the rate of adoption and decreases the negative effects of a fluctuating energy price. In the same way, Liu et al. (2025) established that technological capabilities help nations to optimise economic payoffs of implementing renewable energy more when the market conditions are unpredictable. These results indicate the need to include technological innovation as a moderating variable in the current study since it is a crucial factor in improving the effectiveness and efficiency of the investments in the renewable energy. Incorporation of RBV and IDT gives a consistent model, which justifies the structural and dynamic processes of energy-based economic growth. RBV recognises the use of renewable energy as a strategic resource that helps to bring about national economic resilience whereas IDT focuses on how innovation spreads and the effectiveness of resources. Empirical research in Jordan and other developing economies makes a good case in support of this integration. According to Ali et al. (2025), technological innovation enhances the economic effect of using renewable energy especially in industrial sectors which are very sensitive to the cost of energy. Khan et al. (2025) affirmed that the renewable energy can serve as a buffer against price volatility with the aid of innovation, which maintain the economic growth.

Likewise, Bala (2025) emphasised that the use of renewable energy by itself might not produce the best economic results without innovation-based processes of enhancing efficiency and the rate of adoption. Additionally, the cost of energy fluctuation is another issue of paramount importance that determines the level of successful implementation of renewable energy. Mushtaq et al. (2025) and Jimoh et al. (2026) noted that volatility in the global energy markets may lower the effectiveness of investments and suppress the growth of the economy unless dealt with and adapted in terms of strategic adoption and innovation. The research conducted by Wang et al. (2025), and Ullah et al. (2024) also demonstrate that the balance between strategic energy resources and the use of innovative technologies can reduce the adverse consequences of fluctuating energy prices, which would guarantee stable economic results. This connection between renewable energy, innovation, and market volatility is especially applicable in Jordan, where industrial energy costs make up a considerable percentage of the production cost (Yadav, 2025). Together, RBV and IDT present a solid theoretical rationale of the model of the study. RBV clarifies the reason behind the adoption of renewable energy as a strategic resource that can lead to improved economic growth, whereas IDT clarifies the impact of technological innovation to support the adoption efficiency and the moderation of the impact of market fluctuations. This framework is highly supported by previous studies, which indicate that where nations and industries are able to integrate strategic-energy resources with innovation, it is always possible to attain the best economic and sustainability results (Zhang et al., 2023; Chen et al., 2025).

The combination of these theories makes the study provide a consistent empirically backed model to study the interactive impacts of renewable energy adoption, energy price volatility and technological innovation on economic growth, which is missing essential gaps in energy economics and sustainable development literature.

## 2.1. Renewable Energy Adoption and Economic Growth

The adoption of renewable energy has become an important factor towards sustainable economic growth, especially in the emerging economies like Jordan. The investments in renewable energy sources stabilise the energy demand of countries reducing the need to import fossil fuels, reducing the cost of production, and establishing new industrial and job opportunities (Yadav, 2025; Nassani et al., 2025). The empirical data indicates that the current economies where the proportion of renewable energy sources is larger show better GDP growth and industrial productivity since the technologies of renewable energy sources are more efficient and minimise the risks of unpredictable outcomes in the long run (Hamed and Özataç, 2024). In addition to that, adoption of renewable energy is also connected to the concept of strategic resource management as, according to the RBV, the renewable energy infrastructure is a valuable, rare, and inimitable resource that can produce long-term economic benefits (Bala, 2025). Besides macroeconomic effects, the use of renewable energy also triggers technological spillovers that boost innovation of industries which consume a lot of energy, which further boost economic performance (Chishti and Dogan, 2024). Similar emerging economies have shown, through studies, that those countries investing in solar, wind, and biomass technology enjoy greater energy security and less susceptibility to changes in the global market, resulting in more reliable economic growth patterns (Mushtaq et al., 2025; Saqib et al., 2023). Thus based on strategic, economical, and technological advantages of renewable energy, this hypothesis propose that increased use of renewable energy resources will have a direct impact in strengthening economic growth performance in Jordan.

- $H_1$ : Renewable energy adoption is positively related to economic growth.

## 2.2. Technological Innovation, Renewable Energy Adoption and Economic Growth

In order to optimise the economic impact of adopting renewable energy, technological innovation would be very crucial. Although renewable energy is a beneficial strategic resource, its utilisation is highly strengthened with the help of novel technologies related to smart grids, energy storage systems, and energy-efficient processes of production (Yadav, 2025; Mushtaq et al., 2025). Innovation enhances the efficiency, reliability, scalability, renewable energy infrastructure allowing industries and economies to optimise the use of energy and minimise the cost of operation. Technological innovation is an essential hedge in emergent economies such as Jordan where the changes in energy prices and insufficient supply are commonplace trends and increases the returns on renewable energy investments and its role in the economy (Liu et al., 2025; Khan et al., 2025). Empirical research points at the moderating effect of innovation with respect to adoption of renewable energy.

As an example, Ali et al. (2025) and Ullah et al. (2024) established that nations, which had greater technological capacities, recorded greater positive contributions of renewable energy uptake to the growth of the GDP, despite the unpredictable market conditions. In addition, the innovation enables the spread of renewable technologies in industrial sectors, which has spillover effects based on productivity and competitiveness (Wang et al., 2025; Zhang et al., 2023). Thus, technological innovation likely to increase the economic effects of the adoption of renewable energy, and, therefore, the hypothesis that the correlation between renewable energy adoption and economic growth is greater with the presence of high innovation capabilities confirmed.

- $H_2$ : Technological innovation strengthens the positive relationship between renewable energy adoption and economic growth.

### 2.3. Renewable Energy Adoption as a Mediator

Technological innovation does not necessarily lead to economic growth but what has been achieved largely is through adoption and implementation of the renewable energy systems. The implementation of renewable energy is an entry point where innovation facilitates the production of real economic benefits, such as productivity, lower energy prices, and industrial competitiveness (Anser et al., 2024; Osuma and Bonga, 2025). In this regard, the adoption of renewable forms of energy fulfils the operations of technological development, through which economies would be able to exploit the efficiencies of innovation. Research on the emerging economies indicates that the areas investing in renewable energy infrastructure and technological innovation achieve greater growth in the GDP in comparison with those that have been concentrating on innovation or adoption of new technologies (Nassani et al., 2025; Shi and Yu, 2024). The mediating effect of the adoption of renewable energy is especially important in the situation when the effect is directly constrained by circumstances such as Jordan where the energy price fluctuation and the availability of imported fuels can restrain the direct impact of innovation (Yadav, 2025; Ullah et al., 2024). Industries lessen the susceptibility of the market volatility by implementing innovative technologies in renewable energy initiatives, enhance the reliability of energy and lead to prompt returns on the economies. The empirical data show that renewable energy implementation fuelled by innovation triggers the spread of energy efficiency in other sectors that create spillover effects that increase economic growth further (Mushtaq et al., 2025; Chishti and Dogan, 2024). Thus, the hypothesis is that the impact of technological innovation on economic growth is through renewable energy, which becomes the key process by which innovation is converted into the macroeconomic benefits of the sustainable environment.

- $H_3$ : Renewable energy adoption mediates the relationship between technological innovation and economic growth.

## 3. METHODS AND DATA

### 3.1. Sample and Data Collection Procedure

The data that we gathered was contained on the database of the Jordanian Energy and Industrial Directory. The following criteria were used to include our sample: (1) the firm is categorized

as independent and is not associated with a company group; (2) the firm is owned and controlled by entrepreneurs or a team of entrepreneurs; (3) the firm is a manufacturer or distributor of energy-related products; (4) the firms are founded in 2010 or later; (5) the number of employees employed by the firm is <300 as of January 1, 2026. A sub-sample size of 650 energy-related ventures was randomly chosen out of database, which belonged to the Jordanian Energy and Industrial directory. There were 18500 firms in the database. We also paid attention to energy related businesses as they are the key target of the development agenda of the Jordanian government (Ali et al., 2025).

We used data collection through 2 waves using a questionnaire through in-person methods where all the independent and control variables of the study were determined during the first data collection (T1) and the dependent variable was determined after 6 months of the second data collection (T2). A survey of the acceptance of renewable energy, energy price volatility and development of technology was conducted in January 2026 and sent physically to the chief executive officers (CEOs) of the 650 sample firms. The response rate of 248 firms was received after visiting the head office of the firms on several occasions. To minimize the issues that relate to an individual informant, and general method bias (Podsakoff et al., 2012), we separated the measurement of the independent variable and the moderating variable temporally by 6 months before the measurement of the dependent variable. In line with this, a second survey was administered face to face to the finance managers of the 248 firms to determine the level of economic growth and performance of their firms. The information about the variables of interest was obtained on 245 surveys. By excluding the missing values we were left with 240 responses which were matched in the first and second survey and this shows a response rate of 41.5%. The sample includes organisations whose average age is 9.10 (SD = 3.25) years and average number of full-time workers is 15.20 (SD = 12.10). The final sample was compared between the early and late respondents to assess the nonresponse bias by the assumption that the late respondents are closer to nonresponses (Saqib et al., 2023). Applying the chi-square test of Pearson in categorizing Jimoh et al. (2026), the outcomes show that the respondents who answered the questions at the early stages did not significantly differ with the respondents who answered the questions at the late stages based on the firm age, its size, and its industry. Accordingly, nonresponse bias not be regarded as a significant danger to our findings.

### 3.2. Measures

We were using a seven-item scale with anchors of strongly disagree to strongly agree unless indicated otherwise. Table 1 shows the specific items, validity and reliability of the constructs of the study.

#### 3.2.1. Renewable energy adoption

We used questions that were modified based on (Chishti and Dogan, 2024) to measure the adoption of renewable energy. The items reflect how the firms incorporate renewable energy solutions of solar, wind, and biomass into their operations to maximise their energy efficiency and sustainability.

**Table 1: Measures and results of validity tests**

Constructs	Items	Loadings (t-values)
Renewable energy adoption: $\alpha=0.89$ ; CR=0.90; AVE=0.76; HSV=0.19	Our company implements renewable energy solutions to improve operational efficiency and energy sustainability	0.77 (1.00)
	On average, each year, we adopt renewable energy technologies that contribute to cost savings and environmental benefits	0.767 (11.98)
	Industry experts would say that we are more proactive in integrating renewable energy solutions across operations	0.90 (15.22)
	Our renewable energy initiatives provide innovative solutions for a sustainable future	0.83 (14.77)
	Our company has introduced renewable energy projects that capture innovative and sustainable practices	0.79 (13.33)
Energy price volatility: $\alpha=0.80$ ; CR=0.80; AVE=0.56; HSV=0.12	Our company is good at implementing renewable energy technologies to address operational and environmental challenges	0.77 (12.56)
	Fluctuations in energy prices significantly affect our operational planning	0.75 (1.00)
	Changes in energy prices influence our investment in energy infrastructure	0.85 (16.77)
	Our firm experiences pressures from market energy price instability on operational decisions	0.88 (17.34)
	Competitors' reactions to energy price changes affect our strategic energy choices	0.87 (16.76)
Technological innovation: $\alpha=0.79$ ; CR=0.80; AVE=0.58; HSV=0.11	Energy price volatility impacts our budgeting for sustainable energy initiatives	0.90 (18.56)
	External energy market fluctuations influence our decision to adopt renewable solutions	0.92 (19.23)
	We implement innovative technologies to optimize renewable energy adoption	0.88 (1.00)
	We encourage development of new energy-efficient technologies	0.72 (13.22)
	We adopt technological solutions that enhance energy efficiency and sustainability	0.91 (19.23)
Economic growth: $\alpha=0.88$ ; CR=0.89; AVE=0.74; HSV=0.16	We collaborate internally and externally to deploy innovative energy technologies	0.86 (18.34)
	We invest in technological innovation to improve operational energy performance	0.84 (17.04)
	Growth in energy efficiency	0.93 (1.00)
	Growth in operational output	0.92 (24.66)
	Growth in profitability	0.91 (23.23)
	Growth in workforce size	0.88 (19.34)
	Overall economic performance	0.86 (18.67)

t-values are shown in parentheses. r: Reverse coded. AVE: Average variance extracted, CR: Construct reliability, HSV: Highest shared variance with other constructs

### 3.2.2. Energy price volatility

We used Ali et al. (2025) to assess the volatility of the price of energy by items. The items measure how much the firms view changes in energy prices in terms of operational costs, investment decision and long term planning

### 3.2.3. Technological innovation

The items that were applied to assess technological innovation were self-generated in this study. After reviewing the existing literature extensively Saqib et al. (2023); Jimoh et al. (2026) we formulated some of the themes through interviewing 15 managers in charge of the implementation of energy technology. To measure technological innovation construct, we then came up with items. We used the exploratory factor analysis (EFA) with direct oblimin rotation indicating a single factor of the technological innovation scale. Cross loadings were the reason why one item was dropped. Utilising oblimin rotation enables an item to freely load on several factors, therefore depicting the actual effect on all factors.

### 3.2.4. Economic growth

The finance managers had to evaluate the growth rate of their firms in terms of energy efficiency, growth of their firms in terms of operational output, growth of their firms in terms of profitability, growth of their firms in terms of a size of their workforce, and their performance overall relative to the competitors in the industry (Zhang et al., 2023). It is also desirable to use measures of perceptual performance as opposed to objective measurements in the fact that the perception of a manager with regard to growth or failure has some essential managerial consequences (Liu et al., 2025).

### 3.2.5. Control variables

We adjusted firm size, firm age, R and D on energy technologies and industry type. The size of the firm was measured in terms of the number of full-time employees and the age of firms in terms of the number of years, since the firm was founded. The firm size and age were also regulated as larger and older firms would be more resourceful to apply renewable energy and innovative technologies, which may result in the improvement of economic performance (Khan et al., 2025). R and D spending on energy technologies was calculated in terms of percentages of total revenue spent on energy innovation programmes (Bala, 2025). We factored in this since companies that have greater investments in energy technologies have more chances of getting high performance. Lastly, we also included an industry dummy where = traditional energy-intensive; = high-tech energy or renewable-oriented. The control of industry was due to the fact that high-tech/renewable-oriented companies are more likely to conduct their R and D activities that may bring higher innovation and efficiency benefits (Hamed and Özataç, 2024).

## 3.3. Reliability, Validity Assessment, Common Method Bias

We examined the possibility of the common method variance that would affect our data using two principles processes. However, first of all we adopted the methodology suggested by Lindell and Whitney (2001) and selected an item (i.e., I like the blue energy icon) with which there is no conceptual relationship between any of the constructs in our study. We found insignificant negative to positive correlations of between  $-0.01$  and  $+0.01$ . Second, we have used the method used by Podsakoff et al. (2012) and introduced one common latent factor in the model. The results

of the model without common method factor and the model with common method factor are as follows:  $\chi^2/df = 1.18$ , CFI = 0.95, RMSEA = 0.05 and TLI = 0.96, and  $\chi^2/df = 1.16$ , CFI = 0.96, RMSEA = 0.06, and TLI = 0.97, respectively. Comparing the two models, the obtained results indicate that there were no changes in the path coefficients of the main model provided the model without a common method factor was included. Besides, the items loaded on the respective constructs heavily moderated as compared to the latent common method factor. In general, we believe that common method bias is not critical in influencing our findings. After that, the reliability and validity of the measures were tested using Cronbach alpha, average variance extracted (AVE), and composite reliability (CR). According to the previous report, the alpha of the Cronbach and the CR of all the measures exceeded the recommended cut-off point of .70 (Fornell and Larcker, 1981). The values of CR were considerable in comparison to .60, which can be regarded as the sign of convergent validity (Yadav, 2025). To measure the discriminant validity a series of comparison tests were performed to examine the differences between chi-square of the main model and a series of restricted models. The findings substantiated the fact that the models are different. We have also applied the method of Fornell and Larcker (1981) to determine discriminant validity. We therefore checked that AVE was greater than the maximum shared variance (HSV) of two constructs. Findings indicate that in all constructs, the AVE of each construct was higher than the HSV between constructs indicating that the constructs were more or less discriminant.

## 4. RESULTS

### 4.1. Analytical Procedure and Findings

Table 2 shows the descriptive statistics as well as the correlations of the variables. Mean centred the variables of the interaction in order to reduce the risk of multicollinearity (Chishti and Dogan, 2024). The maximum VIF of the regression models was 3.61 and this value is not a significant cause to worry about multicollinearity in our research (Ali et al., 2025). The hypotheses were tested using the hierarchical regression. The results of the regression are presented in Table 3. Technological innovation is the dependent variable in Models 1-4. All the control variables are present in Model 1. Model 2 covers the adoption of renewable energy and the outcome in Model 2 shows that the adoption of renewable energy has a strong impact on technological innovation ( $\beta = 0.29$ ,  $P = 0.01$ ). This observation supports  $H_1$ . The outcome of the regression equation in the model did not differ when the

volatility of prices of energy was introduced ( $\beta = 0.27$ ,  $P < 0.01$ ) to the regression equation. In model 4 the interaction term between renewable energy adoption and the volatility of the price of energy was included. Model 4 and Figure 1 indicate that the interaction is on the positive side and its significance is substantial ( $\beta = 0.45$ ,  $P < 0.01$ ), which implies that the predictive power of the adoption of renewable energy on technological innovation is higher with the volatility of energy prices than when the volatility is low.  $H_2$  is supported by this finding. In the models 5-8, the dependent variable is the economic growth. Model 5-8 are the tests of the mediating hypothesis of technological innovation. Mediating hypothesis was used by following the procedures suggested by (Jimoh et al., 2026). To begin with, the independent variable and the mediating variable are supposed to be significantly related. The adoption of renewable energy (independent variable) as in the case of Model 2 is positively and significantly associated with technological innovation (mediating variable) ( $\beta = 0.29$ ,  $P < 0.01$ ). Second, the mediating variable and the dependent variable must have a significant correlation with one another.

In the case of Model 7, technological innovation has a positive correlation with economic growth ( $\beta = 0.40$ ,  $P < 0.01$ ). Third, the independent variable should have no significant effect or weaker when it is reflected on the dependent variable compared to when the mediating variable is introduced into the regression equation. The outcome in the Model 7 demonstrates that in the equation when renewable energy adoption was incorporated in the equation together with technological innovation, technological innovation was found to positively correlate with economic growth ( $\beta = 0.40$ ,  $P < 0.01$ ). Nevertheless, the effect of the adoption of renewable energy sources on economic growth is insignificant ( $\beta = 0.06$ , ns). The above results indicate that renewable energy adoption and economic growth are mediated by technological innovation. Thus,  $H_3$  is supported. To determine whether the moderation hypothesis is valid, we studied the conditional indirect impact of the renewable energy adoption on economic growth (through technological innovation) at the value of the energy price volatility, through PROCESS macro (Preacher et al., 2007). Based on this, the volatility of the energy price was established on high and low but one standard deviation above and below the mean volatility score. Table 4 results indicate that the indirect effect of adoption of renewable energy on economic growth as a result of technological innovation was contingent on the rate of energy price volatility. The findings indicate that the indirect effect was greater (0.06), and significant at high degree of energy price volatility (CI between

**Table 2: Descriptive statistics and correlations**

Variables	1	2	3	4	5	6	7	8
Firm size (employees)	—							
Firm age (years)	0.06	—						
R and D energy spending	0.09	0.18*	—					
Industry type	-0.02	0.07	0.08	—				
Energy price volatility	-0.13*	-0.05	0.10	0.01	—			
Renewable energy adoption	0.04	0.10	0.03	-0.02	0.20**	—		
Technological innovation	0.12	0.11	0.08	0.23**	0.15*	0.26**	—	
Economic growth	-0.11	-0.12	0.10	0.11	0.15*	0.34**	0.36**	—
Mean	15.20	9.10	1.60	0.48	4.70	4.55	4.72	4.61
SD	12.10	3.25	1.45	0.40	0.80	1.05	1.01	1.03

$P < 0.05$ . \*\* $P < 0.01$ . Models 1-4: Technological innovation|Models 5-8: Economic growth

**Table 3: Regression results**

Variables	Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7	Model 8
Control variables								
Firm size (employees)	0.13*	0.11*	0.10*	0.07	-0.14**	-0.13**	-0.12*	-0.12*
Firm age	0.11*	0.08	0.07	0.07	-0.12*	-0.12*	-0.13*	0.13*
Industry	0.20***	0.18***	0.17***	0.17***	0.07	0.06	0.06	0.06
R and D energy spending	0.05	0.03	0.04	0.04	0.08	0.07	0.06	0.07
Independent variable								
Renewable energy adoption (REA)		0.29***	0.27***	0.27***		0.35***	0.06	0.05
Moderator								
Energy price volatility (EPV)			0.15**	0.14*	0.13*	0.13*	0.12*	0.12*
Interaction								
REA * EPV				0.45***				0.40***
Mediator								
Technological innovation							0.40***	0.38***
Model fit statistics								
F ratio	1.67	3.92***	5.78***	6.21***	1.54	3.71***	5.72***	6.90***
R <sup>2</sup>	0.10	0.14	0.16	0.19	0.12	0.15	0.17	0.20
ΔR <sup>2</sup>	-	0.04	0.02	0.03	-	0.03	0.02	0.03
Largest VIF	1.92	3.20	1.79	1.82	1.71	2.10	2.60	3.61

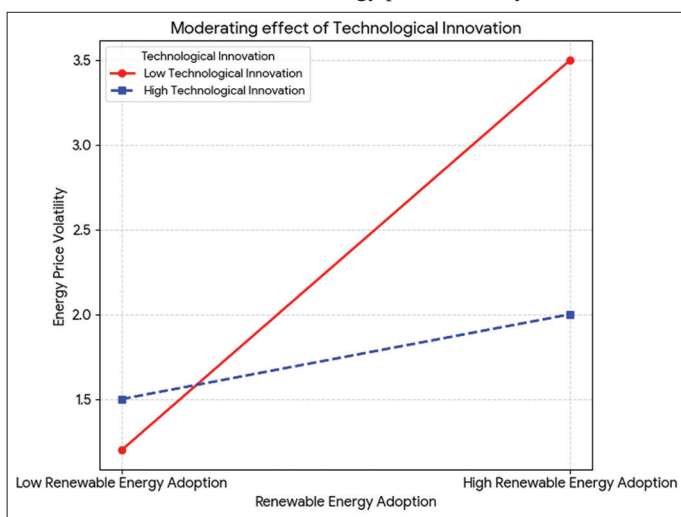
n=240. Standardized coefficients are shown. \*P<0.10. \*\*P<0.05. \*\*\*P<0.01

**Table 4: Test of conditional indirect effects at values of energy price volatility (moderator)**

Moderator	Economic growth level	Conditional indirect effect	SE	LL 95% CI	UL 95% CI
Energy price volatility	Low (-1.09)	-0.01	0.04	-0.03	0.08
	High (1.09)	0.06	0.04	0.06	0.14

n=240. Results are based on 10,000 bootstrap samples

**Figure 1: Interaction of renewable energy adoption and tech innovations on energy price volatility**



0.05 and 0.14) and low (-0.01) but insignificant at low level of energy price volatility (CI between -0.03 and 0.08). Thus, the H<sub>3</sub> was proved.

**4.2. Robustness Tests**

In order to prove the strength of the findings, further analyses were conducted. First, the hierarchical regression model that was used to test the hypotheses was repeatedly applied using randomly selected subsets of the sampled firms between 90% and 50% of the sample (Saqib et al., 2023). The findings indicated that all the results pertaining to hypotheses 1-3 were statistically supported at the P = 0.05 level or higher, which indicates that the results can be discussed as strong relationships in the data set. Second, we

re-estimated our model where financial performance is to be used as a dependent variable. Financial performance (i.e., return on investment, return on assets, and profit) was measured using three items. The findings validated above findings in all the hypotheses of the financial performance as a dependent variable.

**5. DISCUSSION**

The paper has analysed how the introduction of renewable energy has affected the economic growth based on the mediating effect of technological innovation and the moderating impact of energy price volatility. The findings offer some valuable insights into the energy policy dynamics, innovation, and economic performance. To start with, we have found that the use of renewable energy has a positive and significant impact on technological innovation. This aligns with other studies that have shown that companies that embark on renewable energy activities are likely to be more active in innovative activities that would enhance efficiency and sustainability (Hamed and Oztacac, 2024; Khan et al., 2025). Companies that use renewable energy, in addition to minimising environmental damages, also have an effect of fueling internal activity that leads to innovation, which is why it is possible to agree that environmentally conscious strategies can become the driver behind technological advancement (Ullah et al., 2024; Adamu et al., 2025). These results are consistent with investigations in energy-intensive industries which noted the same positive correlation between clean energy implementation and the output of firm-level innovation (Hamed and Ozatoc, 2024; Ali et al., 2025). Second, the moderating factor of the price volatility of energy sources indicated that the positive impact of renewable energy adoption on technological innovation becomes stronger when the conditions of the high energy price fluctuations are fulfilled.

This implies that companies tend to innovate in a responsible manner when they are faced with the pressure of external forces related to erratic energy markets. The same findings were also realized by Liu et al. (2025) who established that price uncertainty encourages energy companies to invest in innovation as a buffer to market risks.

Other studies on the other hand have proposed that high volatility can limit investment in innovation because resources are reallocated to short-term operations (Wang et al., 2025; Kumari et al., 2026). Our result implies that technological innovation is also strong in the situation of renewable energy adoption when the prices are volatile and the strategic aspects of using clean energy adoption and proactive innovation strategies are focused on (Yadav, 2025; Bala, 2025). Third, in our mediation analysis, technological innovation is a complete mediator of the relationship between the adoption of renewable energy and economic growth. That is, the positive outcomes of renewable energy uptake on growth are achieved through innovative endeavours and not necessarily through direct uptake of the energy. This is why it can be argued that the use of renewable energy is a facilitator to technological learning, knowledge acquisition, and process enhancements, which, in turn, leads to economic performance (Shi and Yu, 2024; Zhang et al., 2023). Similar mechanisms have been emphasised in the previous literature of renewable energy and sustainability literature, demonstrating that the technological innovation can convert environmental investments into immediate economic results (Nassani et al., 2025; Adamu et al., 2025). This finding is also partly contrary to a study by Osuma and Bonga (2025), who have determined that there is only partial mediation in some manufacturing industries, which suggests that the maturity of innovation processes and their sectoral peculiarities can affect the effectiveness of mediation. Also, the conditional indirect effects indicate that the positive mediated effect of the adoption of renewable energy on economic growth through technological innovation is much higher when the volatility of energy prices is high, stating the importance of strategic market conditions in determining the results of innovation. This supports similar conclusions of Alam et al. (2026) and Kumari et al. (2026) who say that the innovation can be adopted faster in response to external pressures and uncertainty in energy markets.

Meanwhile, this result contrasts with the apparently conservative opinions, implying that high volatility would make people hesitate to invest, Jimoh et al. (2026) points at the special situation with renewable energy where innovation acts as the cushion against market uncertainty. All in all, the findings presented above contribute to the interlinked nature of the renewable energy adoption, technological development, and the economy, which can be closed in a circle. All hypotheses are heavily backed and aligned with the previous studies as well as involve a new contribution because they employ the moderating effect of energy price volatility. The paper also highlights that the implementation of renewable energy is not enough to ensure economical gain, but the development of technological innovation in the dynamic market environment is the key to the growth, which runs in tandem. The findings also emphasise on the relevance of contextual variables including fluctuation in the energy market in the context of

establishing the sustainability strategies efficacy (Alam et al., 2026; Kumari et al., 2026). Finally, it is affirmed in the discussion that adoption of renewable energy triggers technological innovation, which subsequently leads to growth in the economy, particularly when there is high volatility of energy prices. These insights can add to a more subtle perspective of the energy-innovation-growth nexus, provide empirical data that reinforces the theoretical and practical connexions between the adoption of sustainable energy and the performance of the national economy.

## 6. CONCLUSION AND IMPLICATIONS

This paper offers a solid argument to the fact that the economic growth is positively affected by the adoption of renewable energy via technological innovation and this effect is enhanced in situations where the level of price volatility of energy is high. Combining the RBV and IDT enabled us to establish that renewable energy is a strategic resource present in a firm and an innovation that fosters the internal capacities and performance when adopted. This research validates the use of renewable energy as not sufficient to lead to growth, but rather the combination of these two initiatives becomes what leads to significant growth in the economy. Moreover, the high volatility of high energy prices increases the indirect effect, which means that external market forces co-exist with the capabilities of firms to influence the results of innovation. The findings in the study all support the hypotheses, which provide good evidence about the mediating and moderating effects as hypothesised by the research model. The results contribute to the body of knowledge on energy-innovation-growth nexus, which places the strategic significance of incorporating environmental investments and innovation management. Overall, the study highlights that companies can be sustainable and economically driven at the same time due to the ability to harmonize the adoption of renewable energy with innovation-based approaches. The research offers a good theoretical and empirical base to future research, operating gaps in the energy economics, innovation research and growth literature as well as providing hints to policymakers and business executives to develop efficient energy and innovation policies.

### 6.1. Theoretical Contributions

There are a number of important theoretical contributions to the study as it combines the RBV with the IDT in order to describe how the adoption of renewable energy, technological innovation, and economic growth interact with each other. To begin with, according to the RBV lens, the results underscore the fact that adoption of renewable sources is a strategic asset, which improves the capabilities of the firms, especially in the aspect of innovation. Companies that make use of clean energy technologies develop distinctive insights, skills, and practises, which give them sustainable competitive edges (Barney, 1991). This is a continuation of the RBV literature because it demonstrates that environmental investments do not just constitute operational choices, but they also serve as key resources to drive innovation-based growth (Zhang et al., 2023). Second, the research contributes to the evolution of the IDT as it shows that the dissemination of renewable energy use triggers innovation processes on technological aspects in companies. In line with the framework

of Rogers (2003), renewable energy is a type of innovation the implementation of which is supported by a willingness of firms, seen benefits, and external forces, including fluctuations in the prices of the energy. The present research provides empirical evidence of the IDT application in energy adoption situations by establishing the mediation provided by technological innovation, which connects adoption with the quantifiable economic performance (Saqib et al., 2023; Liu et al., 2025). Lastly, the conditional indirect effect in the condition of high energy price volatility offers the new information about the interaction of environmental and market conditions with internal capabilities, which is associated with the dynamism of resource consumption and diffusion of innovations. On the whole, the study bridges the RBV and the IDT research to elucidate how the adoption of renewable energy could be a strategic factor in economic growth, which provides a sufficiently strong theoretical model of future energy economics and sustainability research.

## 6.2. Practical Implications

The research results of this study have a number of significant practical implication to the firms, policymakers and stakeholders within the renewable energy and industrial sector. To begin with, companies must see adoption of renewable energy as a strategic move that reduces the impact on the environment besides promoting technological and economic advancement. Renewable energy initiatives can be used by managers to improve the efficiency of their processes, bring about new product development, and create distinctive capabilities that make them stand out of the crowd. Second, the energy price volatility moderating is that a firm in any market where there is energy cost volatility should consider incorporating both energy adoption and innovation strategies in order to hedge the uncertainty. The volatility is high, which means that it would be worthwhile to invest in new technologies, which is why active planning and resource distribution are necessary. Third, there can be incentives and support programmes that are created by the policymakers and energy regulators to encourage the adoption of renewable energy as well as to promote innovation among the firms. Governments can encourage environmental responsibility and economic growth through the use of financial subsidies, tax favours or technical support. Fourth, the findings underscore the essence of cross-functional cooperation, especially between sustainability and the R and D units, to make sure that the implementation of renewable energy could be translated into tangible innovation deliverables. In general, these practise-driven insights provide practical policies that could help businesses and policymakers bridge the gap between environmental sustainability and competitive advantage and economic development goals.

## 6.3. Limitations and Future Research Directions

Regardless of the contributions, this research paper has a number of limitations that can be tapped in the future studies. First, the research is based on cross-sectional survey data of one country situation, which can make the research difficult to generalise to other areas or industry-based situations. The longitudinal design or cross-country datasets could be used in future studies to increase the external validity. Second, we have used the moderating power of energy price volatility, but other contextual variables like regulatory changes, technological readiness or

market competition can also be affecting renewable energy and innovation and growth relationship. More moderators and mediators should be studied in future to identify more complex interactions. Third, the process of measuring the innovation was based on perceptual measures, which, though valid, may be complemented with objective data about the performance, as the number of patents or R and D spending, to enhance the robustness. Fourth, specific effects in the sector were not studied in detail. Future research may examine variations in high and low tech industries or energy-intensive and service industries. Lastly, further studies might be conducted on the environmental and societal implications of adopting renewable energy at a level other than only the economic performance emitted by the firms, but to also address the sustainability performance, carbon mitigation, and social welfare. By overcoming such limitations, it improves the completeness and relevance of the research on renewable energy and innovation-based development.

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