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Renewable energy and economic growth: New insight from country risks

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ABSTRACT

This study explored the relationship between renewable energy consumption and economic growth from new risk-based perspectives, including political risks, financial risks, economic risks and composite risks. The study uses a panel threshold model to empirically analyze panel data for the Organization for Economic Cooperation and Development (OECD) countries from 1997 to 2015. The results show when composite risks and political risks are used as threshold variables, there is a single threshold between renewable energy consumption and economic growth. When that threshold is exceeded, the positive effect of renewable energy on economic development increases. When economic risks and financial risks are used as threshold variables, there is a double threshold between renewable energy consumption and economic growth. When the first threshold value is exceeded, but not the second, renewable energy positively impacts economic development. However, when economic risk and financial risk do not lie between the two threshold values, there is an insignificant negative correlation between renewable energy consumption and economic growth.

1. Introduction

Energy is an indispensable source of power for economic development. Mainstream research has concluded that energy can be divided into two types: renewable and non-renewable. Research analyzing the impact of non-renewable energy on economic development is very comprehensive. Many studies have shown that the use of traditional fossil energy can promote economic growth [1–5]. However, economic growth is not the only goal, and the use of non-renewable energy has been widely criticized for its unsustainability and significant carbon emissions. In recent decades, as climate change has become more significant and there has been an increased awareness of environmental protection, the importance of developing renewable energy has gradually emerged; particularly in recent years, significant attention has been paid to renewable energy consumption [6]. With the increase in this consumption, more researchers have begun to study renewable energy [7], focusing particularly the relationship between renewable energy consumption and economic development. Some studies have found that renewable energy positively impacts economic development [8–10]; other studies have found that renewable energy inhibits it [11–13].

However, previous studies on the relationship between the two have not considered country-level risks. More specifically, few studies have assessed the impact of renewable energy consumption on economic development at different levels of country risks. Country risks refer to the probability of loss or the degree of instability faced by investors or traders within a country; these risks mainly include political risk, financial risk, and economic risk.

First, with respect to political risk, a stable political environment helps to promote the implementation of renewable energy policies. In the early stage of a country's development, renewable energy development is often driven by policies, rather than being demand-driven. A changing political environment may increase the economic cost of developing renewable energy, which does not support economic development. One study noted that improving political stability and the quality of bureaucracy can increase government sensitivity to the environment and encourage the establishment of incentives to increase the use of renewable energy [14].

Second, with respect to financial risk, financing is a consistent problem facing the renewable energy industry. Renewable energy projects require high upfront costs and long capital payback

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periods [15]. These challenges are coupled with the uncertainty of new technologies that require long innovation cycles, and a strong dependence on infrastructure; clean energy requires more patience and high-risk funds [16]. Without a stable financial environment, these problems are further magnified. Therefore, a higher level of financial risk will increase the economic cost of renewable energy consumption, which does not support economic development. One study noted that eliminating financial risk may help release the potential of renewable energy, as in a hypothetical “low risk” scenario, the advantages of renewable energy are more clear [17]. This scenario shows the highest installed capacity and significantly reduced total system cost.

Finally, economic risk mainly emerges from an unstable economic environment. An unstable economic environment may greatly reduce energy demand, especially for renewable energy. Renewable energy has higher development costs and more infrastructure construction demands compared to non-renewable energy. This leads to a significant increase in the economic cost of renewable energy development and consumption. A stable economic environment provides for better technology, capital, and talent conditions, encouraging reductions in the economic cost of renewable energy consumption.

In summary, political, financial, and economic country risks directly or indirectly affect renewable energy and economic development, and therefore play an important role in the relationship between renewable energy consumption and economic growth. This study explores the impact of different levels of country risks on the relationship between the two, in addition to considering the role of composite factors. The analysis above and the literature review that follows reveal the following research gaps. (1) Few studies have used empirical analysis to determine whether country risks impact on relationship between renewable energy consumption and economic development. (2) Previous studies have reached conflicting conclusions concerning the linear relationship between renewable energy consumption and economic development. This highlights the need to consider the non-linear impact of country risks on the relationship between renewable energy consumption and economic growth.

The innovations and contributions of this article are as follows. First, to better explain the impact of country risk on the relationship between renewable energy consumption and economic growth, we apply multifaceted risk indicators (composite risk, political risk, financial risk, economic risk) to explore the impact of country risks on this relationship. Second, to focus on previously conflicting conclusions about the linear relationship between renewable energy consumption and economic development, this study applies a non-linear approach. The study summarizes country risk channels that affect renewable energy consumption and economic development. Based on this, we use a threshold regression model to measure the nonlinear impact of renewable energy consumption on economic development under different risk levels.

We select the Organization for Economic Cooperation and Development (OECD) countries as the sample because their appropriate characteristics for the research topic. Renewable energy consumption has become an important driving force for the economic development of OECD countries. Fossil fuel use in OECD countries is gradually decreasing, and the proportion of renewable energy power is gradually increasing. A 2019 International Energy Agency (IEA) report stated that the proportion of renewable energy reached 10.8% of the total primary energy supply of the OECD; this new high was significantly higher than other organizations. The IEA also predicts that by 2035, renewable energy will provide one-third of OECD countries’ total power generation. These countries have a first-mover advantage in the development and use of renewable energy, and have rich experience in developing and coordinating renewable energy consumption and economic growth. This can serve as a reference for other countries' renewable energy industries.

The rest of this article is organized as follows. The next section provides a literature review related to the research topic. Section 3 introduces the data and methods. Section 4 presents the data processing, display, and analysis of results. Section 5 presents the conclusions and recommendations.

2. Literature review

2.1. The relationship between renewable energy consumption and economic development

In the past ten years, the research on the relationship between renewable energy consumption and economic growth has attracted widespread attention. Similar to broader research on energy consumption and economic development, most studies focus on analyzing the causal relationship between the two. Empirical studies have proposed four testable hypotheses in the context of the renewable energy-growth relationship: growth hypothesis, conservative hypothesis, feedback hypothesis, and neutrality hypothesis. First, the growth hypothesis explains the unidirectional causal relationship between renewable energy consumption and economic growth. This shows that an increase in renewable energy consumption will promote economic growth. Second, the conservative assumption explains the one-way relationship from economic growth to renewable energy consumption, which indicates that economic growth determines energy use. Further, when there is a two-way causal relationship between renewable energy consumption and economic growth, the feedback hypothesis is valid. This hypothesis explains that renewable energy affect economic growth; the reverse is also true. Fourth, the neutrality assumption means that there is no causational link between renewable energy consumption and economic growth.

All four hypotheses have been confirmed by empirical literature using different samples. Inglesi found renewable energy consumption positively impacts economic growth. Encouraging renewable energy benefits the environment and the economic development of individual countries [18]. Lau & Lu used panel data of 29 OECD countries from 1990 to 2013 to analyze the impact of renewable energy and non-renewable energy consumption on economic growth. Renewable energy consumption was found to positively impact economic growth, showing the validity of the growth hypothesis [19]. This is also consistent with the findings of Ben and Ben [20].

Bulut and Muratoglu used data from 1990 to 2015, and applied co-integration and causality tests to study the relationship between renewable energy consumption and GDP in Turkey. They found that the causal relationship between renewable energy consumption and GDP is insignificant. This may be because the proportion of renewable energy is too small to have a significant impact on GDP [21]. Ocal and Aslan also studied Turkey's renewable energy and economic development, but reached different conclusions. That article applied the Toda-Yamamoto causality test and ARDL methods to conduct the research; the results verify that the protection hypothesis applies to Turkey's renewable energy consumption and economic growth [12].

Other studies supported the feedback hypothesis [22,23]. Lin and Moubarak found a long-term two-way causal relationship between renewable energy consumption and economic growth. This finding shows that China's economic growth supports the development of the renewable energy industry, helping promote economic growth [22]. Rafindadi and Ozturk used Germany's studied quarterly time series data from 1971 to 2013; causality analysis revealed the feedback effect between renewable energy consumption and economic growth [23].

The literature discussed above indicates that research on the linear relationship between renewable energy consumption and economic development has achieved fruitful results. However, some scholars have found that renewable energy consumption has a non-linear impact on economic development. For example, Tugcu and Topcu used a nonlinear autoregressive distributed lag model, and found a nonlinear cointegration relationship between energy consumption and economic growth, for all energy sources (renewable/non-renewable energy) [24]. Luqman and Ahmad also applied a nonlinear autoregressive distribution lag model and used Pakistan's annual data from 1990 to 2016 to show that renewable energy consumption has an asymmetric positive impact on economic growth [25].

2.2. The impact of country risks on renewable energy consumption and economic development

When studying renewable energy consumption, some scholars have found that traditional research methods do not consider political risk factors, which can lead to biased model estimates. Brunnschweiler reported that renewable energy projects, like other types of investment projects, benefit from overall political stability, a sound regulatory framework, effective governance, and secure property rights [26]. This is similar to research done by Wu and Broadstock [27]. In addition, studies [28–30] have found that corruption and political instability will reduce the rigidity of environmental policies and do not support renewable energy investments. Unfair competition caused by corruption may also be associated with unfair and illegal treatment of foreign investment companies, which may lead investors to hesitate when making investment-related decisions. Therefore, controlling corruption has a positive impact on renewable energy consumption.

Financial risk and economic risk also affect the relationship between renewable energy consumption and economic development. First, both types of risk may directly affect economic development. Many studies have shown that the inability to obtain financing leads to economic gaps and poverty traps [31–33], and the expansion of financial risk can further increase the difficulty of financing, which does not support economic development. Ibrahim and Alagidede conducted empirical research based on sample data from sub-Saharan Africa, reporting a nonlinear relationship between finance and economic development [34]. Financial development and economic growth are significantly positively correlated; however, below a certain estimated threshold, finance is not sensitive to economic growth. The influencing factors of economic risk, such as inflation, can directly affect economic development [34]. Many studies [35–37] have shown that moderate and stable inflation makes it easier for companies to make investment decisions, promoting economic development. In addition, financial risk and economic risk can indirectly affect economic development by affecting renewable energy consumption. For example, when the financial development system continues to improve, financial risk is reduced, and it becomes more convenient to obtain credit. This not only facilitates the ability to obtain investment opportunities and encourages entrepreneurship [38,39], but also increases investments in renewable energy and promotes the implementation of green technologies [15,40]. During economic downturns, conventional economic activities are damaged, unemployment generally increases, and per capita income declines. These events do not support the development of capital-intensive renewable energy projects and adversely affects renewable energy consumption [41,42].

3. Data and methodology

3.1. Variable description

The sample data for this study includes balanced panel data from 1997 to 2015 for 34 OECD countries. The explanatory variable is renewable energy consumption (renewable energy consumption as a percentage of energy consumption); the explained variable is economic development (real per capita GDP, in 2010 constant U.S. dollars) [43]; and the controlled variables include trade opening (the ratio of total import and export to GDP) and the level of urbanization (ratio of urban population to total population). To study the potential different effects of renewable energy consumption on economic development at different country risk levels, we use 4 different risk indexes as threshold variables: the composite risk index, economic risk index, political risk index, and financial risk index.

The country risk index was created from data in The International Country Risk Guide (ICRG). ICRG is considered an authoritative risk rating agency, with many studies using its data to measure country risk levels [44–46]. The guide predicts and analyzes political, financial, and economic risk for 140 countries and regions. The rating results are considered, “the standard that other ratings can refer to.” Of the guide's risks, the political risk index includes 12 components, with a total score range of 0–100. The economic risk and financial risk indexes include 5 components (details on the components are in the Appendix), with a total score range of 0–50. The composite risk score is generated by dividing the total score of the three indexes (political risk, financial risk, and economic risk) by two, with a total score range of 0–100. The composite risk is selected because it is an indispensable part of ICRG's national risk evaluation system. This risk is used to measure the overall national risk, to avoid the disadvantaged of only studying a single factor, and to provide a more extensive evaluation. A lower risk index score is associated with a higher risk level; a higher risk score is associated with a lower risk level. Table 1 shows the symbols, definitions, and data sources of the variables used in the study.

3.2. Methodology

This study applies advanced econometric methods to study the nonlinear impact of country risk on the relationship between renewable energy consumption and economic growth. The method includes the following steps. 1) LLC [47], Fisher-ADF [48], and Fisher-PP [49] are applied to test the stationarity of the selected variables. 2) If these variables are confirmed to be non-stationary, the Kao panel cointegration test [50] method is applied to test whether there is a cointegration relationship. 3) After confirming the presence or absence of a co-integration relationship between variables, the panel threshold model is used to confirm the threshold value and model regression.

3.2.1. Panel unit root tests

To ensure the reliability of the panel threshold effect regression and prevent spurious regression, we first apply the panel unit root test to test whether the data set is a stationary series, before the empirical research. The LLC test is based on the following equation:

$$\varDelta\delta_{uv} = a_u Y_{uv-1} + \sum_{L=1}^{kl} b_{ug} \varDelta Y_{uv-L} + c_{gu} d_{gv} + e_{uv}\ ,\ \mathrm{q} = 1,2,3 \tag{1}$$

where $a_u, c_{gu}, d_{gv}, e_{uv}$ represent the autoregression coefficients of the model; and the corresponding vectors of the regression

Table 1
Symbols, definitions and data sources of research variables.

Symbol	variable	Definition	data source
GDP	Economic development	GDP per capita (constant 2010 US$)	WDI database
RE	Renewable energy consumption	Renewable energy consumption (% of total final energy consumption)	WDI database
COM	Composite risk	Composite assessment of political risk, financial risk and economic risk	ICRG
POL	Political risk	the score of government's stability, social economy, internal and external conflicts, corruption, religious conflicts, and bureaucratic quality and other components.	ICRG
FIN	Financial risk	the score of foreign debt, current account, international liquidity, exchange rate and other components.	ICRG
ECO	Economic risk	the score of GDP, inflation, and national budget and other components.	ICRG
OPEN	Trade openness	Trade (% of GDP)	WDI database
CO2	carbon emission	CO2 emissions (metric tons per capita)	WDI database
UL	Urbanization level	Urban population (% of total population)	WDI database

parameters are q = 1,2,3. The null hypothesis of this test is $a_u = 0$; when P = 0, the variable has a unit root, and if the null hypothesis is rejected, the variable is stationary.

The Fisher-ADF unit root test is shown in Equation (2):

$$\text{Fisher} - \text{ADF} = -2\sum_{m}^{p} \log(Gm) \rightarrow \text{P} \tag{2}$$

The Fisher-PP unit root test is shown in Equation (3):

$$\text{Choi} - \text{ADF} = \frac{1}{\sqrt{T_{m-1}}} \sum_{m-1}^{K} \gamma^{-1}(Gm) \rightarrow \text{K}(0,1) \tag{3}$$

In these expressions, m, γ^{-1} represent the reciprocal of the normal distribution function; and Gm represents the P value of the ADF unit root test. The null hypothesis is that $a_i = 0$ has a unit root; if $a_i < 0$, there is no unit root.

3.2.2. Panel cointegration test

A time series analysis generally requires that the time series be stable; if the time series is not stable, it can lead to a pseudo regression problem. However, the time series in a real economy is usually non-stationary. The time series can be differentiated to make it stable, but this can lead a loss in the total amount of long-term information, which is needed to analyze the problem. Therefore, cointegration is used to address this problem. If the cointegration test is passed, the combination of a set of non-stationary series has a stable equilibrium, and the original equation can be directly regressed based on the original data. With this outcome, the regression result at this time is accurate, and there is no pseudo regression problem. Because the time series of panel data is short, this study applies the Kao panel cointegration test as the co-integration test method.

3.2.3. Panel threshold regression model

There are many structural mutation problems in economic activities, such as the nonlinear relationship between financial constraints and investment decisions. The typical way to address these problems is to add the quadratic term of the explanatory variable, add dummy variables and interaction terms, or artificially divide the group into groups for regression. Taking these actions, however, causes the explanatory variable to be highly collinear with the quadratic term. Dividing group boundaries also leads to biased regression results. To study this structural mutation phenomenon, Hansen proposed a non-dynamic panel threshold model [51]. The advantage of this model is that the user does not need to provide a nonlinear equation when studying the nonlinear relationship between the independent and dependent variable. Instead, the number of thresholds and threshold values are determined by sample data. This approach avoids errors caused by artificially dividing samples, and the difference in regression coefficients can be compared after endogenous grouping, according to the threshold value division interval.

The general process of threshold regression estimation is as follows: randomly select any one of the threshold variables as the threshold value; divide the data into two intervals; and then use the OLS method to estimate the parameter values of these two intervals. The next steps are to calculate the total residual of the two intervals' sum of squares; record the residual sum of squares; select different threshold values; and record the residual sum of squares corresponding to the threshold value. This operation is repeated continuously, comparing the residual sum of squares. The threshold value corresponding to the smallest residual sum of squares is theoretically the optimal threshold value estimate. Based on this, the presence and authenticity of the threshold value must be tested using hypothesis testing, and the threshold effect of this model can be determined after the test is passed.

The specific steps are as follows:

First, a panel threshold model is established to confirm the nonlinear impact of country risks on the relationship between renewable energy and economic development. The basic model is as follows:

$$lnY_{it} = \alpha lnC + \text{ln}\text{X}_{it} + \mu_i + \varepsilon_{it} \tag{4}$$

Based on formula (4), it is first assumed that there is a single threshold effect to establish a single threshold model (5); this is then extended to a double threshold model (6).

$$lnY_{it} = \alpha lnC + \beta_1 \text{lnX}_{it} \cdot \text{I}(\text{q}_{it} \le \gamma) + \beta_2 \text{lnX}_{it} \cdot \text{I}(\text{q}_{it} > \gamma) + \mu_i + \varepsilon_{it} \tag{5}$$

$$lnY_{it} = \alpha lnC + \beta_1 \text{lnX}_{it} \cdot \text{I}(\text{q}_{it} \le \gamma_1) + \beta_2 \text{lnX}_{it} \cdot \text{I}(\gamma_1 < \text{q}_{it} \le \gamma_2) + \beta_3 \text{lnX}_{it} \cdot \text{I}(\text{q}_{it} > \gamma_2) + \mu_i + \varepsilon_{it} \tag{6}$$

In the basic equation, Y_{it} is the explained variable; C is the controlled variable; α is the coefficient of the controlled variable; X_{it} is the core explanatory variable; q_{it} is the threshold variable; γ is the threshold value; and I(*) is the indicator function. Next, the dummy variable is set as $\text{Iit}(\beta) = \{\text{qit} \le \gamma\}$, when $\text{qit} \le \gamma$, I = 1; otherwise, I = 0. The variables $\beta_1, \beta_2, \beta_3$ are the influence coefficients of the explanatory variables on the explained variables when the threshold variables are in different threshold intervals. The variable $\mu_i$represents constant terms; and ε_{it} is random error terms.

For a given threshold γ, the estimated value β of $\widehat{\beta}$ (γ) and the corresponding residual sum of squares can be obtained after estimating the following model:

$$S_n(\gamma) = \widehat{e}(\gamma)'\widehat{e}(\gamma)$$

The variable $\widehat{\gamma}$ corresponds to the smallest residual sum of squares; $S_n(\gamma)$ is the optimal threshold. After determining the estimated threshold value, the corresponding parameter values of the model are determined. After determining the parameter values, the threshold effect is further tested to assess the significance of the threshold effect and the authenticity of the threshold estimated value.

To test the significance of the threshold effect, the hypothesis of the model test is H_0: $\beta_1 = \beta_2$; H_1:$\beta_1 = \beta$, and the following LM statistics are constructed to test the null hypothesis:

$$F_1(\gamma) = \frac{S_0 - S_1\widehat{\gamma}}{\widehat{\sigma^2}}$$

In this expression, S_0 and $S_1\widehat{\gamma}$ are the null hypothesis (no threshold effect) and the residual sum of squares under the condition of the threshold effect, respectively; and $\widehat{\sigma^2}$ is the variance of the threshold regression residuals. Because the threshold value is not identifiable under the null hypothesis, F_1 does not obey the standard asymptotic distribution, and the critical value cannot be obtained.

The Hansen test involves applying the self-sampling method (Bootstrap) to obtain the first-order asymptotic distribution, and then generate the P value. If the P value is less than the significance level, the null hypothesis can be rejected, and the threshold effect is significant at the significance level. In contrast, if the P value is greater than the significance level, it support that the threshold effect is not significant at this level.

Then, the authenticity of the threshold estimate is tested, and the corresponding null hypothesis is: H_0 : $\widehat{\gamma} = \beta_0$. The specific statistics are as follows:

$$LR\gamma = \frac{S_1\gamma - S_1\widehat{\gamma}}{\widehat{\sigma^2}}$$

$S_1\gamma$ is the unconstrained residual sum of squares. At the α level of significance, when:

$$LR\gamma \le C\alpha = -2\ln\left[1 - \sqrt{1-\alpha}\right]$$

The null hypothesis is accepted under the 95% confidence level, with $C\alpha = 7.35$. After the first true threshold is obtained, to determine whether there are double thresholds or other thresholds, the existence of two or more thresholds can be tested in turn until the null hypothesis cannot be rejected. The specific thresholds are then determined. According to one study's non-dynamic threshold regression model [51], and based on the assumption that there is a threshold effect, this study constructs the following threshold regression model to examine the single threshold effect and the double threshold effect of renewable energy consumption on economic development under different country risk levels. The specific models are presented in model (7) and model (8):

$$lnGDP_{it} = \alpha_1 lnOPEN + \alpha_2 lnUL + \alpha_3 lnCO_2 + \beta_1 \mathrm{lnRE}_{it} \cdot \mathrm{I}(q_{it} \le \gamma_1) + \beta_2 \mathrm{lnRE}_{it} \cdot \mathrm{I}(q_{it} > \gamma_1) + \mu_i + \varepsilon_{it} \tag{7}$$

$$lnGDP_{it} = \alpha_1 lnOPEN + \alpha_2 lnUL + \alpha_3 lnCO_2 + \beta_1 \mathrm{lnRE}_{it} \cdot \mathrm{I}(q_{it} \le \gamma_1) + \beta_2 \mathrm{lnRE}_{it} \cdot \mathrm{I}(\gamma_1 < q_{it} \le \gamma_2) + \beta_3 \mathrm{lnRE}_{it} \cdot \mathrm{I}(q_{it} > \gamma_2) + \mu_i + \varepsilon_{it} \tag{8}$$

In these expressions, GDP_{it} is the explained variable, representing the economic development of country i in year t; RE_{it} is the explanatory variable, representing the renewable energy consumption of country i in year t; and $OPEN, UL, CO_2$ are the control variables, representing trade opening, urbanization, and carbon emissions, respectively. The variable q_{it} is the threshold variable; γ_1, γ_2 represents the threshold value of different levels; $\alpha_1, \alpha_2, \alpha_3$ is the coefficient of the control variable; and $\beta_1, \beta_2, \beta_3$ represents the coefficient of the core explanatory variable in different intervals. The variable $I(*)$ is the indicator function; μ_i is the constant term; and ε_{it} is the random error term.

4. Empirical findings

4.1. Panel unit root test

This article applies three unit root test methods: LLC, Fisher-ADF, and Fisher-PP. The panel unit root test is used to test whether the variable is stable [52]. Table 2 shows the test results, and indicates that when only the LLC method is used, the overall risk and political risk are stable at level. The other variables are all non-stationary series at level and cannot be directly regressed. However, after the first-order difference, the results obtained are very significant, indicating that the null hypothesis has been rejected. After the first difference, each group of variables has no unit root. The results of the four test methods are consistent. Therefore, the selected variables can be considered to be stable after the first-order difference.

4.2. Panel cointegration test

The Kao panel cointegration test is a reliable method of testing whether variables have a long-term stable coordination relationship [53]. It is applied in this study to assess the long-term relationship between economic development, renewable energy consumption, national risks, trade openness, urbanization and carbon emissions. Table 3 shows the results of the panel cointegration test, which includes all variables. The figure shows that the null hypothesis is rejected; in other words, in 34 OECD countries, a long-term cointegration relationship has been established between all variables since 1997. This indicates that the regression residuals of the equation are stable, and the regression results are accurate. The next step is to estimate the panel threshold model.

4.3. Threshold effect test

Before estimating the specific threshold of the model, it is necessary to ensure that the sample data has a threshold effect. The threshold model is used to measure the specific threshold. The statistical package Stata16.0 is used to perform a threshold effect test on the sample data (results in Table 4; Table 5). The per capita gross national product (LNGDP) indicates economic development; and composite risk, political risk, economic risk, and financial risk are used as threshold variables for empirical testing. Stata16.0 generated specific F statistics and P values through 300 repeated Bootstrap sampling events (bootstrap method) to determine the

Table 2
Panel unit root test results.

Variable	Test method	At level		At 1st difference		Order of integration
		t-statistic	Prob.	t-statistic	Prob.	
LNGDP	LLC	14.4442	1.0000	−12.6702***	0.0000	I (1)
	Fisher-ADF	3.11177	1.0000	212.208***	0.0000	I (1)
	Fisher-PP	2.12549	1.0000	217.276***	0.0000	I (1)
LNRE	LLC	4.80711	1.0000	−15.4496***	0.0000	I (1)
	Fisher-ADF	24.7123	1.0000	349.851***	0.0000	I (1)
	Fisher-PP	26.3544	1.0000	766.351***	0.0000	I (1)
LNCOM	LLC	−2.29770**	0.0108	−23.1220***	0.0000	I (0)
	Fisher-ADF	52.8249	0.9122	486.082***	0.0000	I (1)
	Fisher-PP	50.9827	0.9387	802.277***	0.0000	I (1)
LNPOL	LLC	−2.80742***	0.0025	−12.3993***	0.0000	I (0)
	Fisher-ADF	61.8681	0.6861	276.647***	0.0000	I (1)
	Fisher-PP	72.4215	0.3343	343.403***	0.0000	I (1)
LNFIN	LLC	0.42100	0.6631	−19.0683***	0.0000	I (1)
	Fisher-ADF	67.6613	0.4888	374.730***	0.0000	I (1)
	Fisher-PP	70.1988	0.4038	497.731***	0.0000	I (1)
LNECO	LLC	1.88391	0.9702	−21.2724***	0.0000	I (1)
	Fisher-ADF	19.1599	1.0000	410.460***	0.0000	I (1)
	Fisher-PP	16.1839	1.0000	1206.92***	0.0000	I (1)
LNOPEN	LLC	18.0873	1.0000	−21.5188***	0.0000	I (1)
	Fisher-ADF	21.3753	1.0000	150.052***	0.0000	I (1)
	Fisher-PP	54.9960	0.8723	102.635***	0.0042	I (1)
LNUL	LLC	5.11864	1.0000	−20.7158***	0.0000	I (1)
	Fisher-ADF	11.8874	1.0000	353.165***	0.0000	I (1)
	Fisher-PP	11.3200	1.0000	570.368***	0.0000	I (1)
LNCO2	LLC	3.2133	1.0000	−18.1031***	0.0000	I (1)
	Fisher-ADF	36.4857	0.9994	371.087***	0.0000	I (1)
	Fisher-PP	31.9192	0.9999	702.997***	0.0000	I (1)

Note: *, **, *** represent significant at 1%, 5%, and 10% inspection levels, respectively. I (0), I (1) respectively represent in levels, first differences stationary of the variables.

Table 3
Kao panel cointegration tests results.

	Statistic	P-value
ADF	2.135955**	0.0163
Residual variance	0.002372	
HAC variance	0.001884	

Note: *, **, *** represent significant at 1%, 5%, and 10% inspection levels, respectively.

threshold value and the number of thresholds for each threshold variable. The F statistic is used to determine whether there is a threshold effect. When the F statistic is significant, the impact of renewable energy consumption on economic development is considered to have a threshold effect. First, the existence of threshold is tested; this includes testing whether there is a significant threshold effect when different variables are used as threshold variables. If there is a single threshold then check the double threshold effect, and if there is no single threshold effect, no threshold regression analysis is required. The resulting threshold existence results are shown in Table 4.

Table 4
Threshold effect test results 1: Existence Test results.

Threshold variable	Threshold test	F	P-value	1% critical value	5% critical value	10% critical value
LNCOM	Single threshold effect	32.930***	0.007	29.172	18.015	11.528
	Double threshold effect	9.292	0.120	27.383	13.692	10.305
LNPOL	Single threshold effect	23.516**	0.020	29.188	15.811	11.283
	Double threshold effect	8.115	0.127	25.850	11.495	9.027
LNECO	Single threshold effect	15.581*	0.060	30.841	16.743	11.667
	Double threshold effect	11.930**	0.010	12.255	3.620	0.258
LNFIN	Single threshold effect	11.835*	0.083	27.904	17.699	10.648
	Double threshold effect	13.273**	0.043	18.425	11.911	9.154

Note: *, **, *** represent significant at 1%, 5%, and 10% inspection levels, respectively.

Table 5
Threshold effect test results 2: Authenticity Test.

Threshold variable	Threshold number	Threshold value	95% confidence interval
LNCOM	Single threshold	4.109	[4.109, 4.117]
LNPOL	Single threshold	4.205	[4.204, 4.205]
LNECO	Single threshold	3.656	[3.302, 3.670]
	Double threshold	3.702	[3.418, 3.768]
LNFIN	Single threshold	3.480	[3.401, 3.670]
	Double threshold	3.552	[3.546, 3.560]

The test results show that when renewable energy consumption is used as the core explanatory variable and composite risk is used as the threshold variable, the single threshold F statistic of LNCOM is 32.930, which is greater than the 1% significance level critical value of 29.172. The single-threshold test is significant at the 1% level; that is, it passes the single-threshold test with a threshold value of 4.109. The double-threshold F statistic is 9.292, which is less than the 10% significance level critical value of 10.305. This means the double-threshold effect test failed. Similarly, when political risk is used as a threshold variable, the LNPOL single threshold F statistic is 23.516, which is greater than the critical value of 15.811 at the 5% significance level. This means it passes the single threshold test with a threshold value of 4.205. The double-threshold F statistic is 8.115, which is less than the critical value of 9.027 at the 10% significance level. As such, it does not pass the double-threshold test.

When economic risk is used as a threshold variable, the LNECO single threshold F statistic is 15.581, which is greater than the critical value of 11.677 at the 10% significance level; that is, it passes the single threshold test. The double threshold F statistic is 11.930, which is greater than the critical value of 3.620 at a 5% significance level. As such, it passes the double threshold test, the two thresholds are 3.656 and 3.702, respectively. Similarly, when financial risk is used as a threshold variable, it also passes the double threshold test with thresholds of 3.656 and 3.702, respectively.

4.4. Analysis of threshold effect regression results

After obtaining the threshold value of each variable, we further analyze the threshold effect of renewable energy consumption on economic development using the risk threshold interval of different countries. Table 6 shows the specific regression results.

The first step in the analysis is to consider the parameter estimation result of composite risk (LNCOM), which reflects the overall risk setting using country risks as the threshold variable. The LNCOM column in Table 6 shows the test result of the single threshold effect model. When the composite risk of the sample is less than the threshold value of 4.109, the estimated coefficient of renewable energy consumption on economic development is 0.0115; the overall risk of the country is high. Renewable energy consumption promotes economic development, but this effect is not significant. When the threshold value is exceeded, the estimated coefficient of the impact of renewable energy consumption on economic development is 0.0863. This indicates that, when the country's overall risk is stable, the role of renewable energy consumption in promoting economic development increases. In other words, the impact of renewable energy consumption on economic development is affected by the overall stability of the country. Countries with lower overall risk have a more stable national environment, where more renewable energy consumption will promote economic development. The impact of renewable energy consumption on economic development is not significant when the overall risk of the country is high. This may be due to the fact that when country risk is high, economic and social instability causes little willingness for industrial production, and the control of risk may impose additional costs and regulatory burdens on the government, the higher the economic cost required to develop renewable energy. As the risk decreases, business expectations of the aftermath increase and national policies become more willing to shift to the green economy, the renewable energy sector will attract an inflow of capital and technology, which will lead to a further reduction in the cost of renewable energy and significantly increase the support of renewable energy for economic development.

Table 6
Threshold effect regression results.

Variable	Threshold variable			
	LNCOM	LNPOL	LNECO	LNFIN
LNRE($\mathbf{q}_{it}$<γ1)	0.0115	0.0204	−0.0193***	−0.0183***
	(0.56)	(0.96)	(-4.42)	(-3.19)
LNRE($\mathbf{q}_{it}$≥γ1)	0.0863***	0.0892***		
	(5.45)	(5.59)		
LNRE(γ1<$\mathbf{q}_{it}$≤γ2)			0.106***	0.105***
			(6.47)	(6.41)
LNRE($\mathbf{q}_{it}$>γ2)			−0.0223***	−0.0242***
			(-4.51)	(-4.78)
LNOPEN	0.464***	0.472***	0.460***	0.465***
	(13.12)	(13.23)	(12.74)	(12.99)
LNUL	0.145	0.377**	0.397**	0.315*
	(0.85)	(2.25)	(2.36)	(1.87)
LNCO2	0.300***	0.333***	0.356***	0.351***
	(6.63)	(7.38)	(7.74)	(7.73)
constant	6.851***	5.742***	5.652***	6.007***
	(9.53)	(8.21)	(8.09)	(8.57)
$\mathbf{R}^2$	0.439	0.430	0.434	0.432

Note: *, **, *** represent significant at 1%, 5%, and 10% inspection levels, respectively.

Second, when political risk (LNPOL) is used as the threshold variable, the regression results show that the impact of renewable energy consumption on economic development is consistently positive during the sample period. However, the positive impact is greater when the political risk is higher than the threshold. When the political risk is lower than the threshold of 4.205, a 1% increase in renewable energy consumption promotes economic growth by 0.0204%. When the economic risk exceeds the threshold, a 1% increase in renewable energy leads to a 0.0892% increase in economic development. This shows that improving the political risk situation stimulates an increase in renewable energy consumption, reducing the economic cost of renewable energy development. This view is consistent with a previous study [54], who argue that a 1% improvement in the political risk profile increases the consumption of renewable energy by 0.025%. The improvement in political stability and institutional quality will eventually increase the use of renewable energy, further leading to an increase in economic efficiency. A stable political environment contributes to the continuity of environmental protection policies; the policy-driven nature of the renewable energy industry causes this effect to deepen. A more stable political environment also supports the voice of democracy, and the government's initiative to support the renewable industry can be enhanced by citizens freely expressing their environmental expectations. Corruption, on the other hand, undermines the establishment of strong laws that prevent projects having a negative impact on the environment. In corrupt environments, these projects crowd out the renewable energy development market [29]. This increases the economic cost of developing renewable energy. Moreover, corruption will directly threaten economic development, by exploiting public finances and reducing market efficiency.

Third, the two thresholds of economic risk (LNECO), 3.656 and 3.702, are used to divide the sample countries into three levels: high risk, medium risk, and low risk. Under different economic risk levels, the impact of renewable energy consumption on economic development is significantly different. Below the first threshold, the estimated coefficient of renewable energy consumption on economic development is −0.0193. In other words, when the economic risk is high, renewable energy consumption inhibits economic development. When the economic risk is higher than the first threshold, but lower than the second threshold of 3.702, the effect coefficient of renewable energy consumption on economic development is 0.106. This indicates that the economic risk is at a medium level. In this scenario, the impact of renewable energy consumption on economic development has changed from being inhibited to being promoted. When the economic risk exceeds the second threshold, the estimated coefficient of the impact of renewable energy consumption on economic development is −0.0223. This result shows that the consumption of renewable energy positively impacts economic development only when the economic risk is moderate. If the economic risk is too high or too low, the risk will have a negative impact. First of all, high economic risk does not support investments in renewable energy, because few investors are willing to invest in capital-intensive industries when the risks are higher than expected. An unstable economic environment will also cause low social productivity. These do not support economic development. When risks are too low, investment opportunities will decrease in an overly stable economic environment, and the potential for economic development is limited. Moderate economic risk generally occurs during the rising period of economic development, which provides a relatively stable economic environment, and fully releases economic vitality. This helps maximize the role of renewable energy consumption in promoting economic development.

Finally, when financial risk (LNFIN) is used as the threshold variable, the parameter estimation results show that the sample is also divided into three levels. When the financial risk is below the first threshold, the consumption of renewable energy has a restraining effect on economic development. When the financial risk exceeds the first threshold and is lower than the second threshold, the impact of renewable energy consumption on economic development is positive; for every 1% increase in renewable energy consumption, economic development increases by 0.105%. When the financial risk exceeds the second threshold, the impact coefficient of renewable energy consumption on economic development becomes negative again, with an elasticity coefficient of −0.0242. Similar to economic risk, moderate financial risk helps ensure moderate financial stability and makes the financial system more flexible. In this scenario, renewable energy consumption can promote economic development; otherwise, it has a negative effect. In summary, when the level of risk is at different levels, the countermeasures needed are different. When the financial risk is high, measures should be taken to reduce the financial risk. When the financial risk is low, corresponding policies should be adjusted; the rigidity of policies should be changed; and the flexibility of risk control measures should be improved. When the financial risk is between the first threshold and the second threshold, the financial risk is a medium level. This facilitates the positive impact of renewable energy consumption on economic growth. The intensity of risk control policies can be maintained or minor adjustments can be made. Finance, whether it is financial stability or financial development, is critical to developing renewable energy. This is because the financial market plays a vital role in the financing of renewable energy projects. As such, the quality of financial development has a profound impact on the renewable energy industry; a stable financial system is a prerequisite for renewable energy investment. The development of renewable energy is inseparable from financial support. Renewable energy projects have high upfront capital costs and require a significant initial investment to start production [55]. In terms of continuous innovation and research investment, continuous capital support is also needed to enable clean energy technology for long-term development and substantive breakthroughs. This contributes to national economic development.

5. Conclusions and recommendations

With the increasing severity of global climate change and an increasing awareness about environmental protection, renewable energy has the potential to gradually replace traditional energy. An increasing number of studies have focused on the relationship between renewable energy consumption and economic development. However, past studies on the relationship between the two have not considered country-level risk factors. To fill this gap, this study applied a panel threshold model to analyze the panel data sets of OECD countries from 1997 to 2015.

The results provide evidence of the nonlinear impact of renewable energy consumption on economic development under different country risks (composite risk, political risk, financial risk, and economic risk). The impact of renewable energy consumption on economic development differs within different threshold intervals of different country risks. In general, renewable energy consumption promotes economic development. According to the composite risk indicator, measuring overall country risks, the impact of renewable energy consumption on economic development is affected by the country's composite risk. Countries with a lower composite risk have a more stable environment, and renewable energy consumption has a greater promotional effect on economic development.

Similarly, a stable political environment helps renewable energy consumption play a larger role in promoting economic development. In countries with higher political risk, every 1% increase in renewable energy consumption promotes economic growth by 0.0204%. In countries with low political risk, a 1% increase in renewable energy leads to a 0.0892% increase in economic development. In contrast with the single threshold effect associated with the first two risks, both financial risk and economic risk pass the dual threshold test. The two thresholds divide the risk levels into high risk, medium risk, and low risk. The empirical results of the panel threshold model show that when economic and financial risk thresholds are used, the impact of renewable energy consumption on economic growth exhibits an inverted U shape: when the risk is low or high, renewable energy has a negative impact on economic growth; when the risk is moderate, renewable energy has a positive effect on economic growth.

This conclusion indicates that the positive impact of renewable energy consumption on economic growth is conditional. To play an important role of renewable energy consumption in the economic growth, economic and financial risks must be held at a medium-risk level. The specific countermeasure is that policymakers should formulate policies consistent with the development stage of national risks based on ICRG economic risk and financial risk data, and fully consider the complexity of the impact of economic risks and financial risks on the relationship between renewable energy and economic growth. Risk control measures need to be both soft and hard to avoid results that conflict with the policy starting point, due to the adoption of a single policy. It is also important to appropriately adjust risk control measures to control risk indicators within the medium risk threshold.

The conclusions above lead to the following recommendations. Our results show that in general, renewable energy consumption positively impacts economic development. It is important that the government plan an energy transition strategy, because developing renewable energy under appropriate conditions can improve environmental conditions and benefit the macro economy. In addition, country risks play an important role in the relationship between renewable energy and economic development, and the direction and extent of the impact of renewable energy on economic development depends on the level of different types of country risks, so policy makers should consider country risk factors when developing renewable energy policies. It is also important to improve composite risks and the political risk index because countries with more stable social order and low levels of corruption are more likely to attract investments by high-quality multinational companies. The overflow effect of foreign capital can advance technical progress and upgrade industrial structures, helping to increase renewable energy consumption and encourage green economic growth. Therefore, it is necessary to establish a long-term corruption prevention and monitoring mechanism, improve government credibility and ensure policy implementation, which is crucial for the development of the new energy industry. Furthermore, the government should focus on stimulating market vitality, while maintaining the smooth operation of the economy and financial stability. When the risk is too high, the policy authorities should adjust corresponding currency and fiscal policies according to the situation, control the inflation rate, and prevent harmful levels of inflation. It is also important to improve the construction of financial market systems, advance the financial marketization process, and improve the efficiency of financial market operations. When the risk is too low, the government should adopt cuts in the reserve requirement ratio (RRR) or interest rates to fully release liquidity, improve the quality of foreign debt, and encourage banks to develop green credit and protect the responsible financing needs of renewable energy companies.

Author contribution statement

Qiang Wang: Conceptualization, Methodology, Software, Data curation, Writing – original draft, Supervision, Writing- Reviewing and Editing. Zequn Dong: Methodology, Software, Data curation, Investigation Writing- Original draft, Writing- Reviewing and Editing. Rongrong Li: Conceptualization, Methodology, Software, Data curation, Writing – original draft. Lili Wang: Methodology, Investigation Writing- Original draft, and Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix. Risk components and scores of ICRG risk rating

Country risks and its components	Points (max.)
(I) Political risk	**100**
Government Stability	12
Socioeconomic Conditions	12
Investment Profile	12
Internal Conflict	12
External Conflict	12
Corruption	6
Military in Politics	6
Religious Tensions	6
Law and Order	6
Ethnic Tensions	6
Democratic Accountability	6
Bureaucracy Quality	4
(II) Financial risk	**50**
Foreign Debt as a Percentage of GDP	10
Exchange Rate Stability	10
Foreign Debt Service as a Percentage of Exports of Goods and Services	10
Current Account as a Percentage of Exports of Goods and Services	15
Net International Liquidity as Months of Import Cover	5
(III) Economic risk	**50**
GDP per Head	5
Real GDP growth	10
Annual Inflation Rate GDP	10
Budget Balance as a Percentage of GDP	10
Current Account as a Percentage of GDP	15

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