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Can Financial Development Promote Renewable Energy Transition? An Empirical Research Based on Global Panel Data

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Abstract

Faced with increasingly severe global environmental and energy challenges, promoting the transition to renewable energy is of paramount importance. Based on the panel data of 167 countries spanning the period from 2000 to 2020 and employing the dynamic panel model, this paper empirically investigates the impact of financial development on renewable energy transition. The results indicate that from a global perspective, overall financial development does not exert significant influence on renewable energy transition. Among the sub-indicators of financial development, only the depth of the financial institution shows a significantly positive effect at the 10% level, while the others are not statistically significant. Sub-sample regression analysis reveals that, for countries with lower development levels, financial development has a significantly negative impact on renewable energy transition, whereas for countries with higher development levels, the impact is not significant. This indicates notable country-specific differences in the influence of financial development on renewable energy transition. It is recommended that countries formulate differentiated financial support policies tailored to their respective development stages to promote the transition to renewable energy.

Keywords: financial development; renewable energy transition; global perspective; country heterogeneity; dynamic panel model

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1. Introduction

Currently, the increasingly severe global environmental and energy issues have become core challenges restricting sustainable development. With the acceleration of industrialization and the continuous expansion of human activities, greenhouse gas emissions continue to rise. Global carbon emissions have reached a historical high, triggering a series of ecological crises such as climate change, frequent extreme weather events, and rising sea levels, which seriously threaten the human living environment and the balance of ecosystems. Meanwhile, over-reliance on traditional fossil fuels not only exacerbates environmental pollution but also exposes the vulnerability and instability of energy supply, with energy security issues becoming increasingly prominent. Fossil fuels still dominate the energy consumption structure, and factors such as the risk of resource depletion, price fluctuations, and geopolitical conflicts further intensify the uncertainty of the global energy system. Against this backdrop, promoting the optimization of the energy structure, reducing carbon emissions, enhancing energy efficiency, and ensuring energy supply security have become urgent tasks facing the international community. Achieving a green,

low-carbon, and sustainable energy transition is not only a critical path to addressing climate change but also a strategic choice to safeguard global energy security and promote high-quality economic development.

To address the increasingly severe environmental and energy challenges, numerous scholars have conducted extensive and in-depth research from multiple dimensions in an effort to explore effective solutions. Related studies cover a wide range of fields, including industrial restructuring, technological innovation pathways, and energy policy design, yielding a wealth of theoretical achievements and empirical evidence. Through theoretical discussions, empirical analyses, and case studies, scholars have explored issues such as effective means of energy conservation and emission reduction, pathways for improving energy efficiency, and diffusion mechanisms of clean energy technologies, providing important references for policy formulation.

Among the numerous coping strategies, the development of renewable energy stands as one of the vital options. Renewable energy has garnered increasingly widespread attention due to its notable advantages of being clean, low-carbon, and sustainable. During the utilization process, renewable energy sources such as solar, wind, and hydro energy generate almost no greenhouse gas emissions, effectively mitigating environmental pollution and climate change issues caused by the combustion of fossil fuels. Meanwhile, renewable energy resources are widely distributed and possess the potential for localized development and utilization, which helps reduce dependence on imported fossil fuels and enhances the autonomy and security of a nation's energy supply. Furthermore, with technological advancements and the manifestation of scale effects, the power generation costs of renewable energy have continued to decline, and its economic competitiveness has been constantly strengthening, laying the foundation for its large-scale promotion and application. Therefore, advancing the transition to renewable energy is regarded as an important pathway to achieve sustainable development goals and ensure energy supply security [1]. In recent years, a large number of scholars have conducted in-depth research on the influencing factors of renewable energy transition, exploring the mechanisms of various factors such as urbanization, environmental regulation, and technological innovation.

Among all these factors, financial development is considered a crucial supporting force for promoting the transition to renewable energy. The renewable energy industry, as a typical capital-intensive and technology-intensive emerging sector, highly relies on sustained, stable, and substantial capital investment for its development [2–4]. From technology research and development, equipment manufacturing, to project construction and operation and maintenance, the entire industrial chain faces high upfront investment costs and long investment payback periods [5,6]. Moreover, renewable energy projects often exhibit strong externalities and public-good characteristics, making it difficult for market mechanisms to fully capture their social benefits, which results in insufficient willingness of private capital to participate. Coupled with the rapid technological iteration in the industry, projects face dual risks of technological obsolescence and market volatility, further increasing financing difficulties [7]. Therefore, a sound financial system, diversified financing channels, and effective risk-sharing mechanisms are of paramount importance for alleviating financing constraints, reducing capital costs, and thereby promoting the development of the renewable energy industry [8,9]. Actually, many scholars have discovered empirical evidence that financial development can increase the consumption of renewable energy.

Although the existing literature has confirmed from multiple dimensions that financial development significantly promotes renewable energy consumption, this does not necessarily imply the optimization of the energy structure. Against the backdrop of continuously rising energy demand, the expansion in the allocation of financial resources may not only drive the growth of investment in and consumption of renewable energy but also further

expand the consumption scale of fossil fuels by supporting high-energy-consuming industries and traditional energy infrastructure construction, thereby resulting in the concurrent phenomenon of "dual increases" in the consumption of renewable and traditional energy. At this juncture, even if the absolute increase in renewable energy rises, if its growth rate is insufficient to offset or replace the inertial expansion of fossil fuel consumption, a structural paradox of "increment failing to outweigh the existing stock" may emerge, leading to a failure to optimize the energy structure and even generating negative impacts. Therefore, relying solely on the development of the financial sector to promote renewable energy consumption does not necessarily lead to an improvement in the energy structure. Compared to the absolute increase in renewable energy consumption, the rise in its proportion within the energy structure holds greater practical significance, as it signifies enhanced substitution of traditional energy by renewable energy, reduced reliance on fossil fuels, lower carbon emissions, more effective promotion of the transition to green and low-carbon energy, and the achievement of sustainable development goals.

The existing research primarily focuses on the marginal effects of financial development on the scale of renewable energy consumption, with relatively limited discussion on its ability to drive structural transformation, and no unified conclusion has yet been reached.

Therefore, this paper attempts to examine the impact of financial development on renewable energy transition, based on global panel data and the dynamic panel model, aiming to make a certain marginal contribution to the research in this field. The remaining sections of this paper are organized as follows: Section 2 provides a literature review, sorting out relevant theoretical and empirical studies on the impact of financial development on renewable energy. Section 3 introduces the research hypotheses, model selection, and data sources. Section 4 presents the empirical results and related discussions. Section 5 offers the research conclusions and policy recommendations of this paper.

2. Literature Review

In this section, we systematically review the relevant research on renewable energy. In Section 2.1, we review the literature on the influencing factors of renewable energy. Subsequently, we focus on studies examining the impact of financial development on renewable energy. Regarding this topic, scholars typically conduct research from either a "quantity" or a "structure" perspective, that is, the impact of financial development on renewable energy consumption or the renewable energy transition. Therefore, in Sections 2.2 and 2.3, we respectively review the relevant literature on the impact of financial development on renewable energy from quantity and structure perspectives. In Section 2.4, we provide a critique of the existing literature.

2.1. Influencing Factors of Renewable Energy

With numerous advantages such as being clean and environmentally friendly, abundant in resource reserves, and widely distributed, renewable energy has become a research hotspot in the global energy sector in recent years. Numerous scholars are committed to exploring the driving factors of renewable energy development, aiming to identify the key influencing variables and provide theoretical support for accelerating the development and utilization of renewable energy. Currently, a substantial amount of research has indicated that renewable energy is subject to the influence of numerous factors, including but not limited to trade openness, economic growth, and foreign direct investment (FDI).

For instance, Huang et al. [10] delved into the specific impacts of trade, environmental degradation, and governance on renewable energy consumption, and revealed that the expansion of trade scale, the intensification of environmental degradation, and the acceleration of urbanization had all exerted negative effects on renewable energy consumption,

leading to a decline in its usage. Conversely, an increase in foreign direct investment and an improvement in governance quality have significantly promoted renewable energy consumption, providing positive impetus for the development of renewable energy. Rahman and Raeisi Sarkandiz [11] discovered that foreign direct investment and the regulatory quality index exerted negative effects on renewable energy consumption. Conversely, the progress in urbanization and the increase in per capita GDP (Gross Domestic Product) significantly spurred the growth of renewable energy consumption, reflecting the positive demand for renewable energy arising from economic development and the urbanization process. Osińska et al. [12] found that key variables such as per capita carbon dioxide emissions, terms of trade, GDP, and foreign direct investment exhibited significant differences in their impacts on renewable energy consumption across countries at varying stages of development.

In addition, other scholars [13–17] have also explored the influencing factors of renewable energy from different perspectives. These studies have laid the foundation for understanding the internal mechanisms of renewable energy development and provided important references for subsequent in-depth discussions on the role of financial development.

2.2. The Impact of Financial Development on Renewable Energy Consumption

In recent years, an increasing number of scholars have found that financial development may be a crucial factor in promoting renewable energy consumption. By alleviating financing constraints and reducing investment risks, financial development effectively fosters the development of the renewable energy industry [18–20]. A series of empirical research conclusions support this assertion [21–25]; for instance, Brunnschweiler [26] discovered that the expansion of the banking industry had a significantly positive impact on the total output of renewable energy, with a particularly prominent promoting effect on non-traditional hydropower fields such as wind and solar energy. Ngcobo and De Wet [27] indicated that financial development demonstrated a statistically significant positive effect on South Africa's renewable energy supply in both the long term and short term. Mukhtarov and Mikayilov [28] showed that financial development played a crucial role in Poland's energy transition.

However, some scholars also argued that the promoting effect of financial development on renewable energy was limited [5,7,29]. Renewable energy projects typically require substantial initial investments, have long payback periods, and are associated with relatively high risks. Due to risk-control considerations, financial institutions tend to allocate more resources to the well-developed and risk-controllable traditional energy sectors, creating a "crowding-out effect" that restricts capital allocation to renewable energy. Some empirical studies indicated that financial development does not promote renewable energy consumption and may even have a negative impact [30–32]. For instance, Van Nguyen [33] found that financial development did not promote renewable energy consumption but instead had an inhibitory effect. Jiang et al. [34] showed that although financial development theoretically should promote the development of renewable energy, it showed an inhibitory effect on renewable energy production in the BRICS country sample.

In summary, the research on the impact of financial development on renewable energy consumption is relatively well-established. From the perspective of results, although several scholars hold negative views, the majority believe that financial development can promote renewable energy consumption. In terms of research samples, relevant empirical studies cover individual countries, regional organizations, and the global context, with a wide range of sample selections that are highly representative.

2.3. The Impact of Financial Development on Renewable Energy Transition

Compared to research on renewable energy consumption, studies on the impact of financial development on renewable energy transition are relatively scarce, and the conclusions drawn are inconsistent [35–37]. For instance, Ullah et al. [38] discovered that financial development had a long-term and stable positive effect on the renewable energy transition of G-7 countries, revealing the crucial role of the financial sector in promoting the optimization of the energy structure. However, Zhou et al. [39] considered that the existing financial system might still be biased towards the traditional energy sector in resource allocation; therefore, financial development did not promote energy transition but instead exhibited a negative correlation with it. The empirical study by Huang and Uddin [40] also arrived at similar conclusions. Additionally, some scholars argue that the impact of financial development on renewable energy transition exhibits complexity. For instance, Olaniyi et al. [41] found that there existed a threshold effect in the impact of financial development on renewable energy transition, Zhang et al. [42] argued that there were variations in the allocation efficiency of financial resources across countries with different income levels and across different time periods.

In summary, the research on the impact of financial development on renewable energy transition is relatively scarce, and the conclusions are notably controversial, indicating significant uncertainty regarding whether financial development can effectively drive the transition to renewable energy. In terms of research samples, relevant empirical studies primarily focus on individual countries and regional organizations, such as China, the Association of Southeast Asian Nations (ASEAN), and African countries.

2.4. Comment and Discussion

From the existing literature, when it comes to the impact of financial development on renewable energy, most scholars choose to analyze, from a "quantity" perspective, the influence of financial development on renewable energy consumption. The conclusions drawn are relatively consistent, and the studies cover a wide range in terms of sample selection and methodological approaches. Conversely, there is relatively limited research examining, from a "structural" perspective, the impact of financial development on renewable energy transition, and the conclusions are controversial.

Research on the impact of financial development on renewable energy from a "structural" perspective holds significant practical implications. An increase in the proportion of renewable energy within the total energy mix can more directly reflect the depth of energy structure transformation and the progress of decarbonization. The absolute increment in renewable energy consumption merely indicates new installed capacity or power generation, which may be diluted by the overall growth in energy demand, and fails to demonstrate whether fossil fuels are being effectively replaced. In contrast, a rise in proportion signifies an enhanced relative position of renewable energy within the energy system, indicating its systematic substitution for fossil fuels and driving the overall energy system towards low-carbon evolution. From the perspective of energy security, an increased proportion enhances the stability and autonomy of energy supply, reduces reliance on imported fossil fuels, and mitigates the risks of energy supply disruptions caused by factors such as fluctuations in the international energy market and geopolitical tensions.

Based on the existing literature, research on the impact of financial development on renewable energy transition still has room for expansion in three aspects: Firstly, in terms of sample selection, most scholars have focused on individual countries or regional organizations as research subjects in studies concerning renewable energy transition, with a relative lack of research from a global perspective. Research based on a global perspective can provide more empirical evidence at the overall level, further revealing the universal

laws concerning the global financial system and energy transition. Secondly, the majority of studies employ a single or a small number of indicators to measure financial development at the macro level. For instance, many scholars have used "domestic credit to the private sector (% of GDP)" or "total value of traded stocks (% of GDP)". These indicators are relatively easy to obtain and publicly transparent, with clear meanings. However, a single indicator typically captures only one aspect of financial development and may overlook differences in financial structures. Therefore, the selection of financial development indicators needs to fully consider their representativeness and multidimensionality to more accurately reflect the connotations and structures of financial development. Finally, the existing research mostly focuses on the overall effects of financial development. Given the differences in factors such as economic development levels and institutional environments among countries, the pathways and effects of financial development on energy transition may vary. Therefore, research on country-specific differences from an international perspective needs to be deepened.

Therefore, this paper attempts to examine the impact of financial development on renewable energy transition from a global perspective, while also paying attention to the multidimensional characteristics of financial development and the heterogeneous manifestations among countries at different development stages. The main research features and contributions of this paper are as follows: Firstly, this paper selects panel data from 167 countries to construct a large-sample cross-country empirical model, examining the macro impact of financial development on renewable energy transition from a global perspective. This research design facilitates an intuitive and comprehensive understanding of the overall impact trend of financial development on renewable energy transition. Secondly, this paper utilizes the financial development indicator system constructed by Svirydzenka [43] to analyze whether financial structure has differentiated impacts on renewable energy transition. This indicator system is divided into three tiers and includes nine specific indices, measuring the level of financial development from multiple dimensions. Finally, based on sub-sample groupings according to comprehensive development levels and income levels, this paper investigates the country-specific heterogeneity in the impact of financial development on renewable energy transition, thereby identifying the boundary conditions for policy effects and providing empirical evidence for formulating differentiated green finance policies.

3. Research Hypotheses, Methodology, and Data

3.1. Research Hypotheses

Based on a theoretical analysis and empirical research of the existing literature, this paper proposes the following research hypotheses:

Hypothesis 1. *Financial development has no significant impact on renewable energy transition.*

Financial development does not solely exert its influence on the renewable energy sector; it may also have a notable positive impact on the traditional fossil fuel industry. Since financial development promotes both traditional and renewable energy sources, the consumption of both types of energy may increase simultaneously under the impetus of financial development. In this scenario, the proportion of renewable energy consumption in total energy consumption does not change significantly due to financial development. Secondly, in cross-country macro research, it is challenging to account for the impact of financial development on renewable energy transition in each economy, as the positive and negative effects across different countries may offset each other. Lastly, the impact of financial development on renewable energy transition may be altered by other influencing

factors. Without considering these factors, financial development may not have a positive impact on renewable energy transition. Therefore, this paper posits that, on the whole, financial development does not have a significant impact on renewable energy transition.

Hypothesis 2. *In terms of financial structure, there is no significant difference in the impact of financial development on renewable energy transition.*

From the perspective of financial structure, the financial sector primarily comprises financial institutions and financial markets. Whether it is a banking-centered financial institution system or a capital market-dominated financial market system, despite differences in specific business scopes and financing models, there are no fundamental disparities between the two in terms of business objectives, risk appetite tendencies, and capital allocation orientations. Therefore, this paper argues that neither financial institution nor financial market has a significant impact on renewable energy transition.

Hypothesis 3. *There exist country-specific heterogeneous characteristics in the impact of financial development on renewable energy transition.*

For countries with a high level of development, their financial sectors are relatively mature, and a substantial amount of financial resources has already been preferentially allocated to the existing green assets. This results in a limited role for financial development in further enhancing the proportion of renewable energy consumption. Consequently, financial development may not have a significant impact on renewable energy transition in these countries. In contrast, for countries with a low level of development, their financial systems are still imperfect. Due to risk aversion and considerations of short-term returns, the financial sector is more inclined to invest significant funds in traditional energy industries rather than in the renewable energy sector, leading to a decrease in the proportion of renewable energy. Therefore, this paper posits that there are country-specific heterogeneous characteristics in the impact of financial development on renewable energy transition.

3.2. Methodology

To investigate the impact of financial development on renewable energy transition, this paper employs a dynamic panel model for analysis. Compared with traditional static panel models, the dynamic panel model takes into account the influence of lagged terms of the dependent variable, enabling it to better capture the dynamic behavioral characteristics of individuals and reflect the continuity and changes in variables over time. By introducing a lagged term, the model can more accurately identify the causal relationships between variables, thereby enhancing its explanatory power and predictive accuracy. Drawing on the research of relevant scholars [44–48], the dynamic panel model constructed in this paper is as follows:

$$RET_{it} = \alpha + \beta_0 RET_{it-1} + \beta_1 FD_{it} + \gamma Control_{it} + \mu_i + \varepsilon_{it} \quad (1)$$

In the equation, RET represents the renewable energy transition; RET_{it-1} denotes the lag term of renewable energy transition; FD is the core explanatory variable financial development, and in the following text, it serves as a comprehensive indicator of financial development in some sections and as a sub-indicator of financial development in others; $Control$ denotes a series of control variables, including urbanization, economic growth, and foreign direct investment; α represents the intercept term; β_0, β_1, and γ denote the coefficients of the lag term of renewable energy transition, financial development, and the control variables, respectively; μ_i is the unobserved country-specific effect; ε_{it} indicates the residual term; and i and t represent the country and year, respectively.

Since the dynamic panel model includes lagged terms of the dependent variable, if traditional static panel model estimation methods such as fixed effect or random effect are employed, the lagged explained variable will be correlated with individual effect and error term, leading to biased and inconsistent estimation results, and thus making it impossible to obtain valid estimates. For instance, it may underestimate or overestimate the long-term impact of financial development on the renewable energy consumption transition. To address potential endogeneity issues, this paper uses the System GMM (Generalized Method of Moments) for model estimation [49–51]. This method effectively resolves the endogeneity problem in the dynamic panel model, especially the correlation between the lagged term of the explained variable and the error term, by constructing instrumental variables. Compared with traditional static panel models, the System GMM method utilizes information from both the level and difference equations, controlling for individual fixed effects while preserving dynamic characteristics, and enabling accurate identification of long-term equilibrium relationships. Its over-identification tests and autocorrelation detection functions ensure the consistency and validity of the estimators, making it suitable for analyzing the inter-temporal impact mechanism of financial development on the renewable energy transition.

3.3. Data

3.3.1. Financial Development

Financial development is a multi-dimensional and abstract concept. Its connotation is not merely confined to the simple expansion of credit scale or the growth in the number of financial institutions, but also encompasses multiple aspects such as the deepening of financial markets, the optimization of institutional structures, and the improvement in resource allocation efficiency. Therefore, accurately measuring the level of financial development is an important yet highly challenging issue. In relevant empirical research, scholars typically employ a single indicator or a set of indicators as proxy variables for financial development [8,52–55]. For instance, the indicator "Domestic credit to the private sector (% of GDP)" has been widely used by scholars. Given the rich connotation and complexity of financial development, this paper adopts the indicator system constructed by Svirydzenka [43] as proxy variables for financial development.

This indicator system comprises nine specific indices categorized into three levels. The primary indicator is the Overall Financial Development (FD), which measures a country's financial development level from the most macro perspective. The secondary indicators are the Financial Institution (FI) and the Financial Market (FM), which measure the level of financial development from the perspectives of the financial institution and the financial market, respectively. The tertiary indicators are FID, FIA, FIE, and FMD, FMA, FME, which measure the depth, access, and efficiency of the financial institution and the financial market, respectively. More detailed information about the indices can be obtained by referring to the original literature.

This indicator system offers the following advantages: Firstly, it not only encompasses the depth of financial development but also takes into account the accessibility and efficiency of the financial sector, providing a more comprehensive assessment of financial development. Secondly, the dataset covers samples from over 180 countries, with data continuously updated in recent years, enabling the maximum expansion of the sample size and thereby enhancing the universality of the empirical conclusions. Thirdly, the raw data used in constructing the indicator system are sourced from authoritative databases such as the World Bank Database and the International Monetary Fund (IMF) Database, and standardized and transparent statistical methods are employed during the index construction process, ensuring the robustness and reliability of the indices to the greatest extent possible.

Specifically, compared with the commonly used financial development indicator "domestic credit to the private sector (% of GDP)", the IMF's indicator system has distinct advantages: The composite indicators within this system are calculated using a series of raw indicators, enabling a more precise reflection of the rich connotations of financial development. Meanwhile, this indicator system includes sub-indicators of financial development, allowing us to study the impact of financial development on renewable energy transition from the perspective of financial structure. Additionally, the author employs relevant statistical methods to reasonably handle missing values, thereby maximizing the expansion of the sample size.

Meanwhile, to ensure the reliability of the empirical results, this paper also employs four commonly used financial development indicators for a robustness test. Specific indicators can be found in Table 1.

Table 1. Descriptions of variables and data sources.

Variable	Symbol	Measurement	Unit	Data Source
Overall financial development	FD	FD index	Index	Constructed by Svirydzenka [43]
Financial institution	FI	FI index	Index	
Financial market	FM	FM index	Index	
Depth of financial institution	FID	FID index	Index	
Access of financial institution	FIA	FIA index	Index	
Efficiency of financial institution	FIE	FIE index	Index	
Depth of financial market	FMD	FMD index	Index	
Access of financial market	FMA	FMA index	Index	
Efficiency of financial market	FME	FME index	Index	
Renewable energy transition	RET	Renewable energy consumption (% of total final energy consumption)	Percentage (%)	World Bank (WDI)
Urbanization	UR	Urban population (% of total population)	Percentage (%)	
Economic growth	EG	GDP per capita growth (annual %)	Percentage (%)	
Foreign direct investment	FDI	Foreign direct investment (% of GDP)	Percentage (%)	
Financial development (for robustness test)	FDRT1	Domestic credit to the private sector (% of GDP)	Percentage (%)	
	FDRT2	Domestic credit to private sector by banks (% of GDP)	Percentage (%)	
	FDRT3	Total value of traded stocks (% of GDP)	Percentage (%)	
	FDRT4	Market capitalization of listed domestic companies (% of GDP)	Percentage (%)	
Industrial structure (for robustness test)	IS	Industrial value added (% of GDP)	Percentage (%)	
Trade openness (for robustness test)	TO	Total import and export (% of GDP)	Percentage (%)	

3.3.2. Renewable Energy Transition

Drawing on relevant literature studies [56–58], this paper employs the indicator "Renewable energy consumption (% of total final energy consumption)" to measure renewable energy transition. This indicator quantifies the penetration rate of renewable energy in final energy consumption, offering a straightforward reflection of a country's structural shift from traditional fossil fuels to renewable energy sources.

3.3.3. Control Variables

Based on the relevant literature on renewable energy transition [59–63], and taking into account the sample period and data availability, this paper selects urbanization, economic growth, and FDI as control variables. Moreover, in the section of robustness test, two more variables, namely, industrial structure and trade openness, are included to further eliminate the potential impact of control variables on the regression results. Detailed information on the variables used in the empirical research and the data sources is presented in Table 1.

Based on data availability, in the main regression, this paper selects panel data from 167 countries spanning from 2000 to 2020 for analysis. In the robustness test and extended research, the sample size and period will be adjusted, with specific details provided in the corresponding sections. It should be noted that the term "country" used in this paper refers to "country and region". The data for the 9 financial development indicators constructed by Svirydzenka [43] are sourced from the IMF's Financial Development Index Database, while the remaining indicators are obtained from the World Bank's WDI (World Development Indicators) database. All data used in this paper are publicly accessible from the aforementioned databases. The range of 9 financial development indicators is from 0 to 1, with higher values indicating a greater level of financial development. To facilitate the interpretation of empirical results, this paper scales the indicators to a range of 0 to 100, a practice that does not alter the empirical findings in any way.

4. Results and Discussions

In this section, we conduct empirical tests on the impact of financial development on renewable energy transition, with the specific arrangements as follows: Section 4.1 performs tests on the appropriateness of data selection based on the data used in the main regression; Section 4.2 carries out the main regression analysis on the full sample using the FD indicator to examine the impact of financial development on renewable energy transition from an overall perspective; Section 4.3 conducts robustness tests on the results of the main regression using different methods; Section 4.4 undertakes extended research from the perspectives of sub-indicators of financial development and sub-samples to further explore whether there are structural and country-specific heterogeneous impacts of financial development on renewable energy transition.

4.1. Pretests

Prior to the empirical analysis, we verify the applicability of the data through correlation coefficient tests, panel unit root tests, and panel cointegration tests to minimize issues such as multicollinearity and spurious regression. The following are the pretest results of the model based on the main regression data.

Table 2 presents the correlation coefficient matrix among variables. As evident from the table, the absolute values of all correlation coefficients between variables are below 0.8, indicating that there is no significant multicollinearity problem in the model.

Table 2. Correlation matrix of the variables.

Variable	FD	RET	UR	EG	FDI
FD	1.0000				
RET	−0.5186	1.0000			
UR	0.6143	−0.5709	1.0000		
EG	−0.0708	0.0150	−0.0927	1.0000	
FDI	0.0905	−0.1150	0.0948	0.0653	1.0000

To ensure the reliability of the results, we employ five commonly used methods [64–68] for panel unit root tests and three commonly used methods [69–71] for panel cointegration tests on the data.

Table 3 displays the results of the panel unit root tests. As can be seen from the table, the HT test method for the UR variable fails the unit root test, while all other methods pass for all other variables. For the UR variable, only one out of the five methods fails the test. Therefore, it can be considered that all variables have passed the panel unit root tests, effectively avoiding the issue of spurious regression.

Table 3. Results of panel unit root tests.

Variable	LLC	HT	Breitung	IPS	Fisher
FD	−6.5101 ***	0.8110 ***	−2.3887 ***	−5.0712 ***	−18.9820 ***
	(0.0000)	(0.0000)	(0.0085)	(0.0000)	(0.0000)
RET	−11.7009 ***	0.9906 **	−4.1920 ***	−2.4589 ***	−12.8311 ***
	(0.0000)	(0.0392)	(0.0000)	(0.0070)	(0.0000)
UR	−34.4535 ***	0.9994	−5.4292 ***	−4.9218 ***	−13.9950 ***
	(0.0000)	(0.4545)	(0.0000)	(0.0000)	(0.0000)
EG	−9.2434 ***	0.2695 ***	−12.5351 ***	−20.3288 ***	−19.8580 ***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)
FDI	−30.9858 ***	0.7044 ***	−5.0416 ***	−16.5113 ***	−19.7398 ***
	(0.0000)	(0.0000)	(0.0000)	(0.0000)	(0.0000)

Note: LLC, HT, Breitung, IPS, and Fisher signify Levin–Lin–Chu test, Harris–Tzavalis test, Breitung test, Im–Pesaran–Shin test, and Fisher test, respectively. Values in parentheses are the *p*-values. *** and ** indicate significance at the 1% and 5% levels, respectively.

Table 4 presents the results of the panel cointegration tests. It can be observed that all test statistics reject the null hypothesis of "no cointegration relationship" at the 1% significance level, indicating the existence of a robust long-term co-evolutionary mechanism among the variables.

Table 4. Results of panel cointegration tests.

Approach	Statistics
Kao	16.1738 *** (0.0000)
Pedroni	−18.9393 *** (0.0000)
Wester Lund	2.5758 *** (0.0050)

Note: Values in parentheses are the *p*-values. *** indicates significance at the 1% level.

From the above test results, it can be seen that the data employed in the main regression have passed all pretests and are suitable for panel regression analysis. In addition to the main regression, this paper also conducts a series of regressions in robustness tests and extended research. Since the datasets used in these regressions are different, they have similarly undergone and passed data pretests. Given that these pretests are solely intended to assess data applicability and do not provide additional substantive insights, and due to

space constraints, these results are not presented in the manuscript but can be provided to readers upon request.

4.2. Results of Main Regressions

First of all, we employ the FD indicator to conduct the main regression analysis on the full sample, examining the impact of financial development on renewable energy transition from an overall perspective. Table 5 presents the results of the stepwise regression tests.

Table 5. Results of main regressions.

Variable	Stepwise Regressions			
L.RET	0.9798 *** (72.70)	0.9994 *** (86.33)	0.9974 *** (91.91)	0.9971 *** (91.28)
FD	−0.0016 (−0.19)	0.0053 (1.26)	0.0041 (0.97)	0.0041 (0.95)
UR		0.0111 (1.56)	0.0096 (1.49)	0.0094 (1.46)
EG			−0.0385 *** (−2.84)	−0.0382 *** (−2.80)
FDI				−0.0011 (−0.99)
AR (1)	−5.03 *** (0.000)	−5.04 *** (0.000)	−5.06 *** (0.000)	−5.06 *** (0.000)
AR (2)	0.97 (0.331)	0.97 (0.331)	0.97 (0.331)	0.97 (0.330)
Hansen test	103.65 (0.122)	129.47 (0.203)	129.16 (0.208)	129.79 (0.197)
No. countries	167	167	167	167

Note: L.RET denotes the first-order lag term of RET. AR (1) and AR (2) represent the first-order and second-order autocorrelation estimators, respectively. No. countries is the number of sample countries in each regression. Values in parentheses are the *p*-values for AR (1), AR (2), and the Hansen test, and all other values in parentheses are *t*-statistics. ***, **, and * signify levels of significance at 1%, 5%, and 10%, respectively. The notes for the following tables are identical to those of this table.

As can be seen from the table, for all regressions, the first-order serial correlation test AR (1) is significant at the 1% level, indicating the presence of first-order autocorrelation in the residuals, which aligns with the expected characteristics of a dynamic panel model. The second-order serial correlation test AR (2) is not significant, suggesting that the model has adequately controlled for higher-order autocorrelation issues and that the instrumental variables are appropriately specified. The Hansen over-identification test is not significant, indicating that the instrumental variables used exhibit good exogeneity and that the model specification does not suffer from over-identification bias [72]. These test results support the rationality of the model specification and the reliability of the estimation results. Furthermore, the stepwise regression results demonstrate that the coefficient of FD and its significance level do not undergo notable changes, further confirming that the empirical results are not influenced by variations in the number of control variables.

According to the empirical results of Table 5, the coefficients of FD in each regression are −0.0016, 0.0053, 0.0041, and 0.0041, and the absolute value of all t-statistics are less than 1.26, which imply that the coefficients in all regressions are not statistically and economically significant, indicating that from a global overall perspective, financial development does not exert a significant impact on renewable energy transition. This conclusion can be inferred and discussed from the following aspects.

Firstly, the core of renewable energy transition lies in the increase in the proportion of renewable energy within the overall energy consumption structure. However, financial development does not solely exert its influence on the renewable energy sector; it also has a significant positive impact on the traditional fossil fuel industry [22]. During the financing process of the energy sector, traditional fossil fuel projects often tend to be more

favored by financial institutions due to their mature technologies and relatively stable revenue expectations [73]. Financial sectors provide traditional fossil fuel enterprises with substantial financing support, such as large-scale loans and bond issuances, to facilitate their expansion of production scale, technological upgrades, and resource exploration and development activities [31]. This augmentation bolsters the supply capacity of traditional fossil fuels, thereby facilitating their ability to sustain or even augment their proportion in global energy consumption during specific time intervals. Considering that financial development serves as a catalyst for both traditional and renewable energy sources, the consumption levels of these two energy types have concurrently escalated under the propulsion of financial development. Under these circumstances, the proportion of renewable energy consumption relative to total energy consumption has not undergone a marked alteration attributable to financial development. As the global financial market continues to evolve, the production and consumption volumes of both traditional fossil fuels and renewable energy have exhibited an upward trend. However, the growth rate of renewable energy's share in the total energy mix has been comparatively sluggish, indicating an absence of a substantial driving impact exerted by financial development on the transition towards renewable energy.

Secondly, this paper focuses on research at the global macro level, exploring the impact of financial development on renewable energy transition from an overall perspective, and thus cannot account for the heterogeneous characteristics of different countries and regions. In some countries, the financial sector can offer a diverse range of financial products and services for renewable energy projects, effectively reducing the financing costs and risks for renewable energy enterprises [74,75]. Meanwhile, developed financial markets facilitate the establishment and operation of carbon emissions trading markets, which, through financial instruments such as carbon futures and carbon options, assign a price to carbon emissions, directly increasing the cost of using fossil fuels and prompting enterprises to shift towards cleaner, renewable energy sources [76]. Hence, the advancement of the financial sector in certain nations has exerted a positive driving force on the transition to renewable energy, fostering an elevation in the proportion of renewable energy consumption within the overall energy mix. Conversely, in other countries, the development of the financial sector lags comparatively behind. Financial institutions in these regions possess restricted knowledge and assessment proficiencies concerning renewable energy projects, which gives rise to financing obstacles for renewable energy enterprises. Under such conditions, the financial sector generally exhibits a propensity to support the traditional energy sector, given its greater maturity and more straightforward risk assessment characteristics. This, in turn, exerts a detrimental influence on the transition to renewable energy. When scrutinizing this issue from a macroscopic standpoint, the positive and negative impacts observed across different countries counterbalance one another, ultimately culminating in the conclusion that the impact of financial development on the transition to renewable energy is not statistically significant.

Finally, the impact of financial development on renewable energy transition may be influenced by other factors, such as environmental regulations and fiscal subsidies [52,77,78]. The intensity and enforcement of environmental regulations vary significantly across different countries and regions. Strict environmental regulations raise the cost of using traditional fossil fuels, guiding financial resources to flow towards the renewable energy sector and strengthening the driving effect of financial development on energy transition. Conversely, lax environmental regulations may keep traditional energy sources attractive, weakening the positive effects of financial development [79]. Meanwhile, the extent of government fiscal subsidies for the renewable energy industry directly affects project profitability and market competitiveness [80]. Sufficient fiscal subsidies are capable of mitigating project

risks, enticing heightened investment from financial institutions, and facilitating the energy transition process. Conversely, inadequate subsidies are likely to dissuade financial institutions from participating. Given the limitations of spatial constraints within this paper, it is unable to conduct a thorough and all-encompassing consideration of these factors. This omission may well constitute one of the reasons underlying the statistically insignificant results yielded by the full-sample regression analysis.

Based on the aforementioned empirical results and discussions, the research Hypothesis 1 has been verified.

4.3. Results of Robustness Tests

In this section, we conduct three robustness tests, namely, replacing the proxy variable for financial development, adding control variables, and extending the sample period, to ensure the reliability of the main empirical results.

(1) Replacing the proxy variable for financial development. As mentioned earlier, this paper employs the comprehensive financial development indicator, FD, constructed by Svirydzenka [43] as the proxy variable for financial development. In fact, in empirical research related to financial development, the indicators used to measure financial development are not uniform. This paper selects four other commonly used indicators of financial development for robustness tests: domestic credit to the private sector (% of GDP), domestic credit to private sector by banks (% of GDP), total value of traded stocks (% of GDP), and market capitalization of listed domestic companies (% of GDP), denoted as FDRT1, FDRT2, FDRT3, and FDRT4, respectively. It should be noted that due to data availability constraints, when using these four indicators for regression, the sample size will decrease to varying degrees. Table 6 presents the relevant regression results. It is evident from the table that after replacing the proxy variable for financial development, the coefficients of financial development are all insignificant, which is consistent with the results of the main regression, thereby verifying the reliability of the conclusions.

Table 6. Results of robustness tests with different independent variables.

Variable	FDRT1	FDRT2	FDRT3	FDRT4
L.RET	Added	Added	Added	Added
FD	0.0036 (1.54)	0.0024 (0.87)	−0.0002 (−0.38)	−0.0003 (−1.36)
Control variables	Controlled	Controlled	Controlled	Controlled
AR (1)	−4.40 *** (0.000)	−4.92 *** (0.000)	−4.93 *** (0.000)	−4.04 *** (0.000)
AR (2)	1.15 (0.250)	0.99 (0.321)	−0.76 (0.449)	−0.10 (0.922)
Hansen test	97.33 (0.233)	118.47 (0.141)	47.89 (0.108)	47.00 (0.126)
No. countries	136	159	67	59

(2) Adding control variables and extending the sample period. To achieve a balance between the sample size and the number of control variables, three control variables—urbanization, economic growth, and foreign direct investment—are included in the main regression. To further mitigate the omitted variable bias and verify the reliability of the empirical results, two additional control variables, industrial structure and trade openness, are added to the main regression for a robustness test.

Moreover, to strike a balance between the sample size and the sample period, the sample period for the main regression is set from 2000 to 2020. To exclude the impact of

sample period selection on the empirical result, the sample period is extended from 1990 to 2020 based on the main regression.

Due to data availability constraints, both adding control variables and extending the sample period result in a reduction in the sample size. Since each of these two robustness tests involves only one regression, the results of both tests are presented in Table 7 for ease of reading and to save space. It is evident from the table that, after adding control variables and extending the sample period, there are no significant changes in the results compared to the main regression, indicating that neither the control variables nor the sample period exerts a significant impact on the conclusions, thereby further validating the reliability of the main regression results.

Table 7. Results of robustness tests with more control variables and a longer sample period.

Variable	More Control Variables	Longer Sample Period
L.RET	Added	Added
FD	0.0047 (0.85)	0.0080 (1.23)
Control variables	Controlled	Controlled
AR (1)	−4.72 *** (0.000)	−5.39 *** (0.000)
AR (2)	0.20 (0.845)	0.72 (0.474)
Hansen test	114.51 (0.206)	89.98 (0.335)
No. countries	144	132

4.4. Extended Research

In this section, we conduct two extended studies to further explore whether there exist structural and country-specific heterogeneous impacts of financial development on renewable energy transition from the perspectives of sub-indicators of financial development and sub-sample analysis, respectively.

4.4.1. Results of Sub-Index Regressions

In the main regression analysis, we employ the comprehensive financial development indicator "FD" as an overall metric to gauge the level of financial development. The results indicate that, at a macro level, financial development does not exert a significant impact on the transition to renewable energy. Financial development represents a complex, multi-tiered, and multidimensional system, with distinct characteristics and functions at different levels. Therefore, the mechanisms and extent of its influence on renewable energy transition warrant further exploration.

To gain a deeper understanding of the impact of financial development on renewable energy transition, we further refine and decompose financial development, conducting research on the specific structure of financial development. The financial system can typically be divided into two core aspects: financial institution and financial market. The former is dominated by financial intermediaries such as banks, which support the development of the real economy through credit allocation, risk management, and long-term financing [81]. The latter, represented by stock and bond markets, focuses on capital pricing, equity financing, and liquidity provision [82]. Theoretically, these two types of mechanisms possess distinct functional advantages in supporting renewable energy projects. Financial institutions may be more adept at providing stable loans for large-scale infrastructure projects [83,84], whereas financial markets are more conducive to enabling renewable energy companies to obtain direct financing capital [85,86]. We employ two secondary indicators of financial development, FI and FM, as proxy variables for financial institution and financial market, respectively, for regression analysis.

On this basis, we further decompose financial institution and financial market into three key functional dimensions: depth, access, and efficiency. Among them, depth reflects the overall supply level of financial resources, access measures the breadth of coverage and inclusiveness of financial services, and efficiency embodies the cost and quality of resource allocation [43]. The depth, access, and efficiency of the financial institution and the financial market are represented using six tertiary indicators of financial development—FID, FIA, and FIE for financial institution, and FMD, FMA, and FME for financial market—as proxy variables, respectively.

Table 8 presents the regression results for FI and FM. As can be seen from the table, the regression coefficients for financial institution (FI) and financial market (FM) are 0.0089 and 0.0002, respectively, and the absolute value of all t-statistics is less than 1.39, which indicates that the coefficients are not statistically and economically significant. These results are consistent with the findings of the main regression. This indicates that there are no structural differences in the impacts of the financial institution and the financial market on the transition to renewable energy. These results suggest that, on a global scale, the overall level of financial development and its internal structure (whether intermediary-dominated or market-dominated) have not yet formed a systematic driving force for renewable energy transition. Whether it is financial intermediaries centered around banks or the direct financing system represented by capital markets, their current functional performance is still insufficient to significantly alter the energy structure.

Table 8. Results of sub-index regressions (FI and FM).

Variable	FI	FM
L.RET	Added	Added
FD	0.0089 (1.39)	0.0002 (0.09)
Control variables	Controlled	Controlled
AR (1)	−5.06 *** (0.000)	−6.32 *** (0.000)
AR (2)	0.97 (0.330)	−1.23 (0.220)
Hansen test	128.66 (0.217)	129.97 (0.194)
No. countries	167	150

As previously mentioned, this paper posits that the insignificant impact of financial development on the transition to renewable energy may stem from three reasons: the bidirectional nature of financial resource allocation rendering the impact indistinct, national differences leading to the cancellation out of impacts, and interference from other factors diminishing the effectiveness of the influence. From the perspectives of the two distinct financial structures—financial institution and financial market—these circumstances may similarly exist, with both exhibiting strong homogeneous characteristics.

Firstly, both financial institutions and financial markets possess profit-seeking characteristics and are more inclined to support traditional fossil fuel industries that have undergone long-term development, feature mature technologies, and entail relatively controllable risks. This disperses the financial support from the financial market to renewable energy enterprises, thereby undermining their driving effect on the transition to renewable energy. Secondly, both financial institutions and financial markets exhibit significant disparities in their developmental stages, scales, and business scopes across different countries, lacking uniform characteristics. Consequently, the positive and negative impacts of financial institutions and financial markets on renewable energy transition tend to offset each other, resulting in insignificant empirical findings. Finally, their impacts may be influenced by external factors, leading to insignificant empirical results. For instance, in countries with stringent environmental regulations, financial institutions and financial

markets face higher compliance requirements and regulatory pressures. When assessing the risks of energy projects, financial institutions, considering the higher environmental costs and potential policy penalties associated with traditional fossil fuel projects, are more inclined to allocate funds to the renewable energy sector. Similarly, investors in financial markets adjust their investment portfolios based on environmental risk considerations, increasing their holdings of renewable energy-related assets. Conversely, in countries with lax environmental regulations, financial institutions and financial markets lack sufficient policy incentives and constraints, and traditional energy projects, with their relatively stable returns and lower short-term risks, continue to dominate. This diminishes the support from financial institutions and financial markets for the transition to renewable energy.

Tables 9 and 10 present the regression results of six tertiary indicators of financial development. As can be seen from the tables, except for the coefficient of FID, all the other five tertiary indicators are not statistically significant. The coefficient of FID is 0.0043 and significantly positive at the 10% level.

Table 9. Results of sub-index regressions (FID, FIA, and FIE).

Variable	FID	FIA	FIE
L.RET	Added	Added	Added
FD	0.0043 * (1.72)	0.0052 (0.84)	−0.0028 (−0.31)
Control variables	Controlled	Controlled	Controlled
AR (1)	−5.03 *** (0.000)	−5.06 *** (0.000)	−5.06 *** (0.000)
AR (2)	0.97 (0.333)	0.98 (0.328)	0.98 (0.330)
Hansen test	127.24 (0.244)	117.39 (0.157)	128.32 (0.223)
No. countries	165	165	167

Table 10. Results of sub-index regressions (FMD, FMA, and FME).

Variable	FMD	FMA	FME
L.RET	Added	Added	Added
FD	0.0007 (0.39)	0.0013 (0.51)	0.0020 (1.08)
Control variables	Controlled	Controlled	Controlled
AR (1)	−6.27 *** (0.000)	−5.73 *** (0.000)	−4.98 *** (0.000)
AR (2)	−1.14 (0.255)	−1.11 (0.267)	−0.60 (0.546)
Hansen test	129.79 (0.197)	100.76 (0.166)	81.66 (0.204)
No. countries	149	111	89

On the one hand, this implies that the expansion of financial institutions' scale will, to a certain extent, exert a positive effect on the transition to renewable energy. An enlarged scale of financial institutions signifies stronger financial capacity and broader business coverage, enabling them to provide more substantial financial support for renewable energy projects. Large financial institutions often possess greater risk tolerance, allowing them to participate in large-scale renewable energy infrastructure construction projects, thereby promoting the scaled development of the renewable energy industry and driving the shift in the energy structure towards renewable energy sources [87,88].

On the other hand, it suggests that the accessibility and efficiency of financial institutions, as well as the depth, accessibility, and efficiency of financial markets, do not have a significant impact on renewable energy transition. The insignificance of financial institution accessibility may stem from the fact that, despite an increase in the number or broader distribution of financial institutions, specific services tailored to the renewable energy sector have not effectively kept pace, resulting in no substantial improvement in the

actual convenience for enterprises to access financial services. The insignificance of financial institution efficiency could be attributed to the current challenges and uncertainties that financial institutions face when evaluating and approving renewable energy projects, which hinder the effective enhancement of capital allocation efficiency. Regarding financial markets, the insignificance of depth, accessibility, and efficiency reflects deficiencies in global financial markets in supporting the transition to renewable energy. Financial markets may lack effective pricing mechanisms and risk diversification tools specific to renewable energy, leading to low investor participation in renewable energy projects and difficulties in channeling funds effectively into this sector, thereby failing to generate a significant positive impact on renewable energy transition. The above empirical results imply that, whether at the macro or micro level, apart from the depth of a financial institution, there is insufficient evidence to suggest that financial institutions and financial markets can effectively promote the transition to renewable energy. It should be noted that, due to limitations in data availability, the sample sizes for some secondary and tertiary indicators of financial development have decreased to varying degrees. Given this, the regression results of sub-indicators may only be suitable for local analysis and may not be appropriate for horizontal comparison. Therefore, we need to approach the corresponding empirical results with caution.

Based on the aforementioned empirical results and discussions, except for FID, the research Hypothesis 2 has been verified from the macro perspective.

4.4.2. Results of Sub-Sample Regressions

In the main regression, we utilized full-sample data of 167 countries for analysis. This approach enables us to grasp the impact of financial development on renewable energy transition from a holistic perspective, but fails to account for the heterogeneous characteristics of different countries and regions. As previously mentioned, significant disparities exist among countries in terms of economic development levels, institutional environments, and policy frameworks [89–91]. Consequently, the mechanisms through which financial development affects renewable energy may exhibit asymmetry. In particular, there are systemic differences in the allocation efficiency of financial resources, the enforcement of environmental policies, and the adoption capacity of green technologies between developed and developing countries or among different income-level groups, which may lead to substantial variations in the actual effects of financial development [79,92–95].

Therefore, in this section, we conduct sub-sample regression analyses to further investigate the potential country-specific heterogeneous impacts. Based on the economic classification criteria of the IMF, the sample is divided into two sub-samples: developed countries and developing countries, to examine the differentiated effects of financial development across economies at different development stages. Additionally, to further refine the analytical framework, this paper also categorizes the sample into four income groups—high-income, upper-middle-income, lower-middle-income, and low-income countries—according to the World Bank's income classification standards. This approach aims to explore whether the impact of financial development on renewable energy transition exhibits a gradient feature with varying income levels, thereby enhancing the reliability of the sub-sample regression results. It should be noted that the sample includes 35 developed countries and 57 high-income countries, and all developed countries fall under the category of high-income countries according to these two classification criteria.

Tables 11 and 12 present the sub-sample regression results based on the IMF and World Bank classification standards, respectively. The empirical findings indicate significant differences in the impact of financial development on renewable energy transition across countries at different development stages and income levels. Specifically, for developed

countries, as well as high-income and upper-middle-income countries, the coefficient of FD is not statistically significant, suggesting that financial development does not have a significant impact on the transition to renewable energy. Conversely, for developing countries, as well as lower-middle-income and low-income countries, the coefficient of FD is significantly negative at least at the 5% level, indicating that financial development has a significant negative impact on the transition to renewable energy. Specifically, the coefficients of developing countries and lower-middle-income countries are −0.1456 and −0.2438, respectively, and both of them are significant at the 1% level. The coefficient of low-income countries is −0.1487 and significant at the 5% level.

Table 11. Results of sub-sample regressions (classification of IMF).

Variable	Developed Countries	Developing Countries
L.RET	Added	Added
FD	0.0019 (0.28)	−0.1456 *** (−3.07)
Control variables	Controlled	Controlled
AR (1)	−3.28 *** (0.001)	−4.65 *** (0.000)
AR (2)	−0.66 (0.512)	1.09 (0.274)
Hansen test	9.34 (0.156)	119.23 (0.217)
No. countries	35	132

Table 12. Results of sub-sample regressions (classification of World Bank).

Variable	High-Income Countries	Upper-Middle-Income Countries	Lower-Middle-Income Countries	Low-Income Countries
L.RET	Added	Added	Added	Added
FD	0.0031 (1.43)	0.0166 (0.65)	−0.2438 *** (−2.74)	−0.1487 ** (−2.05)
Control variables	Controlled	Controlled	Controlled	Controlled
AR (1)	−2.56 *** (0.010)	−3.04 *** (0.002)	−2.93 *** (0.003)	−3.20 *** (0.001)
AR (2)	0.92 (0.359)	0.08 (0.938)	0.89 (0.374)	−1.13 (0.257)
Hansen test	11.44 (0.121)	40.37 (0.245)	40.93 (0.343)	3.76 (0.289)
No. countries	57	44	48	18

Based on the aforementioned sub-sample regression results, we can conclude that the impact of financial development on renewable energy transition exhibits significant country-specific heterogeneous characteristics. For countries with relatively high development levels (or income levels), financial development fails to effectively promote the transition to renewable energy (although no evidence of hindrance is found). Conversely, for countries with lower development levels (or income levels), financial development exerts a notably negative influence on the transition to renewable energy.

On the one hand, in nations characterized by relatively high levels of development, financial markets exhibit a relatively mature state, and the allocation of financial resources operates with a relatively high degree of efficiency. During the nascent stages of development, a substantial quantum of financial resources has been preferentially channeled towards existing green assets. As these pre-existing green assets continue to amass over time, the marginal effect of additional financial investments in them gradually wanes. Consequently, newly injected financial resources are incapable of inducing a notable upsurge in the proportion of renewable energy consumption, in contrast to the impact observed during the initial phases. This leads to a constrained role of financial development in further augmenting the share of renewable energy consumption, ultimately culminating in statistically insignificant findings. On the other hand, despite the fact that countries with advanced

development levels place significant emphasis on the development of renewable energy, traditional energy sources continue to hold sway over their energy structures. To safeguard the stability and security of energy supply, these nations are still compelled to allocate a considerable amount of financial resources to the maintenance, upgrading, and expansion of the traditional energy sector. To a certain extent, this diverts financial resource investments away from the renewable energy sector, thereby impeding a significant increase in the proportion of renewable energy consumption as a result of financial development.

In countries with relatively low levels of development, the financial system remains underdeveloped and has not yet attained a well-established status, with financial resources being comparatively scarce. Throughout the capital allocation process, financial institutions, driven by risk aversion and in pursuit of short-term returns, may allocate a significant proportion of funds to traditional energy industries instead of the renewable energy sector. Meanwhile, to promote economic development, policy makers may prioritize ensuring the funding needs of traditional energy industries and related infrastructure construction, while providing insufficient financial guidance for the renewable energy sector. This results in financial development failing to effectively promote the transition to renewable energy; instead, it generates a crowding-out effect due to resource misallocation, leading to a decline in the proportion of renewable energy [96]. Additionally, these countries lag relatively behind in the research, development, and application of renewable energy technologies, relying heavily on imported technologies and equipment. This keeps the costs of renewable energy projects high and further extends the investment return period, reducing the willingness of financial institutions and investors to invest in this sector. Even if the financial system develops to a certain extent, due to the cost and technological constraints inherent in the renewable energy industry, financial resources are difficult to effectively translate into momentum for industrial development. Instead, they may have a negative impact on the proportion of renewable energy consumption as funds flow into traditional energy industries.

Based on the aforementioned empirical results and discussions, the research Hypothesis 3 has been verified.

5. Conclusions and Policy Implications

Based on panel data from 167 countries spanning the period of 2000–2020, this paper employs a dynamic panel model and the System GMM estimation approach to empirically examine the impact of financial development on renewable energy transition. The research findings provide the following conclusions: Firstly, the regression coefficient for the full sample, using the FD indicator as the core explanatory variable, is not statistically significant. This indicates that, from a global perspective, financial development has not exerted significant influence on the proportion of renewable energy consumption relative to total energy consumption, and this result has passed a series of robustness tests. Secondly, the regression results for sub-indicators of financial development show that, except for the financial institution depth (FID), which is significantly positive at the 10% level, all other sub-indicators are not statistically significant. This implies that the impact of financial development on renewable energy transition does not vary significantly across different dimensions. Finally, the sub-sample regression results indicate that for countries with higher development levels, financial development does not have a significant impact on renewable energy transition, whereas for countries with lower development levels, financial development exerts a significant negative impact on renewable energy transition. This suggests that the impact of financial development on renewable energy transition exhibits pronounced country-specific differences.

Therefore, this paper argues that financial development is not a universal tool for promoting the transition to renewable energy. Countries need to establish differentiated financial support pathways based on their own realities, including the development stage of the financial system, the demands of energy structure transformation, and policy coordination capabilities, so as to precisely guide financial resources into the renewable energy sector and thus advance the transition to renewable energy. Based on the aforementioned research findings, this paper proposes the following policy implications:

Firstly, policymakers in various countries should attach great importance to the limitations of financial development in driving energy transition. The empirical results of this paper indicate that, on a global scale, financial development does not significantly contribute to the increase in the proportion of renewable energy consumption, and even exerts a negative impact in countries with lower development levels. Policymakers need to be vigilant against the risk that financial resources may reinforce dependence on traditional energy pathways, particularly in developing countries where there is an urgent need for energy infrastructure construction. It is essential to strengthen the overall coordination between financial policies and energy strategies to prevent an excessive inflow of financial resources into traditional energy industries in the absence of proper guidance.

Secondly, optimize the structure of the financial system and enhance the service efficiency of the financial sector towards the renewable energy industry. In terms of financial institutions, accelerate their specialized transformation and product iteration. By establishing green finance business divisions or specialized institutions, a financial service system covering the entire lifecycle of renewable energy projects should be constructed. Develop specialized products such as carbon reduction-linked loans and green equipment leasing, and utilize dynamic interest rate pricing mechanisms and flexible repayment arrangements to systematically reduce corporate financing costs and lower access thresholds. Regarding financial markets, strengthen the transmission effect of market mechanisms and product innovation on the renewable energy industry. Promote the standardization of the green bond market, improve the third-party evaluation and certification system along with information disclosure norms, and enhance the transparency and liquidity of financing for renewable energy projects. Explore innovations in derivative instruments such as carbon futures and green asset-backed securities to provide market participants with options for risk hedging and asset allocation.

Finally, it is essential to implement differentiated and targeted financial support policies based on the varying development levels and financial structure characteristics of different countries. For countries with higher development levels, the marginal supportive effect of financial development on renewable energy transition diminishes, and policy priorities should focus on enhancing the green efficiency of financial resource allocation and deepening participation. This can be achieved by improving carbon markets, introducing paid allocation and auction mechanisms for carbon allowances to boost corporate emission reduction incentives; strengthening environmental information disclosure by formulating sector-specific disclosure guidelines to enhance information comparability; and promoting green bond standards while establishing a third-party evaluation and certification system. For countries with lower development levels, where financial development hinders renewable energy transition, policy intervention is necessary. In terms of risk-sharing, a risk-sharing pool involving the government, financial institutions, and enterprises should be established to alleviate financial institutions' risk concerns. Regarding subsidies, direct financial subsidies should be provided for the early-stage R&D (Research and Development) investment in renewable energy projects, with higher subsidy rates for projects adopting advanced technologies. In terms of institutional reform, the approval process for policy-oriented green banks should be streamlined, granting them certain autonomous

pricing rights to improve capital allocation efficiency and guide funds precisely toward the renewable energy sector.

There are several limitations of this research: (1) This study only employs "renewable energy consumption (% of total final energy consumption)" as the indicator to measure renewable energy transition. This indicator solely focuses on the consumption proportion and fails to comprehensively reflect the multi-dimensional development of renewable energy, such as technological innovation and industrial scale expansion. (2) Although this paper utilizes the system GMM method to estimate the dynamic panel model, which to a large extent mitigates endogeneity issues, this method is based on a series of assumptions, such as the validity of instrumental variables. Further exploration is still needed regarding solutions to endogeneity problems. (3) Due to limitations in data availability, it is difficult to obtain appropriate measurement indicators for policy or regulatory frameworks, making it impossible to further analyze the influencing factors of financial development on renewable energy transition.

Future research directions can be explored from the following aspects: (1) Based on the latest research findings related to renewable energy transition, efforts can be made to construct a comprehensive indicator system to measure renewable energy transition. This system should incorporate multi-dimensional data, such as technological R&D investment and industrial scale growth rates, to comprehensively depict the transition process. (2) More effective solutions to endogeneity issues should be explored, such as attempting new methods for selecting instrumental variables or combining multiple econometric models to reduce reliance on specific assumptions. (3) Continuous attention could be paid to research advancements in measurement indicators for policy or regulatory frameworks. In the future, appropriate indicators could be introduced to conduct in-depth analyses of the role played by policy factors in the process of financial development driving renewable energy transition, as well as the differential effects of various policy combinations, thereby providing more targeted bases for policy formulation.

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Abbreviations

The following abbreviations are used in this manuscript:

FDI	Foreign Direct Investment
ASEAN	Association of Southeast Asian Nations
GDP	Gross Domestic Product
OECD	Organization for Economic Co-operation and Development
ARDL	Autoregressive Distributed Lag
BRICS	Brazil, Russia, India, China, South Africa

STIRPAT	Stochastic Impact of Regression on Population Affluence and Technology
CS-ARDL	Cross-Sectionally Augmented Autoregressive Distributed Lag
RET	Renewable Energy Transition
GMM	Generalized Method of Moments
IMF	International Monetary Fund
WDI	World Development Indicators
R&D	Research and Development

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