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Bioenergy for Sustainable Rural Development: Elevating Government Governance with Environmental Policy in China

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Abstract: Energy is not only the crucial driver of economic activities within rural areas. Conventional energy sources are crucial for the prosperity of rural areas; however, they also prove detrimental to the rural ecosystem. To achieve sustainable rural development, increasing the consumption of renewable energy sources can prove vital. Among all the renewable energy sources, bioenergy is the cheapest and easiest to produce in rural areas. Therefore, it is crucial to estimate the impact of bioenergy on the rural development of China. Thus, the primary purpose of this analysis is to analyze the impact of bioenergy and environmental policy stringency on the rural development of China from 1995 to 2022 by employing the autoregressive distributed lag (ARDL) and quantile autoregressive distributed lag (QARDL) framework. The results highlight the significance of bio-energy for rural development in the short and long run. Likewise, environmental policy stringency is also a vital factor in fostering short- and long-run rural development. Based on these outcomes, it is recommended that policymakers integrate bioenergy development policies into broader rural development strategies.

Keywords: sustainable rural development; bioenergy; environmental policy stringency

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1. Introduction

More than 50% of people living in rural regions across the globe still do not have access to modern energy sources [1]. Modern energy includes clean and efficient sources, such as hydro, solar, and wind energy [2]. There is a direct connection between energy use and quality of life, as the economic progress of a nation depends heavily on energy. The world's energy resources are crucial for the world's sustainable economic and environmental progress. Primarily, energy resources are divided into three broad categories: nuclear, renewable, and fossil fuels [3]. Despite the popularity of renewable and nuclear energy sources, almost 80% of the worldwide energy demand is fulfilled by fossil fuels. The significant increase in consumption of fossil fuel-driven energy sources has severely damaged the global ecosystem. Fossil fuels are widely believed to be the primary contributors to the surge in carbon dioxide (CO_2) and other greenhouse gasses in the environment, resulting in climate change and global warming [4]. However, whether the rising amount of CO_2 in the atmosphere is of natural origin or a consequence of human activity has created a controversy. This controversy has been resolved by the United Nations [5] by reporting that "greenhouse gases are accumulating in Earth's atmosphere as a result of

human activities. The changes observed over the last several decades are likely mostly due to human activities". Replacing fossil fuels with renewable sources is universally acknowledged as the most suitable approach for decreasing the carbon content in the atmosphere. According to the IRENA [6], renewable energy sources will meet almost 90% of the global energy demand by 2050. To deal with environmental degradation and global warming, the policy of transition to renewable energy sources has become the choice of world leaders, environmentalists, and academia. Therefore, there is a gradual increase in the proportion of renewable energy and alternative energy sources in the energy mix of many countries across the globe.

Renewable energy sources are the ones that can be easily replenished. Ever since man stepped on earth, renewable energy has been the main energy source. Some of the most common forms of renewable energy sources are solar, wind, hydel, and biofuels, and the sources of the generation of renewable energy are the natural processes that occur repeatedly over our lifetimes [7]. Thus, theoretically, renewable energy is believed to be infinite in nature. Bioenergy is also a type of renewable energy obtained from the burning of wood and has been the main source of energy for cooking and heating since the primitive age [8]. Given the significance of biomass energy, policymakers of developed and emerging regions are now aggressively promoting the growth of bioenergy production as a part of energy transition policy, with three main goals in mind. First, the main objective of the increased production of bioenergy is to reduce reliance on petrol and fossil fuel imports [9]. Second, advocates of the growth of bioenergy emphasize maintaining a good balance between bioenergy generation and the possibility of reducing carbon footprints by restricting the use of coal and lignite [10]. Third, due to the increased bioenergy production in rural areas, the agriculture industry is to become a point of focus in particular, while rural regions are to, in general, experience a significant increase in job opportunities and affluence [11].

With regard to the attainment of energy transition objectives, metropolitan regions have been given greater consideration in the past. However, in current times, rural regions have also gained attention and become the discussion point of energy policy experts. The deployment of renewable energy, including bioenergy, is feasible in rural areas and has the potential to offer visible benefits for the development of sustainable rural communities [12]. Hence, energy policymakers have suggested increasing the proportion of carbon-free and green energy sources, such as bioenergy, which are crucial for rural development and offer vital support for the progress of rural economies [13]. For instance, the European Union's renewable energy policy framework intends to foster rural development by explicitly pointing out the specific areas that need greater attention and designing financial plans for them. In addition, some other reports and policy papers suggest that renewable and green energy sources, including bioenergy, should be used prudently to safeguard local community interests and advance rural development [14]. In light of these suggestions, a well-coordinated strategy for rural development that may increase the advantages of using bioenergy and other green energy sources in rural regions is the need of the hour.

Although increasing the share of renewables is crucial for successfully implementing energy transition policy, strict environmental policies also complement the transition process to renewable energy sources and contribute to rural development. Environmental degradation, in a real sense, is a negative externality. In order to take notice of this externality and diminish pollutant emissions from individuals, businesses, and governments, it is crucial for the authorities to design suitable environmental laws and regulations [15]. In the development of any strategy adopted by people, firms, or enterprises to mitigate carbon footprints, deploy renewable energy sources, and conserve drinking water and agricultural land, the role of the government cannot be underestimated. The implementation of environmental policy is one of the main tools in the hands of the government to practice environmental governance effectively [16].

The main objective of strict environmental regulations is to safeguard ecosystems and natural resources, but they may also have a big impact on rural communities because

rural economies in most parts of the world are dependent on land-based businesses like agriculture and resource extraction [17]. On the one side, stringent environmental policies exert more financial and administrative pressure on farmers and rural businesses, negatively impacting their ability to compete and thrive economically. On the other hand, strict environmental laws are helpful in fostering creativity and funding for eco-friendly ventures, which can contribute to protecting biodiversity, enhancing soil and water quality, and fostering resilience against environmental catastrophes [18]. Moreover, environmental policies help promote the smooth transition towards the use of renewable energy sources and sustainable land management procedures, which play a vital role in creating new business prospects and job opportunities in rural regions, leading to enhanced rural development [19]. Thus, strict environmental policies may hinder the development of rural regions in the short run, but they may eventually help to develop more resilient, inclusive, and sustainable rural economies.

Over the last few decades, China has enjoyed rapid economic growth and has become one of the leading economies in the world. Due to this rapid economic growth, the energy demand in China has also increased significantly, making China the world's largest energy consumer and polluter. To meet the rising energy demand and mitigate climate change, China is trying to increase the share of renewables in its energy mix. Currently, the share of bioenergy is 12% of all renewable energy sources [20]. Currently, China is home to about 600 million people living in vast rural regions [21]. According to Gong et al. [22] and Imura [23], significant health and ecological problems exist. A significant rise is observed in the demand for electricity, gas, and coal in rural areas of China. Between 1980 and 2014, the yearly rate of growth in rural home power consumption was 10.7% [24]. In addition, the Chinese government has actively encouraged the use of new, clean, and alternative sources, such as biogas and solar energy, in rural regions. This initiative aims to address ecological and health concerns [25] and contribute to sustainable rural development. Bioenergy has the potential to mitigate carbon footprints, fulfill the energy demand, and enhance the development of rural China. Further, China implemented a revised Environmental Protection Law (EPL) in 2015, with the main objective to enhance environmental quality and governance from several aspects [26]. This law allows the imposition of severe penalties and heavy fines on the enterprises that are responsible for environmental degradation in China, thus inducing the owners of the polluting firms to upgrade their production techniques in line with environmental standards and increase the consumption of green energy. Hence, stringent environmental policy complements the production and consumption of bioenergy and indirectly contributes to rural development in China. Therefore, the primary motive of this analysis is to investigate how bioenergy and environmental policy stringency can contribute to sustainable rural development in China.

The empirical literature on rural development is growing with every passing day. Particularly, a large number of empirics have estimated the nexus of different types of bioenergy and rural development. For instance, Sørensen and Jørgensen [27] analyzed the role of bioeconomy in the rural development of Denmark by mainly focusing on the impact of biogas production on job creation in rural regions. The findings of input–output analysis confirmed that biogas production positively influences job creation and income generation, thereby contributing to rural development. Lehtonen and Okkonen [28] observed that rural development policy that depended on bioenergy production had significant socioeconomic benefits in North Karelia, Finland. In the context of the USA, Low and Isserman [29] estimated how the growth of the ethanol industry has contributed to the development of the rural economy. Using input–output analysis, they confirmed that with the development of an ethanol plant, 35–40 jobs were created within each county. Okkonen and Lehtonen [30] relied on the input–output model and confirmed that bio-oil production helped improve the rural economy by fostering job creation and income generation. By employing the difference-in-differences model, Zhu et al. [31] confirmed that the development of biorefineries fosters employment opportunities in the EU labor market. Mumtaz et al. [32] confirmed the positive role of bioenergy in fostering a rural circular bioeconomy.

Singh et al. [33] underscore the significance of biofuels in fulfilling the energy requirement of rural areas, thus contributing to rural development.

Indeed, the literature has confirmed the positive role of bioenergy in fostering rural development. Most of these studies have investigated the nexus at the micro-level or in some areas of a particular nation. However, none of these studies have estimated the impact of biodiesel production on the rural development of China by using a comprehensive index of rural development. In addition, the role of environmental policy stringency in shaping rural development in China has not been investigated previously. Therefore, a significant literature gap exists, and this analysis fills this gap by investigating the influence of bioenergy and environmental policy stringency on rural development in China. Thus, the study extends the rural development literature in the following ways. First, this initial empirical effort reveals the role of bioenergy and environmental policy stringency in fostering rural development in China. This analysis reveals the potential role of bioenergy in promoting rural development as well as the supportive role of environmental policy stringency in affecting the uptake and use of bioenergy technology in rural settings. Second, the analysis proves crucial in providing an empirical and theoretical foundation for future studies. Third, the analysis employs the ARDL and QARDL methods for long- and short-term result estimations. Lastly, the results of the analysis help design policies that promote rural development, with bioenergy and environmental policy stringency functioning as crucial components of such policies.

2. Theoretical Framework

Sustainable development theory stresses achieving economic growth by maintaining environmental quality and social equity [34]. In other words, sustainable development simply means fostering economic activities by sustainably using natural resources and preserving them for future generations to meet their own needs. Thus, the idea of sustainable development stands on three main pillars or dimensions: economic, social, and environmental [35]. In this context, it is crucial to address the issue of growing energy demand to achieve sustainable development objectives. This includes but is not limited to enhancing the quality of life for individuals, fulfilling society's production requirements, and diminishing the pollution caused by the resources utilized in these endeavors [36]. In order to meet the growing energy need, the role of renewable energy sources, such as geothermal, solar, wind, biomass, and biofuels, cannot be underestimated. These resources can effectively minimize pollution from these sources, ensuring sustainable development. According to Dincer [37], sustainable development requires long-term action plans and measures, and renewable energy sources (geothermal, solar, wind, biomass, and biofuels) are believed to be the most plausible options in this regard. The seventh goal of the UN 2030 Agenda emphasizes that all people around the globe must have access to inexpensive, reliable, sustainable, and clean energy, ensuring the importance of renewable energy for promoting sustainable development.

Diffusion theory explains the connection between biomass energy and sustainable rural development [38]. This theory states how the spread of innovation can provide us with comprehension with regard to the adoption and impact of renewable energy in rural areas. This theory further elaborates on the role of awareness, perceived benefits, costs, and social norms in the development of renewable energy technologies, which is crucial for achieving sustainable development. The integrated rural development (IRD) approach also provides the theoretical inferences for this study. The IRD approach is a holistic strategy aimed at improving the social–economic–environmental conditions of rural communities through the coordinated development of multiple sectors, such as economic development, infrastructure development, social development, and environmental sustainability [39,40]. This approach considers environment development as the basic requirement for rural development. However, recent empirical works related to the IRD approach confirm that renewable energy is crucial for rural development [41,42].

Consequently, energy economists have stressed using renewable energy sources for rural development and consider it an important driver of job creation and rural growth [43,44]. Theorists and academics believe that rural areas have a lot of potential for the generation of renewable energy sources and can become the center for energy transition efforts [45]. Biomass energy is a renewable, green, and zero-carbon source of energy. It can significantly affect rural development due to its ability to contribute to achieving the following objectives: providing energy access, promoting economic diversification, and ensuring environmental sustainability. Biomass energy generation largely depends on organic resources such as agricultural wastes, forest biomass, and animal waste [46]. Thus, the most significant benefits of biomass energy are its decentralized nature and its easy accessibility, which may play a vital role in empowering rural communities and raising their living standards [12]. There are several issues that rural communities have to face due to their reliance on conventional energy sources, such as energy poverty, energy security risk, and environmental degradation. These issues can be overcome by increasing the consumption and production of biomass energy, crucial for sustainable rural development. In addition, the development of biomass energy is helpful in creating job opportunities throughout the whole production process, including biomass cultivation, harvesting, processing, and distribution [47]. Consequently, the rural economy expands and poverty in rural areas is reduced. Further, sustainable land management procedures, ecosystem restoration, and the conservation of biodiversity are some other benefits attached to biomass energy generation, which aligns with the broader objectives of rural development. Thus, in order to design a comprehensive strategy to counter the issues related to energy, economy, and ecology in rural areas, it is crucial to include biomass energy within the framework of rural development. Hence, we hypothesize that biomass energy could prove crucial in driving the development in rural areas.

Furthermore, other renewable energy sources, such as solar, wind, and hydel, provide diverse social and environmental advantages, such as creating local job opportunities and improving wellbeing. They also contribute to revenue production in rural regions [42]. The broadening of economic activities in rural areas, promoting social cohesion, and utilizing local resources are aimed at reducing the impact of climate change and fostering a greener environment by adopting clean energy technology. The current efforts aimed at establishing renewable energy clusters demonstrate an alternative strategy to promote regional development and territorial cohesion. These initiatives focus on decentralized renewable energy production, which can generate income and create job prospects. Recent studies have advocated for the use of relevant technologies such as wind, solar, and water energy to enable local communities to become self-sufficient in terms of energy [48]. This may be achieved by establishing energy-independent villages with renewable energy as the core principle.

Moreover, the role of environmental policy stringency cannot be denied in the development of rural areas. Environmental policy stringency, on the other hand, involves economic, social, and ecological dimensions. From an economic perspective, stringent environmental policies require notable investments in technologies and sustainable practices, which can lead to resource allocation within rural economies and foster development in rural areas [18]. On the social front, environmental policy stringency can improve water and air quality, reduce pollution, and enhance overall ecosystem health, thus improving public health and quality of life in rural areas [19]. Ecologically, environmental policy stringency protects biodiversity, preserves natural habitats, and promotes sustainable land use practices, enhancing ecosystem services essential for long-term rural development.

3. Econometric Model

In this research, our objective is to explore the correlation between bioenergy, environmental policy stringency, and rural development by developing the subsequent econometric model:

$$RD_t = \chi_0 + \chi_1 BE_t + \chi_2 EPS_t + \chi_3 GS_t + \chi_4 GDP_t + \varepsilon_t \quad (1)$$

where rural development (RD) in China is dependent on bioenergy (BE), environmental policy stringency (EPS), government spendings (GS), and GDP per capita (GDP). The symbol χ_0 represents intercept, while εit denotes the error term. Bioenergy is an important source of energy in rural areas. Its generation is largely dependent on agricultural waste, animal waste, and forest residues. Its decentralized generation process and easy availability make it the ideal source of energy in driving economies in rural areas. Increased economic activities in rural areas prove vital in creating job opportunities, improving infrastructure, alleviating poverty, and uplifting the living standards of rural communities [49]. Moreover, biomass energy consumption can prove vital in reducing the environmental impacts of economic activities. Thus, we expect a positive sign for bioenergy. Environmental policy stringency has a crucial role in fostering sustainable agricultural and livestock practices in rural areas, which are catalysts for rural development [19]. In addition, stringent environmental policies are crucial for the growth of green projects and ventures in rural areas, contributing to the job creation and expansion of sustainable economic activities. On the basis of these arguments, we believe that biomass energy has a crucial role in fostering sustainable rural development.

Estimation Methods

It is crucial to employ an appropriate methodology to assess the effects of bioenergy environmental policy stringency on sustainable rural development. In the contemporary literature, many research papers have used diverse cointegration methodologies in the context of distinct situations for the empirical assessment. In comparison to the previously described cointegration methodologies, the ARDL approach demonstrates superiority in several aspects. Previous research has preferred the cointegration method established by Johansen [50] and Johansen and Juselius [51] for examining the cointegration connections among the chosen variables. In contrast, due to the superiority of the ARDL over these techniques, the present study used the ARDL approach. Consequently, it is important to organize the variables in a systematic manner to guarantee the accurate use of this approach.

This research study used the ARDL approach, referred to as the bound test, which was established by Pesaran et al. [52]. The ARDL approach has several substantial benefits compared to traditional cointegration techniques. Unlike previous approaches that required large time-series data, it is especially appropriate for analyzing datasets with limited sample sizes. The biggest benefit of employing the ARDL technique is its significant flexibility in dealing with the variables of a mixed order of integration, i.e., I(0) and I(1). In addition, its quality of producing short- and long-run estimates makes it superior to all the above-mentioned techniques. Moreover, it helps in controlling endogeneity and serial correlations while estimating the connection between the variables. This study considers possible deviations in the adjustment process by including the prospect of asymmetry in the conditional error correction coefficients. In order to ensure the precision and robustness of the estimates, this technique relies on the bias-corrected bootstrap technique to guarantee precise statistical conclusions about the long-term cointegration among the relevant variables. Rephrasing Equation (1) into the format given below is crucial for availing the benefits of the ARDL:

$$\begin{aligned}\Delta RD_t = \chi_0 + \sum_{k=1}^{n} \beta_{1k} \Delta RD_{t-k} + \sum_{k=0}^{n} \beta_{2k} \Delta BE_{t-k} + \sum_{k=0}^{n} \beta_{3k} \Delta EPS_{t-k} + \sum_{k=0}^{n} \beta_{4k} \Delta GS_{t-k} + \\ \sum_{k=0}^{n} \beta_{5k} \Delta GDP_{t-k} + \chi_1 RD_{t-1} + \chi_2 BE_{t-1} + \chi_3 EPS_{it-1} + \chi_4 GS_{t-1} + \chi_5 GDP_{t-1} + \varepsilon_t\end{aligned} \quad (2)$$

Specification (2) is the famous ARDL proposed by Pesaran et al. [52]. As stated above, this technique is capable of estimating the short- and long-run linkage between bioenergy, EPS, and rural development; we are able to identify short-run outcomes (represented by Δ variables) and the long-run outcomes (represented by estimates χ_2–χ_5 normalized on χ_1) from the specification (2). Nevertheless, the bounds F-test and ECM (−1) *t*-test, commonly known as the cointegration test, need to be employed to confirm the reliability of the long-run estimates.

Following the literature, checking the robustness of the results by using another estimator adds more reliability to our estimates. To that end, we employ the Cho et al. [53] technique, known as the QARDL model, an upgrade to the conventional ARDL. The QARDL methodology has many benefits. First and foremost, it has the ability to capture asymmetric effects by analyzing variable connections across diverse quantiles, addressing distribution extremes, and help provide more accurate estimates [54]. Moreover, in order to address the common time-series issues of endogeneity, serial correlations, and nonlinearity, many lagged variables must be included. Further, the ability of the QARDL techniques to offer both long-term and short-term estimates across several quantiles can allow better decision making and policy development by fostering the effectiveness and reliability of the estimates. The following Equation (3) signifies the QARDL model:

$$\begin{aligned} Q_{\Delta RD_t} = \mu(\tau) + \rho(\tau)(RD_{t-1} - \chi_{BE}(\tau)BE_{t-1} - \chi_{EPS}(\tau)EPS_{t-1} - \chi_{GS}(\tau)GS_{t-1} - \chi_{GDP}(\tau)GDP_{t-1}) + \\ \sum_{i=1}^{n1} \varphi_{RD_i}(\tau)\Delta RD_{t-i} + \sum_{i=0}^{n2} \varphi_{BE_i}(\tau)\Delta BE_{t-i} + \sum_{i=0}^{n3} \varphi_{EPS_i}(\tau)\Delta EPS_{t-i} + \sum_{i=0}^{n4} \varphi_{GS_i}(\tau)\Delta GS_{t-i} + \\ \sum_{i=0}^{n5} \varphi_{GDP_i}(\tau)\Delta GDP_{t-i} + \varepsilon_t(\tau) \end{aligned} \quad (3)$$

In the above specification, $\varphi^* \sum_{j=1}^{n} \varphi_j$ represents the combined short-run influence of the lagged value of the RD its current value. In addition, $\varphi^* \sum_{j=1}^{n2} \varphi_j$, $\varphi^* \sum_{j=1}^{n3} \varphi_j$, $\varphi^* \sum_{j=1}^{n4} \varphi_j$, and $\varphi^* \sum_{j=1}^{n5} \varphi_j$, represent the combined short-run influence of the short-run influence of BE_t, EPS_t, GS_t, and GDP_t, respectively. $\chi_{BE}* = -\frac{\chi BE}{p}$, $\chi_{EPS}* = -\frac{\chi EPS}{p}$, $\chi_{GS}* = -\frac{\chi GS}{p}$, and $\chi_{GDP}* = -\frac{\chi GDP}{p}$ are used to signify the cointegration or long-run connection between the bioenergy, environmental policy stringency, government spending, and GDP per capita. We used the quantiles from 0.05, 0.10, 0.20, and up to 0.95 for this analysis. For estimating the short- and long-run nonlinear connection between sustainable development, bioenergy, and environmental policy stringency, we conducted our analysis with the help of the Wald test. The null of the Wald test is based on the assumption that ρ is ρ* (0.05) = ρ* (0.10) . . . . . = ρ* (0.95). A similar technique was used for the parameters χ_{BE}, χ_{EPS}, χ_{GS}, and χ_{GDP}, also applicable to the SR parameters signified by the explicit lags φ_{BE_i}, φ_{EPS_i}, φ_{GS_i}, and φ_{GDP_i}.

4. Data and Descriptive Analysis

Using an entire secondary time-series Chinese dataset at the aggregate level, this study investigates the impact of bioenergy and environmental policy stringency on sustainable rural development from 1995 to 2022. Rural development (RD) is quantified through the rural development index. This index is calculated by the authors. The indices used to compute the rural development index in the study are obtained from aggregate-level data. The data represent the entire rural population of China. The RD index is constructed using five variables; (1) the rural individuals using the internet (% of population); (2) average annual income in rural areas (in Yuan); (3) the average years of total schooling in rural areas; (4) access to clean fuels and technologies for cooking in rural areas (% of rural population); and (5) adaptation technologies in agriculture, forestry, livestock or agro-alimentary production (total patents). This index is generated via principal component analysis. The data for rural internet users are sourced from the CNNIC [55]. The data on average annual income in rural areas are derived from Statista. The data on the average years of schooling in rural areas are collected from CHNS [56] and CFPS [57]. The data on

access to clean cooking fuels and technologies comes from the World Bank [58]. Finally, the data on adaptation technologies in rural agriculture is provided by the OECD [59].

Bioenergy (BE) is assessed through biodiesel production, which is equivalent to tons of oil in thousands. Another proxy variable is used to assess bioenergy, i.e., bioenergy technology. Total patent applicants of bioenergy technology measure bioenergy technology (BET). Some examples of bioenergy technologies include biofuel technology, biorefinery technology, and biogas technology [60]. The data series for bioenergy (BE) and bioenergy technology (BET) are collected from the OECD [59]. The second variable focused on is environmental policy stringency (EPS). The OECD [59] calculates it through the EPS index. EPS is a composite index [61], which is used to estimate how strict the environmental policies are in any nation. The EPS index ranges from zero (no policy) to six (most stringent). This index measures the stringency of an inclusive set of environmental policies. The EPS index includes 13 policy instruments that focus on climate change and air pollution mitigation policies. The trends in key variables are reported in Figure 1.

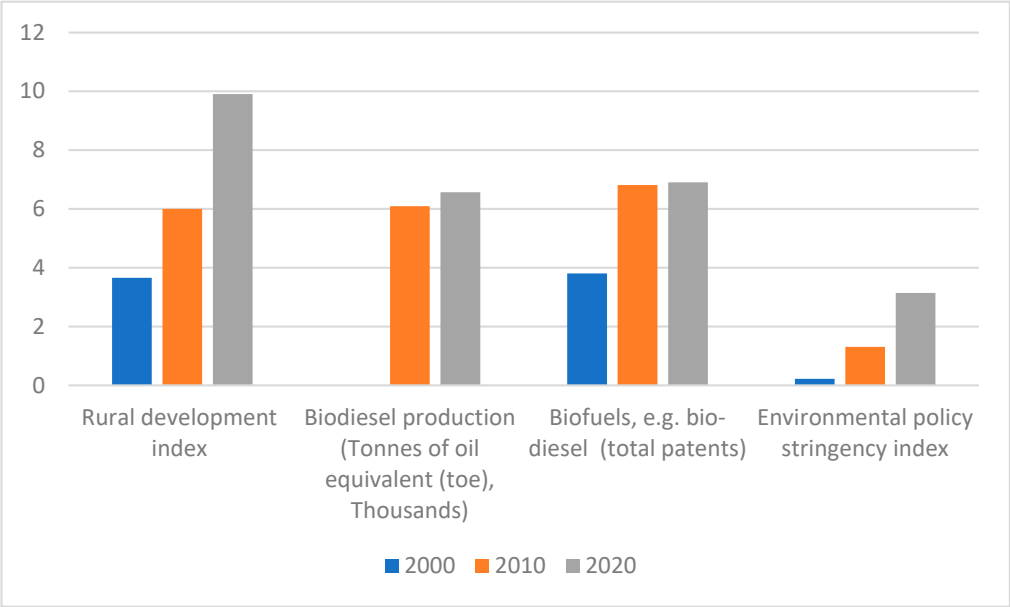


Figure 1. Trend in key variables.

Government spending (GS) and GDP per capita (GDP) are control variables in our model. The selection of these control variables is made from the prior existing literature. For instance, Fan et al. [62] believed that government spending in rural areas activates the process of rural social development. General government final consumption expenditure as a percent of GDP is a proxy measure of public spending. The data are obtained from the World Bank [58]. Our last control variable is GDP per capita. Zhang and Wan [63] illustrated that increased GDP per capita leads to increased investment in education, healthcare, agriculture, and infrastructure development in rural areas, which is crucial for rural development. GDP per capita (GDP) series is taken at constant 2015 US dollars. The data are assembled from the World Bank [58]. Table 1 displays the variables' description.

Table 2 reports the outcomes of descriptive statistics. The descriptive statistics report that the RD data series follows asymmetric distributions, while BE, BET, EPS, GS, FD, and GDP follow normal distribution. The mean score (6.068) exceeds the median score (5.856) for rural development. This discrepancy between the mean and median scores, combined with the skewness scores (0.287), confirms the asymmetric distribution in the rural development data series. However, the mean (median) scores for BE, BET, EPS, GS, FD, and GDP are 3.998 (6.094), 5.712 (6.636), 1.527 (0.970), 15.53 (15.80), 0.509 (0.517), and 8.463 (8.543). The skewness estimates of 0.509 for BE, 0.793 for BET, 0.461 for GS, and 0.194 for GDP indicate negative skewness, demonstrating a negatively skewed distribution.

Conversely, the skewness coefficients of 0.287 for RD, 0.279 for EPS, and 0.034 for FD exhibit positive skewness, implying a positively skewed distribution. The S.D scores for RD, BE, BET, EPS, GS, FD, and GDP are 2.155, 3.140, 1.611, 1.232, 0.986, 0.102, and 0.637. Furthermore, kurtosis statistics also confirm the normality of the data as all the kurtosis statistics are below 3. The kurtosis estimates for RD, BE, BET, EPS, GS, FD, and GDP are 1.596, 1.293, 2.085, 1.381, 2.508, 1.557, and 1.646.

Table 1. Variables' description.

Variable	Symbol	Definitions	Sources
Rural development	RD	Rural development index (rural individuals using the Internet (% of population); average annual income in rural areas (in Yuan); average years of total schooling in rural areas; access to clean fuels and technologies for cooking, rural (% of rural population); adaptation technologies in agriculture, forestry, livestock or agro-alimentary production (total patents)	Authors' calculations
Bioenergy	BE	Biodiesel production (tons of oil equivalent (toe), thousands)	OECD [59]
Bioenergy technology	BET	Bioenergy technology (total patents)	OECD [59]
Environmental policy stringency	EPS	Environmental policy stringency index	OECD [59]
Government spendings	GS	General government final consumption expenditure (% of GDP)	World Bank [58]
GDP per capita	GDP	GDP per capita (constant 2015 USD)	World Bank [58]

Table 2. Descriptive statistics.

	Mean	Median	Max	Min	Std. Dev.	Skewness	Kurtosis
RD	6.068	5.856	9.902	3.387	2.155	0.287	1.596
BE	3.998	6.094	6.784	0.000	3.140	−0.509	1.293
BET	5.712	6.636	7.285	2.485	1.611	−0.793	2.085
EPS	1.527	0.970	3.540	0.060	1.232	0.279	1.381
GS	15.53	15.80	17.13	13.19	0.986	−0.461	2.508
GDP	8.463	8.543	9.355	7.411	0.637	−0.194	1.646

5. Empirical Results and Discussion

Before proceeding with ARDL regression, an important step is to confirm the stationarity of the variables. Two-unit root tests are performed: the PP unit root test and the DF-GLS unit root test. The results of both unit root tests are given in Table 3. Both tests show that only the GS variable is stationary at the initial level, denoted as I(0). Conversely, the other variables (RD, BE, BET, EPS, FD, and GDP) become stationary after applying the first difference, denoted as I(1). Hence, the mixed integration order among variables and absence of I(2) stationary variables allow us to use the ARDL method for estimating the model. The LR and SR coefficient estimates of the ARDL models are given in Table 4. Based on two proxy variables of BE, two ARDL models are estimated. The baseline model considers the role of the bioenergy variable, whereas the robustness model considers the impact of the bioenergy technology variable.

Table 3. Unit root results.

	PP			DF-GLS		
	I(0)	**I(1)**	**Decision**	**I(0)**	**I(1)**	**Decision**
RD	0.093	−5.435 ***	I(1)	0.405	−4.503 ***	I(1)
BE	0.093	−5.435 ***	I(1)	0.405	−4.503 ***	I(1)
BET	−2.515	−4.001 ***	I(1)	−1.231	−1.780 *	I(1)
EPS	0.236	−4.591 ***	I(1)	0.724	−4.623 ***	I(1)
GS	−2.696 *		I(0)	−1.609 *		I(0)
GDP	−1.803	−2.703 *	I(1)	−1.154	−1.747 *	I(1)

Note: *** $p < 0.01$, * $p < 0.1$.

Table 4. Long- and short-run estimates (ARDL).

	ARDL				ARDL (Robustness)			
Variable	**Coefficient**	**S.E**	**t-Stat**	**Prob.**	**Coefficient**	**S.E**	**t-Stat**	**Prob.**
Long run								
BE	0.271 ***	0.029	9.292	0.011				
BET					0.552 ***	0.092	5.978	0.000
EPS	0.134 ***	0.035	3.779	0.063	0.228 **	0.101	2.256	0.041
GS	0.112	0.159	0.704	0.492	0.051	0.052	0.973	0.347
GDP	2.545 ***	0.777	3.276	0.005	4.069 ***	0.297	13.71	0.000
Short run								
BE	0.142 ***	0.047	3.032	0.010				
BE(−1)	0.055	0.050	1.097	0.293				
BE(−2)	−0.199 ***	0.051	−3.934	0.002				
BET					1.072 ***	0.311	3.442	0.004
EPS	0.160 *	0.085	1.874	0.103	0.443 *	0.234	1.898	0.079
EPS(−1)	−0.184	0.246	−0.749	0.468				
EPS(−2)	−0.231	0.192	−1.205	0.250				
GS	0.129	0.092	1.399	0.185	0.231	0.161	1.436	0.173
GS(−1)					0.514 **	0.218	2.359	0.033
GS(−2)					−0.382 ***	0.134	−2.850	0.013
GDP	6.926	4.550	1.522	0.150	3.855	4.386	0.879	0.394
GDP(−1)	1.911	3.766	0.507	0.620	4.830	5.634	0.857	0.406
C	16.01 **	6.620	2.419	0.028	24.20 ***	2.276	10.63	0.000
Diagnostics								
F-test	11.87 ***				9.595 ***			
ECM(−1)	−0.737 ***	0.217	−3.391	0.077	−0.692 ***	0.108	−6.416	0.023
LM	1.365				0.852			
RESET	1.467				1.311			
CUSUM	S				S			
CUSUM-sq	S				S			

Note: ***, **, and * show significance at 1%, 5%, and 10%.

In the baseline ARDL model in Table 4, the BE estimate depicts a significant and positive impact on RD in the LR and SR in China. The coefficient estimate shows that a 1% increase in the BE will cause 0.271% improvement in RD in the LR and 0.142% in the SR in China. This result is supported by Fasse et al. [49], who confirm bioenergy's positive and favorable influence on rural development in China. This result is as per our expectations. Energy is the primary input source for driving rural economic activities. Out of the total energy consumption in China, the share of renewables is 15%, and bioenergy contributes one-third of the total renewable energy. Therefore, bioenergy is one of the important sources of renewables in China, particularly in rural areas; its accessibility and production make it an ideal energy source. According to Xu et al. [64], bioenergy is the primarily important source of energy in the rural regions in Central China, which are not well equipped in terms of energy infrastructure and trends as opposed to urban areas, where

households enjoy a much better, sophisticated, and efficient energy structure. Increasing bioenergy consumption in rural China can significantly reduce the environmental impacts of economic activities. In addition, bioenergy production can lead to increased research and development, innovation, and skill training in the bioenergy sectors, resulting in the rise of entrepreneurship, job creation, and local value addition in rural economies. Therefore, the significance of bioenergy is well established for rural development due to its contribution to achieving socio-economic and ecological objectives in rural areas, and this argument is supported by Kothari et al. [65] and Xu et al. [64].

The EPS also reports a significant and positive impact on RD in the LR and SR in China. The EPS estimate depicts that a 1% change in EPS will enhance RD by 0.134% in the LR and 0.160% in the SR in China. This result is backed by Mittenzwei et al. [17], who noted the positive impact of environmental policy stringency on rural development in China. Environmental regulations are gaining popularity as a supportive policy for other mitigating measures. In the context of rural development, strict environmental policies can promote sustainable practices and economic opportunities in rural areas. The implementation of strict environmental policies plays a vital role in improving the living standards of the people living in rural areas by enhancing the air and water quality, mitigating emissions, conserving natural resources, fostering green industries, and promoting eco-friendly agricultural activities in rural areas. Some past studies also support the positive impact of environmental regulations on rural development [19].

Conversely, GS does not report any significant impact on RD in the LR and SR in China. On the other hand, the impact of GDP on RD is found to be significantly positive in the LR but insignificant in the SR. The GDP estimate shows that a 1% upsurge in GDP will enhance RD by 2.545% in the LR in China. The robustness ARDL model results show that BET is significantly and positively associated with RET in the LR and SR in China. It is reported that a 1% increase in BET will improve RD by 0.552% in the LR and 1.072% in the SR in China. Table 4 shows that EPS and RD are significantly and positively associated in the LR and SR in China. A 1% change in EPS will cause a 0.228% increase in RD in the LR and 0.443% in the SR in China. Similar to the baseline ARDL model, GS does not report any significant impact on RD in the LR and SR in the robustness ARDL model in China. However, GDP impact on RD is significant in the LR but insignificant in the SR in China. The findings show that a 1% escalation in GDP will enhance RD by 4.069% in the LR in China. Hence, it is confirmed that BE, BET, EPS, and GDP can contribute significantly in the process of rural development.

The marginal effect of bioenergy on rural development is quantified via the use of the ARDL. The marginal effects are used to represent the expected change in rural development for every one unit change in bioenergy production and bioenergy technologies. We take the log of the variables to interpret the results in percentage form and to nullify the units attached. To be more precise, if all other factors are held constant, the quantification of the marginal effects states that the rural development changes by 0.271% and 0.552% due to a 1% change in BE and BET variables, implying that bioenergy has a crucial role in rural development. The significance is confirmed by the t-stats and probability attached to each estimate. For instance, the probability value of 0.05 states that we are 95% sure that the sample represents the true picture of the population.

The diagnostic tests for both ARDL models are presented in the lower panel of Table 4. The Ramsey RESET test and CUSUM and CUSUM-sq tests demonstrate that the models are correctly specified and stable. Additionally, long-run cointegration exists among the variables as depicted by statistically significant F-test and ECM test estimates in both models. Moreover, it is confirmed through negative coefficient estimates of the ECM term that the instability in models will converge towards stability in the long run. The speed of adjustment is 73% in one year according to the baseline model and 69% according to the robustness model. No evidence of serial correlations are detected in both models as shown by the estimates of the LM test.

Table 5 reports the outcomes of Granger causality. The results show that one-way causality runs from BE to RD, RD to GS, BE to EPS, GDP to BE, and GDP to EPS. On the other hand, the bi-directional causality is found between EPS and RD and GDP and RD. It demonstrates that both variables (EPS and RD) and (GDP and RD) are causing each other. In short, BE, EPS, and GDP directly affect RD. Thus, we suggest that any policy change that causes prevalent changes in BE, EPS, and GDP also causes improvement in RD. In other words, we can claim that a policy that fosters BE, EPS, and GDP also helps RD to improve.

Table 5. Granger causality results.

Null Hypothesis:	F-Stat	Prob.
BE → RD	2.731 *	0.089
RD → BE	0.998	0.386
EPS → RD	3.592 **	0.047
RD → EPS	4.035 **	0.034
GS → RD	0.966	0.398
RD → GS	7.748 ***	0.003
GDP → RD	9.074 ***	0.002
RD → GDP	6.901 ***	0.005
EPS → BE	0.077	0.926
BE → EPS	2.646 *	0.096
GS → BE	0.438	0.652
BE → GS	1.039	0.372
GDP → BE	3.822 **	0.039
BE → GDP	1.939	0.170
GS → EPS	0.211	0.811
EPS → GS	1.600	0.227
GDP → EPS	4.218 **	0.030
EPS → GDP	2.073	0.152
GDP → GS	0.800	0.463
GS → GDP	0.039	0.961

Note: ***, **, and * show significance at 1%, 5%, and 10%.

The LR, SR, and speed of convergence estimates obtained under the QARDL method are given in Table 6. The QARDL model results confirm that the ECM parameters are significantly negative across all quantiles (0.05 to 0.95), indicating that any disequilibrium between RD and the independent variables will converge towards equilibrium in the LR. The QARDL findings report that BE is significantly positive in the lowest and highest quantiles (0.05 and 0.10) and the highest quantiles (0.80 to 0.95). These findings indicate that BE exerts an increasing impact on RD in the lowest and highest quantiles, while the effect remains insignificant in moderate quantiles (0.20 to 0.70) in the LR. Interestingly, the RD effect of BE increases with the increase in the BE level from the lowest to highest quantiles (0.05–0.95). For instance, for the lowest level of RD (0.05 quantile), the RD effect of BE is 0.065% against the highest RD quantile (0.95), where this effect is 0.087%. EPS also produces the significant and positive impact on RD in most of the quantiles. The coefficient estimates are significant in the lowest quantiles (0.05th) and medium to highest quantiles (0.30th to 0.95th). The RD effect of EPS is continuously rising as shown by the trend in the coefficient estimates of EPS from the lowest to highest quantiles. The EPS estimates show that the RD effect of EPS is 0.634% in the 0.05th quantile, which becomes 0.941% in the 0.30th quantile, and reaches 1.827% in the 0.95th quantile in the LR. In our study, GS reports an insignificant impact on RD in the LR. This finding is consistent with the results obtained under baseline and robust ARDL models. The estimate of GDP is positive and significant in all quantiles except the 0.10 and 0.20 quantiles. These findings represent that GDP reports an increasing impact on RD but the impact is increasing at a diminishing rate. The GDP estimates demonstrate that the RD effect of EPS is 1.751% in the 0.05th quantile, 1.359% in the 0.30th quantile, and 0.073% in the 0.95th quantile in the LR.

Table 6. Long- and short-run estimates (QARDL). Note: *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

	Long Run				Short Run							
	BE	**EPS**	**GS**	**GDP**	**BE**	**EPS**	**EPS(−1)**	**GS**	**GDP**	**GDP(−1)**	**C**	**ECM**
0.05	0.065 ***	0.634 **	0.332	1.751 **	0.062 ***	0.484 *	0.127	0.061	−4.647 **	4.732 **	15.57 **	−0.543 ***
	2.919	2.038	1.538	2.450	4.496	1.719	0.519	1.284	−2.497	2.530	2.078	−6.369
0.10	0.074 ***	0.854	0.252	1.230	0.064 ***	0.584 **	0.040	0.066	−4.346 **	4.430 **	10.24	−0.551 ***
	2.006	1.339	0.978	0.780	4.749	2.298	0.178	1.165	−2.321	2.354	0.631	−6.407
0.20	0.003	0.852	0.123	1.518	0.070 ***	0.557 ***	−0.041	0.048	−5.623 ***	5.729 ***	10.23	−0.505 ***
	0.060	1.630	0.646	1.089	6.073	3.621	−0.298	0.956	−2.801	2.843	0.748	−5.108
0.30	−0.006	0.941 ***	0.067	1.359 ***	0.052 ***	0.602 ***	−0.197	0.046	−1.785	1.845	8.038 ***	−0.372 ***
	−0.210	8.312	1.463	4.006	4.623	5.482	−1.447	0.804	−0.562	0.579	2.806	−5.051
0.40	−0.005	1.035 ***	0.061	1.234 ***	0.058 ***	0.543 ***	−0.116	0.054	−3.031	3.090	6.970 ***	−0.406 ***
	−0.160	9.680	1.468	4.108	4.753	4.513	−1.064	0.719	−0.895	0.911	2.952	−4.994
0.50	−0.008	1.051 ***	0.059	1.246 ***	0.042 *	0.581 ***	−0.140	0.033	−3.491	3.604	7.029 ***	−0.434 ***
	−0.257	9.167	1.380	3.953	1.941	2.875	−1.202	0.637	−0.707	0.734	2.895	−2.633
0.60	0.004	1.103 ***	0.054	1.155 ***	0.028 **	0.594 **	−0.106	0.001	−4.109	4.305	6.252 ***	−0.475 *
	0.131	8.975	1.372	3.593	2.528	2.238	−0.581	0.052	−0.747	0.773	2.658	−1.806
0.70	0.025	1.269 ***	0.043	0.823 **	0.029 ***	0.676 **	−0.042	0.001	−3.996	4.241	3.510 **	−0.599 **
	0.585	7.693	1.047	1.971	2.936	2.389	−0.201	0.037	−0.798	0.833	2.314	−2.224
0.80	0.078 *	1.282 ***	0.039	0.666 *	0.021 **	0.821 ***	0.079	0.021 *	−3.452	3.824	2.202 **	−0.818 ***
	1.925	6.650	0.889	1.792	2.357	5.460	0.636	1.685	−0.868	0.961	2.157	−4.896
0.90	0.084 **	1.475 ***	0.008	0.481 *	0.026 ***	0.739 ***	0.268 ***	0.019 *	−5.744 **	6.189 **	1.819 **	−0.788 ***
	2.104	6.081	0.182	1.719	3.229	4.268	2.633	1.955	−2.159	2.346	2.004	−5.401
0.95	0.087 **	1.827 ***	0.005	0.07 3*	0.023 ***	0.737 ***	0.268 ***	0.036 ***	−5.891 ***	6.344 ***	3.369 *	−0.787 ***
	2.416	8.524	0.646	1.697	3.612	5.453	3.151	2.743	−2.853	3.098	1.928	−6.807

The short-run QARDL dynamics presented in Table 6 reveal that BE positively impacts the RD in all the grids of the lower, medium, and upper ranges of the quantiles (0.05 to 0.95), indicating an increasing impact of BE on RD in the SR. In the short run, EPS also positively and significantly influences RD in all quantiles (0.05 to 0.95). Contrary to the LR dynamics, GS reflects the significant and positive influence on RD in the range of the extreme highest quantiles (0.80 to 0.95), representing that GS only improves RD at the highest level (0.80 to 0.95) in the SR. The effect between quantiles 0.05 to 0.70 is positive but statistically insignificant. The GDP impact on RD is negative and significant in the lowest quantiles (0.05 to 0.20) and highest quantiles (0.90 and 0.95). This nexus is statistically insignificant in quantiles 0.30 to 0.80 in the SR. In conclusion, we find that BE, EPS, and GDP have a long-run positive association with rural development, but in the short run, BE, EPS, and GS are found to have a positive influence on rural development except GDP per capita, which has a negative influence on rural development. The graphical depiction of BE and EPS across quantiles in the short and long run are presented in Figures 2 and 3.

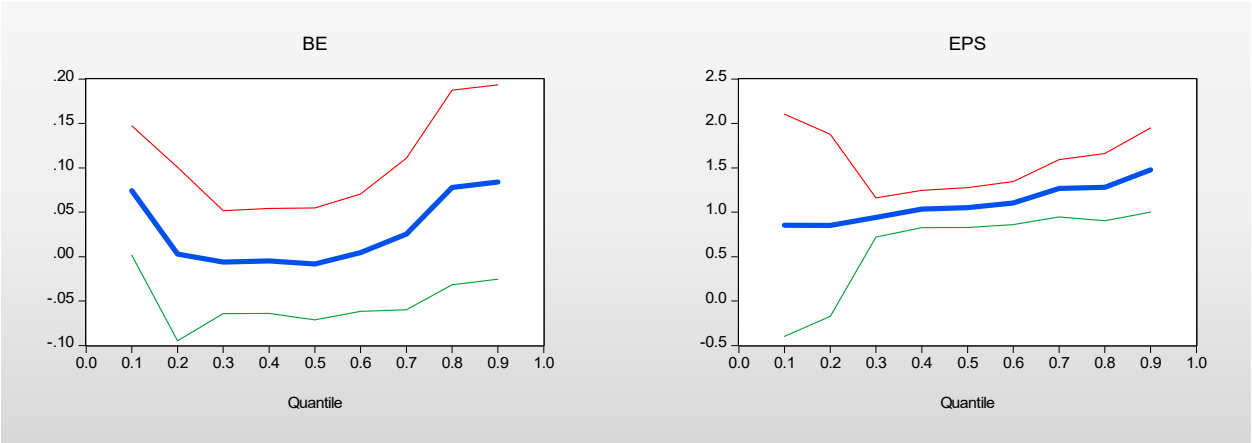


Figure 2. Long-run estimates of BE and EPS. Note: The solid line indicates estimated parameters across quantiles, while the outer lines show confidence intervals.

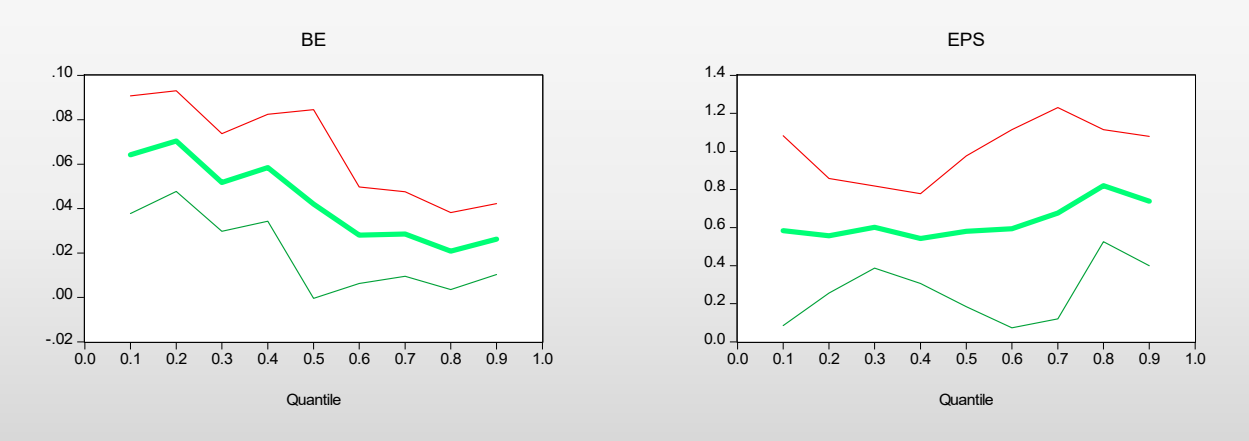


Figure 3. Short-run estimates of BE and EPS. Note: The solid line indicates estimated parameters across quantiles, while the outer lines show confidence intervals.

Table 7 comprises the outcomes of the Wald test. The ECM test result shows that the null of linearity is not accepted. Considering the long-run parameters, the results report that the hypothesis of variable constancy is not accepted for the case of BE, EPS, GS, and GDP. These findings indicate that the cointegration between RD and BE, RD and EPS, RD and GS, and RD and GDP are dynamic across diverse quantiles, which confirms the asymmetry of the parameters. Considering the short-run parameters, the Wald test findings confirm the asymmetric cointegration between RD and BE, RD and EPS, and RD and GS. Conversely, The Wald test fails to reject the null hypothesis in the case of GDP, demonstrating the symmetric influence of GDP on RD in the short run.

Table 7. Wald test results.

		Wald Stat	Prob.
Long run	BE	12.08 ***	0.000
	EPS	10.29 ***	0.000
	GS	9.050 ***	0.000
	GDP	10.35 ***	0.000
Short run	BE	10.05 ***	0.000
	EPS	8.031 ***	0.001
	EPS(−1)	0.055	0.804
	GS	7.096 ***	0.002
	GDP	2.722	0.569
	GDP(−1)	2.949	0.541
	ECM	12.06 ***	0.000

Note: *** show significance at 1%.

6. Conclusions and Implications

Rural areas are the hub of agricultural and livestock activities and play a vital role in the sustainable development of a country. Energy is not only the crucial driver of economic activities within urban areas but also important in shaping economic activities within rural areas. Even though conventional energy sources are crucial for the prosperity of rural areas, they also prove detrimental to the rural ecosystem. To achieve sustainable rural development, increasing the consumption of renewable energy sources can prove vital. Among all the renewable energy sources, bioenergy is the cheapest and easiest to produce in rural areas. Therefore, it is crucial to estimate the impact of bioenergy on rural development. The literature in this regard is in its infancy, and to comprehend the complex nature of the relationship between bioenergy and rural development, we need a fresh empirical analysis. Thus, the primary purpose of this analysis is to examine bioenergy's impact on rural development. To analyze the nexus between bioenergy and rural development,

we employ the ARDL framework. The results highlight the significance of bioenergy for rural development in the short and long run. Likewise, environmental policy stringency is also a vital factor in fostering short- and long-run development. In addition, a one-way causal relationship is observed between bioenergy and rural development and between government spending and rural development. However, a two-way causative link is observed between GDP and rural development, as well as environmental policy stringency and rural development. Lastly, the QARDL results confirm that bioenergy boosts rural development at the lowest and the highest levels.

Based on these outcomes, we can offer some important policy suggestions. First and foremost, bioenergy proves crucial for rural development. Therefore, we suggest that policymakers increase bioenergy's share in the national grid. Particularly, power plants near rural areas should predominantly produce electricity using bioenergy. As bioenergy is obtained from plants, which are vastly available in rural areas, bioenergy production should be part and parcel of the energy policy for rural areas. The energy policy should be designed in such a way that it induces financial institutions and organizations to give priority to bioenergy projects while providing money and capital for energy-related investments. In this regard, a specific energy fund should be established to help promote bioenergy development in rural areas. The government should initiate awareness campaigns with regard to the benefits of enhancing the production and consumption of bioenergy for sustainable rural development. Further, to enhance the synergies and co-benefits, it is suggested that policymakers should integrate bioenergy into broader rural development strategies, including sustainable and land management practices, forest management, and rural electrification plans. Second, the implementation of strict environmental policies can complement all other policies for sustainable development; hence, they are crucial for rural development. Thus, it is suggested to implement strict environmental policies as an important part of rural development policy that can foster sustainable land use practices, the protection of rural ecosystem, and natural resource management in rural areas, contributing to sustainable rural development by increasing the agricultural yield, preserving biodiversity, promoting economic activities, and creating job opportunities in urban regions. Environmental policy stringency can also stimulate investments in renewable energy, energy efficiency, and clean technologies, providing opportunities for rural entrepreneurs and businesses to participate in the green economy.

Additionally, according to sustainable development theory, the integration of renewable energy sources into rural development policies can foster sustainable rural development. Although traditional biomass can have a detrimental impact on sustainable rural development, our findings suggest otherwise. Thus, we contrast the traditional notion of sustainable development theory, suggesting a negative connection between traditional biomass energy and rural sustainable development. This extends the sustainable development theory by unveiling the mechanisms through which biomass energy can foster sustainable development. Further, our study gives a new dimension to the sustainable development theory by clarifying the supportive role of environmental policy stringency in fostering rural sustainable development. These policies are crucial in supporting other policies by setting strict environmental standards to curb pollution-intensive activities and providing economic incentives for eco-friendly practice projects, thereby aligning rural development with sustainability goals. In light of diffusion theory, strict environmental policies play an important role in increasing awareness regarding the benefits of adopting bioenergy technologies and their role in achieving sustainable rural development.

The following are the limitations of the study. First, the study considers only China for empirical analysis, limiting the scope of the study. Due to limited data availability, this study cannot be conducted for other global rural areas (e.g., developing countries). Future studies should address this limitation. Second, the ARDL and QARDL estimates are very sensitive to lag. Upcoming studies should perform robustness models by testing different lag lengths and comparing the results. Third, due to the absence of data for the openness or adaptability of rural local politicians or local society towards bioenergy, this study

overlooked these variables in the analysis. Future research should conduct primary data collection approaches to address these unmeasured factors. Fourth, in this analysis, we use biodiesel production as a proxy for bioenergy. However, biodiesel is mainly produced with residual biomass, which is not a carbon-free energy source as it requires burning food and non-food materials. Thus, using biodiesel as a proxy of bioenergy does not truly represent the impact of bioenergy on sustainable rural development. Therefore, future empirics should use other proxies of bioenergy, particularly the second-generation bioenergy sources that are produced with non-food materials and believed to be cleaner and greener and more appropriate in capturing the true impact of bioenergy on sustainable rural development. Lastly, another limitation of the analysis is the exclusion of some important variables from the model, including the Gini coefficient and human development index, which may prove vital in determining sustainable rural development. In addition, technological level and business innovativeness could be the confounding factors behind BE's impact on rural development. Therefore, future empirics should use the additional control variables stated above, which can provide more in-depth information on the bioenergy, EPS, and rural development nexus.

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References

1. Demirbas, A.H.; Demirbas, I. Importance of rural bioenergy for developing countries. *Energy Convers. Manag.* **2007**, *48*, 2386–2398. [CrossRef]
2. Shrestha, A.; Mustafa, A.A.; Htike, M.M.; You, V.; Kakinaka, M. Evolution of energy mix in emerging countries: Modern renewable energy, traditional renewable energy, and non-renewable energy. *Renew. Energy* **2022**, *199*, 419–432. [CrossRef]
3. Sims, R.E.; Rogner, H.H.; Gregory, K. Carbon emission and mitigation cost comparisons between fossil fuel, nuclear and renewable energy resources for electricity generation. *Energy Policy* **2003**, *31*, 1315–1326. [CrossRef]
4. Yoro, K.O.; Daramola, M.O. CO_2 emission sources, greenhouse gases, and the global warming effect. In *Advances in Carbon Capture*; Woodhead Publishing: Sawston, UK, 2020; pp. 3–28.
5. United Nations. Fact Sheet: Climate Change Science—The Status of Climate Change Science Today. 2011. Available online: https://unfccc.int/files/press/backgrounders/application/pdf/press_factsh_science.pdf (accessed on 5 March 2024).
6. IRENA. Global Energy Transformation: A Roadmap to 2050. 2018. Available online: https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Apr/IRENA_Report_GET_2018.pdf (accessed on 5 March 2024).
7. Hussain, A.; Arif, S.M.; Aslam, M. Emerging renewable and sustainable energy technologies: State of the art. *Renew. Sustain. Energy Rev.* **2017**, *71*, 12–28. [CrossRef]
8. Guo, M.; Song, W.; Buhain, J. Bioenergy and biofuels: History, status, and perspective. *Renew. Sustain. Energy Rev.* **2015**, *42*, 712–725. [CrossRef]
9. Londono-Pulgarin, D.; Cardona-Montoya, G.; Restrepo, J.C.; Munoz-Leiva, F. Fossil or bioenergy? Global fuel market trends. *Renew. Sustain. Energy Rev.* **2021**, *143*, 110905. [CrossRef]
10. Behera, B.K.; Varma, A. *Bioenergy for Sustainability and Security*; Springer International Publishing: Berlin/Heidelberg, Germany, 2019.
11. Zeller, M.; Grass, M. Prospects and Challenges of Biofuels in Developing Countries. In Proceedings of the 106th Seminar of the EAAE, Montpellier, France, 25–27 October 2007; No. 7945. European Association of Agricultural Economists: Wageningen, The Netherlands, 2007.
12. Shaaban, M.; Petinrin, J.O. Renewable energy potentials in Nigeria: Meeting rural energy needs. *Renew. Sustain. Energy Rev.* **2014**, *29*, 72–84. [CrossRef]
13. Aceleanu, M.I.; Șerban, A.C.; Țîrcă, D.M.; Badea, L. The rural sustainable development through renewable energy. The case of Romania. *Technol. Econ. Dev. Econ.* **2018**, *24*, 1408–1434. [CrossRef]

14. Stolarski, M.J.; Dudziec, P.; Krzyżaniak, M.; Olba-Zięty, E. Solid biomass energy potential as a development opportunity for rural communities. *Energies* **2021**, *14*, 3398. [CrossRef]
15. Zheng, D.; Shi, M. Multiple environmental policies and pollution haven hypothesis: Evidence from China's polluting industries. *J. Clean. Prod.* **2017**, *141*, 295–304. [CrossRef]
16. Usman, A.; Ullah, S.; Ozturk, I.; Sohail, S.; Sohail, M.T. Does environmental policy stringency reduce trade in energy resources? Insights from coal, petroleum, and gas. *Resour. Policy* **2024**, *89*, 104679. [CrossRef]
17. Mittenzwei, K.; Gustavsen, G.W.; Grimsrud, K.; Lindhjem, H.; Bjørkhaug, H. Perceived effects of climate policy on rural areas and agriculture: A rural-urban-divide. *J. Rural Stud.* **2023**, *100*, 103001. [CrossRef]
18. Swanson, K.E.; Kuhn, R.G.; Xu, W. Environmental policy implementation in rural China: A case study of Yuhang, Zhejiang. *Environ. Manag.* **2001**, *27*, 481–491. [CrossRef]
19. Huang, Y.; Gan, J.; Liu, B.; Zhao, K. Environmental policy and green development in urban and rural construction: Beggar-thy-neighbor or win-win situation? *J. Clean. Prod.* **2024**, *446*, 141201. [CrossRef]
20. IEA. Implementation of Bioenergy in China. 2021. Available online: https://www.ieabioenergy.com/wp-content/uploads/2021/11/CountryReport2021_China_final.pdf (accessed on 5 March 2024).
21. Shan, M.; Wang, P.; Li, J.; Yue, G.; Yang, X. Energy and environment in Chinese rural buildings: Situations, challenges, and intervention strategies. *Build. Environ.* **2015**, *91*, 271–282. [CrossRef]
22. Gong, P.; Liang, S.; Carlton, E.J.; Jiang, Q.; Wu, J.; Wang, L.; Remais, J.V. Urbanisation and health in China. *Lancet* **2012**, *379*, 843–852. [CrossRef]
23. Imura, H. *Environmental Issues in China Today*; Springer: London, UK, 2013.
24. NBSC. *China Statistical Yearbook 1980–2015*; China Statistic Press: Beijing, China, 1980–2015. (In Chinese)
25. Qiu, H.; Yan, J.; Lei, Z.; Sun, D. Rising wages and energy consumption transition in rural China. *Energy Policy* **2018**, *119*, 545–553. [CrossRef]
26. Li, Z.; Li, Y. Environmental regulation and employment: Evidence from China's new Environmental Protection Law. *Econ. Anal. Policy* **2024**, *82*, 400–416. [CrossRef]
27. Sørensen, J.F.L.; Jørgensen, H.P. Rural development potential in the bioeconomy in developed countries: The case of biogas production in Denmark. *Sustainability* **2022**, *14*, 11077. [CrossRef]
28. Lehtonen, O.; Okkonen, L. Socio-economic impacts of a local bioenergy-based development strategy. The case of Pielinen Karelia, Finland. *Renew. Energy* **2016**, *85*, 610–619. [CrossRef]
29. Low, S.A.; Isserman, A.M. Ethanol and the local economy. Industry trends, location factors, economic impacts, and risks. *Econ. Dev. Q.* **2009**, *23*, 71–88. [CrossRef]
30. Okkonen, L.; Lehtonen, O. Local, regional and national level of the socioeconomic impacts of a bio-oil production system—A case in Lieksa, Finland. *Renew. Sustain. Energy Rev.* **2017**, *71*, 103–111. [CrossRef]
31. Zhu, X.; Vrachioli, M.; Baldoni, E.; M'Barek, R.; Sauer, J. Is biorefinery establishment enhancing the EU labour market on a regional level? *Reg. Stud.* **2024**, *58*, 1603–1617. [CrossRef]
32. Mumtaz, S.; Abbas, Y.; Ahmad, I.; Hassan, A.; Saeed, M.F.; Yun, S.; Almarhoon, Z.M.; Shelkh, M.; Hassan, A.M.; Rosaiah, P.; et al. Sugarcane-bagasse-ash in enhanced mesophilic Co-digestion for biogas and nutrient recovery: A concept of developing rural circular bioeconomy. *Environ. Res.* **2023**, *237*, 116691. [CrossRef]
33. Singh, A.K.; Pal, P.; Rathore, S.S.; Sahoo, U.K.; Sarangi, P.K.; Prus, P.; Dziekański, P. Sustainable utilization of biowaste resources for biogas production to meet rural bioenergy requirements. *Energies* **2023**, *16*, 5409. [CrossRef]
34. Giddings, B.; Hopwood, B.; O'brien, G. Environment, economy and society: Fitting them together into sustainable development. *Sustain. Dev.* **2002**, *10*, 187–196. [CrossRef]
35. Manioudis, M.; Meramveliotakis, G. Broad strokes towards a grand theory in the analysis of sustainable development: A return to the classical political economy. *New Polit. Econ.* **2022**, *27*, 866–878. [CrossRef]
36. Tomislav, K. The concept of sustainable development: From its beginning to the contemporary issues. *Zagreb Int. Rev. Econ. Bus.* **2018**, *21*, 67–94.
37. Dincer, I. Renewable energy and sustainable development: A crucial review. *Renew. Sustain. Energy Rev.* **2000**, *4*, 157–175. [CrossRef]
38. Rezaei, R.; Ghofranfarid, M. Rural households' renewable energy usage intention in Iran: Extending the unified theory of acceptance and use of technology. *Renew. Energy* **2018**, *122*, 382–391. [CrossRef]
39. Leupolt, M. Integrated rural development: Key elements of an integrated rural development strategy. *Sociol. Rural.* **1977**, *17*, 7–28. [CrossRef]
40. Ruttan, V.W. Integrated rural development programmes: A historical perspective. *World Dev.* **1984**, *12*, 393–401. [CrossRef]
41. Benedek, J.; Sebestyén, T.T.; Bartók, B. Evaluation of renewable energy sources in peripheral areas and renewable energy-based rural development. *Renew. Sustain. Energy Rev.* **2018**, *90*, 516–535. [CrossRef]
42. Clausen, L.T.; Rudolph, D. Renewable energy for sustainable rural development: Synergies and mismatches. *Energy Policy* **2020**, *138*, 111289. [CrossRef]
43. Afsharzade, N.; Papzan, A.; Ashjaee, M.; Delangizan, S.; Van Passel, S.; Azadi, H. Renewable energy development in rural areas of Iran. *Renew. Sustain. Energy Rev.* **2016**, *65*, 743–755. [CrossRef]

44. Li, S.; Zhang, L.; Su, L.; Nie, Q. Exploring the coupling coordination relationship between eco-environment and renewable energy development in rural areas: A case of China. *Sci. Total Environ.* **2023**, *880*, 163229. [CrossRef]
45. Naumann, M.; Rudolph, D. Conceptualizing rural energy transitions: Energizing rural studies, ruralizing energy research. *J. Rural Stud.* **2020**, *73*, 97–104. [CrossRef]
46. Babu, S.; Rathore, S.S.; Singh, R.; Kumar, S.; Singh, V.K.; Yadav, S.K.; Yadav, V.; Raj, R.; Yadav, D.; Shekhawat, K.; et al. Exploring agricultural waste biomass for energy, food and feed production and pollution mitigation: A review. *Bioresour. Technol.* **2022**, *360*, 127566. [CrossRef]
47. Openshaw, K. Biomass energy: Employment generation and its contribution to poverty alleviation. *Biomass Bioenergy* **2010**, *34*, 365–378. [CrossRef]
48. Adelekan, O.A.; Ilugbusi, B.S.; Adisa, O.; Obi, O.C.; Awonuga, K.F.; Asuzu, O.F.; Ndubuisi, N.L. Energy transition policies: A lobal review of shifts towards renewable sources. *Eng. Sci. Technol. J.* **2024**, *5*, 272–287. [CrossRef]
49. Fasse, A.; Winter, E.; Grote, U. Bioenergy and rural development: The role of agroforestry in a Tanzanian village economy. *Ecol. Econ.* **2014**, *106*, 155–166. [CrossRef]
50. Johansen, S. Statistical analysis of cointegration vectors. *J. Econ. Dyn. Control* **1988**, *12*, 231–254. [CrossRef]
51. Johansen, S.; Juselius, K. Maximum likelihood estimation and inference on cointegration—With appucations to the demand for money. *Oxf. Bull. Econ. Stat.* **1990**, *52*, 169–210. [CrossRef]
52. Pesaran, M.H.; Shin, Y.; Smith, R.J. Bounds testing approaches to the analysis of level relationships. *J. Appl. Econom.* **2001**, *16*, 289–326. [CrossRef]
53. Cho, J.S.; Kim, T.H.; Shin, Y. Quantile cointegration in the autoregressive distributed-lag modeling framework. *J. Econom.* **2015**, *188*, 281–300. [CrossRef]
54. Ren, X.; An, Y.; Jin, C. The asymmetric effect of geopolitical risk on China's crude oil prices: New evidence from a QARDL approach. *Financ. Res. Lett.* **2023**, *53*, 103637. [CrossRef]
55. CNNIC. China Internet Network Information Center Statistical Reports. 2023. Available online: https://www.cnnic.com.cn/IDR/ReportDownloads/ (accessed on 1 March 2024).
56. CHNS. China Health and Nutrition Survey Datasets. 2023. Available online: https://www.cpc.unc.edu/projects/china/data/datasets (accessed on 1 March 2024).
57. CFPS. China Family Panel Studies Datasets. 2023. Available online: https://www.isss.pku.edu.cn/cfps/ (accessed on 1 March 2024).
58. World Bank. World Development Indicators. 2023. Available online: https://databank.worldbank.org/source/world-development-indicators (accessed on 1 March 2024).
59. OECD. OECD Statistics. 2023. Available online: https://stats.oecd.org/Index.aspx?ThemeTreeId=9 (accessed on 1 March 2024).
60. IRENA. Bioenergy & Biofuels. 2024. Available online: https://www.irena.org/Energy-Transition/Technology/Bioenergy-and-biofuels (accessed on 11 July 2024).
61. Botta, E.; Koźluk, T. *Measuring Environmental Policy Stringency in OECD Countries: A Composite Index Approach (No. 1177)*; OECD Publishing: Paris, France, 2014.
62. Fan, S.; Hazell, P.; Thorat, S. Government spending, growth and poverty in rural India. *Am. J. Agric. Econ.* **2000**, *82*, 1038–1051. [CrossRef]
63. Zhang, Y.; Wan, G. The impact of growth and inequality on rural poverty in China. *J. Comp. Econ.* **2006**, *34*, 694–712. [CrossRef]
64. Xu, X.; Liu, G.; Mola-Yudego, B. Barriers and opportunities for bioenergy expansion in Chinese rural areas. *Energy Sustain. Dev.* **2022**, *70*, 181–193. [CrossRef]
65. Kothari, R.; Vashishtha, A.; Singh, H.M.; Pathak, V.V.; Tyagi, V.V.; Yadav, B.C.; Ashokkumar, V.; Singh, D.P. Assessment of Indian bioenergy policy for sustainable environment and its impact for rural India: Strategic implementation and challenges. *Environ. Technol. Innov.* **2020**, *20*, 101078. [CrossRef]

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