Harnessing Renewable Energy along the Belt and Road: Insights into Capacity and Demographic Influences

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Abstract. The Belt and Road Initiative (BRI) presents a dual opportunity and challenge for participating countries, which possess abundant natural resources and considerable development potential. A critical challenge is the effective utilization of renewable energy resources. This study investigates the influence of the BRI on renewable energy generation in the associated countries, utilizing a difference-in-differences model for empirical analysis of data spanning from 2011 to 2023. The findings indicate a significant enhancement in renewable energy power generation among BRI participant countries. Notably, the installed capacity of generation equipment exerts a positive moderating effect on this relationship, whereas population growth rate demonstrates a negative moderating influence. This research elucidates the advantageous impact of the BRI on renewable energy development, highlighting variances tied to infrastructural conditions across different countries. The results provide empirical support for policy formulation and offer novel perspectives for advancing renewable energy development. The study suggests that countries along the BRI route should actively engage in energy cooperation, augment the capacity of generation equipment, and strategically manage the interplay between short-term population growth and long-term energy objectives to facilitate sustainable energy transitions.

Keywords: Belt and Road Initiative, Renewable Energy Power Generation, Infrastructure Construction, Difference-in-Differences Model.

1 Introduction

Energy is a fundamental driver of modern societal advancement, and energy security constitutes a crucial aspect of national security [1]. In the context of the COVID-19 pandemic, the imperative and urgency of ensuring energy supply security have been underscored [2]. The Belt and Road Initiative (BRI), grounded in the principle of peaceful development, aims to enhance economic cooperation with the nations along its route, fostering a community characterized by shared interests, common destiny, and mutual responsibility [3]. With the BRI's gradual implementation, the countries and regions within its ambit have garnered global attention due to their abundant energy resources and substantial economic development potential. Nevertheless, despite the wealth of natural resources, these nations face significant challenges concerning energy

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security and sustainable development, particularly in terms of leveraging renewable energy to address power supply issues [4].

Existing literature has explored the BRI and the development of renewable energy; however, much of the focus has been on case studies, the initiative's impact on macroeconomic growth, or the examination of energy policies within individual countries [5]. There remains a paucity of research dedicated to assessing the performance of countries along the BRI in renewable energy, specifically in the domain of power generation, within the initiative's framework. Furthermore, there exists a gap in systematic research analyzing regulatory factors influencing policy impacts and infrastructure development. This research gap has impeded a comprehensive understanding of the BRI's effects on the energy sector. Consequently, the objective of this study is to address these research gaps by developing an energy security assessment model and conducting a comprehensive analysis of the current state of renewable energy power generation in countries along the Belt and Road.

The contribution of this paper lies in its exploration of the BRI's impact on renewable energy power generation from a systematic and international comparative perspective, while also assessing the moderating roles of power generation equipment installed capacity and population growth rate. Through empirical analysis, this study elucidates the positive effects of implementing the Belt and Road policy on renewable energy power generation and highlights variances in policy outcomes across differing infrastructure conditions and demographic growth scenarios. This research not only offers empirical support for relevant policy development but also presents novel perspectives and insights for further advancing renewable energy progress within the BRI framework in the future.

2 Literature Review and Research Hypotheses

2.1 Relationship between the Belt and Road Initiative and Renewable Energy Power Generation

Grounded in the theories of Comparative advantage and Factor endowment, it is posited that nations should specialize in the production of goods for which they have a comparative advantage based on their intrinsic natural endowments and production conditions [6]. The BRI serves as a catalyst for participating nations to harness and develop natural resources tailored to local conditions, thereby optimizing the allocation of production factors. This initiative is particularly conducive to attracting technology and capital to resource-rich nations that otherwise lack these critical inputs, thereby enhancing their capacity for renewable energy power generation. Moreover, as discussed in the work of Qamaruzzaman (2025), the technology exchange and transfer facilitated by the BRI allows for the extensive dissemination and application of renewable energy technologies from technologically advanced countries to those along the Belt and Road [7]. This transfer effectively raises the operational efficiency and technological standards of renewable energy projects. Concurrently, the BRI promotes the formulation and enhancement of renewable energy policy frameworks among participating countries, fostering policy communication and coordination, which collectively create an enabling environment for renewable energy project implementation. These factors collectively provide robust support for the expansion of renewable energy generation in countries aligned with the BRI. In contrast, nations that have not engaged in the BRI may lack these systematic supports, potentially constraining their renewable energy development both in scope and depth [8].

Therefore, the paper proposes the following hypothesis.

Hypothesis 1: Countries participating in the Belt and Road Initiative exhibit significant growth in renewable energy power generation compared to those that do not.

2.2 The Moderating Effect of Power Generation Equipment Capacity on the Interplay between the BRI and Renewable Energy Generation

Economies of scale refer to the economic phenomenon where the unit cost of production decreases as the scale of production expands [9]. Within the domain of renewable energy, an increase in installed capacity often correlates with enhanced efficiency and reduced unit costs, thereby augmenting both power generation capabilities and economic returns [10]. Economies of scale facilitate the expansion of renewable energy generation capacity by lowering equipment costs and enhancing technical efficiency. Theoretically, higher installed capacity translates to greater potential power generation and elevates the power generation ceiling of a country or region. In the context of the BRI, the transfer of technology and capital between participating countries can markedly enhance installed capacity, especially in nations with initially inadequate infrastructure. By integrating advanced power generation equipment and technology, these countries can swiftly expand their power generation capacity, thereby optimizing the utilization and efficiency of renewable energy resources. Furthermore, the augmentation of installed capacity is often accompanied by technological advancements. A substantial installed capacity offers ample opportunities and resources for technological innovation, with research indicating a positive correlation between installed capacity and technological progress. Enhanced capacity fosters technology research and application, thereby improving renewable energy generation efficiency and reducing fossil fuel dependency by incorporating more renewable energy sources (Ibid). Based on this contextual framework, the article proposes the following hypothesis.

Hypothesis 2: Within the framework of the BRI, the installed capacity of a nation's power generation equipment exerts a significant positive moderating effect on the growth of renewable energy generation. Specifically, greater installed capacity correlates with more pronounced growth in power generation.

2.3 The Moderating Effect of Population Growth Rate on the BRI-Renewable Energy Generation Relationship

Endogenous growth theory in modern economics posits that population growth can lead to expanded market sizes and increased labor supply, thereby fostering technological innovation and capital accumulation [11]. Consequently, a rapidly growing population amplifies domestic demand for renewable energy, stimulating investment and development in this sector and advancing technological progress and industrial development in renewable energy. The BRI offers participating countries opportunities for international cooperation and access to advanced technologies. Through technology transfer and financial support, countries can achieve significant advancements in renewable energy development. Countries experiencing rapid population growth may exhibit more urgent energy demands, accelerating the deployment and implementation of renewable energy projects. This, in turn, amplifies the impact of the BRI on renewable energy generation. In light of these considerations, the article proposes the following hypothesis.

Hypothesis 3: Population growth rate serves as a positive moderating factor in the effect of the BRI on national renewable energy generation. Specifically, in countries with high population growth rates, the initiative's role in promoting renewable energy generation is more pronounced.

3 Model and Empirical Analysis

3.1 Sample Selection and Data Sources

This study utilizes relevant indicator data from countries spanning the years 2011 to 2023 as the foundational sample. After counting the countries participating in the BRI, non-participating countries with similar economic development levels and resource conditions were selected as control samples to more effectively highlight the unique impact of the BRI on the energy structure transformation of participating countries. The sample data is sourced from multiple authoritative institutions. Prominently, the U.S. *Energy Information Administration* (EIA), operating under the U.S. Department of Energy, is distinguished for its comprehensive global energy statistics. The EIA's data concerning new energy production and the installed capacity of power generation equipment is both precise and trustworthy [12]. Moreover, the *Organization for Economic Co-operation and Development* (OECD) is renowned for its depth of experience in economic analysis and data compilation, employing sophisticated accounting methodologies to ensure that GDP data (expressed in purchasing power parity, current U.S. dollar terms, adjusted for seasonal variations) accurately reflects the prevailing economic conditions [13]. Additionally, as a globally recognized authoritative body, the United Nations employs a variety of methods to collect population data, thereby providing reliable insights into global population trends [14]. To bolster the reliability of the research outcomes, initial samples were subjected to the following screening processes: (1) samples with incomplete variable data were omitted; (2) variables with inconsistent unit scales were log-transformed. Following these procedures, a total of 357 valid national annual samples were obtained for further analysis.

3.2 Variable Definition and Measurement

Dependent Variable - Renewable Energy Power Generation ($Energy$). In this study, renewable energy power generation serves as the dependent variable, representing the aggregate electricity output of diverse new energy facilities within the regions influenced by the BRI. The analysis employs the logarithm of the empirically observed and recorded total new energy generation to address potential right-skewness in the data distribution. An elevated value of this variable signifies a pronounced development of the new energy sector within the region and a higher level of new energy utilization [15].

Explanatory Variable - Implementation of the BRI (BR). The research employs $time$ as a dummy variable to denote the years following the implementation of the BRI. For the post-implementation period in the sample countries, the dummy variable is coded as 1; for the period prior to the initiative's implementation, it is coded as 0. This approach facilitates a direct assessment of the policy impact of the BRI on new energy power generation over different temporal phases. An additional dummy variable, $policy$, is utilized to categorize sample countries, where $policy = 1$ signifies a country's participation in the BRI, and $policy = 0$ indicates non-participation. By employing these dummy variables, the study can distinctly compare changes in new energy power generation pre- and post-initiative implementation. This methodology effectively captures the policy effects engendered by the initiative's execution and provides a robust basis for delineating policy time boundaries for a comprehensive analysis of the BRI's impact on new energy power generation.

Moderating Variables. (1) Installed capacity of power generation equipment ($Capacity$): The installed capacity of power generation equipment refers to the sum of the maximum active power that the equipment can generate under rated operating conditions. It reflects the potential capacity, the supply stability, and the industry scale of new energy generation. (2) Population growth rate ($PGrowth$): The population growth rate is calculated by dividing the difference between the year-end population and the beginning of the year population by the beginning of the year population. This variable can predict the trend of electricity demand, affecting energy structure and industrial market potential.

Control Variables. In the research process, the article also introduces some control variables, including: Gross domestic product (GDP), calculated using the United Nations Purchasing Power Parity evaluation method; $EEXPORT$, which refers to the total amount of electricity and energy exported by a country to other countries or regions during a certain period of time; $ELoss$, an assessment of power grid efficiency based on electricity energy transmission and distribution losses; and the amount of foreign direct investment (INV), which calculates the total amount of funds invested by foreign investors in the field of renewable energy generation in the country during a certain period.

3.3 Empirical Model

The study employs a difference-in-differences model to assess the impact of the BRI on renewable energy power generation.

$$Energy_{i,t} = \beta_0 + \beta_1 time_{i,t} * policy_{i,t} + \gamma * Controls_{i,t} + \varepsilon_{i,t} \tag{1}$$

In Formula 1, $Energy$ represents renewable energy power generation. β_0 serves as an intercept term. This term reflects the baseline level of renewable energy generation in countries not influenced by the BRI prior to the policy's implementation, and it captures the differential in renewable energy generation between countries participating and those not participating in the initiative before its execution. β_1 is the focal parameter of the study, denoting the net effect of the BRI on the renewable energy power generation of participating countries in contrast to non-participating countries, both before and after the policy implementation. If the coefficient is greater than zero, it suggests that the initiative has significantly enhanced renewable energy generation in the participating countries. The interaction term, $time * policy$, serves as the independent variable (BR) in the analysis. γ acts as coefficients for control variables. This term is critical for accounting for other factors that might influence renewable energy generation, thereby facilitating a more precise estimation of the causal effect of the BRI. Additionally, the model incorporates a random error term $\varepsilon_{i,t}$ to account for other unobserved factors impacting renewable energy generation.

4 Research Results and Analysis

4.1 Descriptive Statistics

To perform a descriptive statistical analysis of the fundamental characteristics of each variable, Table 1 presents the descriptive statistical outcomes of the principal variables under investigation. The results reveal that: (1) The mean and standard deviation of $Energy$, an indicator of renewable energy power generation, are 3.1576 and 1.4395, respectively. Notably, on a logarithmic scale, the data exhibits significant deviation from the mean, which translates to exponential variations in actual power generation. This suggests considerable disparities in power generation among the sampled countries; (2) The mean value of BR, representing the implementation of the Belt and Road Initiative, is 0.3894, with a standard deviation of 0.4883. This indicates that countries vary in their adoption timing of the Belt and Road policy, or the pace of policy implementation differs across nations; (3) The distribution of other variables falls within a reasonable range.

Table 1. Descriptive statistical results.

	Count	**Mean**	**Std**	**Min**	**Median**	**Max**
Energy	357	3.1576	1.4395	0.0953	3.1897	6.4350
policy	357	0.6583	0.4750	0.0000	1.0000	1.0000
time	357	0.6695	0.4711	0.0000	1.0000	1.0000
BR	357	0.3894	0.4883	0.0000	0.0000	1.0000
GDP	357	14.3726	1.2102	11.7821	14.3879	16.7037
Capacity	357	20.1650	30.6970	0.3300	9.5000	194.0800
PGrowth	357	0.2876	0.7594	-2.0800	0.2800	2.9000
EExport	357	11.4069	13.3695	0.0000	6.9500	73.1000
ELoss	357	12.3913	19.7486	0.3400	4.5600	10.8800
INV	357	8.7694	1.4615	4.3228	8.9555	12.0809

4.2 Correlation Analysis

To initially assess the presence of significant correlations among the variables, a correlation analysis was performed. Table 2 presents the results of the correlation tests conducted on the primary variables. These results reveal that all variance inflation factors are below the threshold of 10, indicating an absence of severe multicollinearity. Consequently, the correlation between the independent variables does not substantially affect the regression coefficients of the model. Therefore, all variables are retained for further analysis.

Table 2. Statistics of variable Variance Inflation Factor.

	Feature	**VIF**
1	*BR*	6.3192
2	*Capacity*	7.3933
3	*PGrowth*	1.3788
4	*GDP*	3.6757
5	*EExport*	2.0451
6	*ELoss*	7.3012
7	*INV*	3.0311

4.3 Model Regression Results

Based on the research hypothesis outlined above, the paper initially tested hypothesis 1 across the entire sample. Table 3 presents the principal findings of the difference-in-differences model regression. (1) In Column (a), the coefficient of BR for the implementation of the Belt and Road Initiative is positive and statistically significant at the 1% significance level. This indicates that countries participating in the BRI are likely to experience enhanced growth in their renewable energy power generation. Participation in the initiative may provide these countries with access to various resources and collaborative opportunities. For instance, the initiative is expected to attract substantial investment in infrastructure development within participating nations, including renewable energy projects. Consequently, these countries may gain access to larger international markets, thereby facilitating the export and trade of renewable energy products and services, which ultimately accelerates power generation development. (2) Column (b) illustrates that, even after incorporating control variables, the coefficient of BR remains positive and statistically significant at the 1% significance level. This empirical evidence supports the validity of hypothesis H1.

Table 3. Benchmark model regression results.

	Full sample	
	(a)	**(b)**
BR	0.1442***	0.1609***
GDP		0.1647
Capacity		0.0043***

EExport		0.0072**
ELoss		-0.0134***
PGrowth		0.0102
INV		0.0029
Year	Yes	Yes
Country	Yes	Yes
F	762.9	697.9
R-squared	0.990	0.991
N	357	357

Note: The data in the table are the regression coefficients of the variables, ***, ** and * indicate that they are significant at the 1 per cent, 5 per cent and 10 per cent level of significance, respectively.

Secondly, the study evaluated Hypotheses 2 and 3. Table 4 presents the principal findings from the models. (1) In the column (a) of Hypothesis 2, the coefficient for the interaction term $BR\_Capacity\_interaction$, representing the interplay between the implementation of the BRI and the installed capacity of power generation equipment ($Capacity$), is shown to be positive and highly significant at the 1% significance level. This suggests that within the framework of the BRI, an increase in the installed capacity of power generation equipment more effectively enhances renewable energy generation. The likely rationale is that improvements in energy infrastructure under the initiative allow for more efficient operation of power generation equipment and better integration of diverse renewable energy sources. Consequently, as installed capacity increases, renewable energy projects can achieve economies of scale, reduce unit costs, and thereby enhance overall power generation efficiency and output. In column (b), even after the inclusion of control variables, the coefficient for the $BR\_Capacity\_interaction$ remains positive and significant at the 5% significance level, corroborating the validity of Hypothesis 2.

(2) Regarding Hypothesis 3, column (a) reveals that the coefficient for the $BR\_PGrowth\_interaction$ term, which examines the interaction between the BRI and the population growth rate ($PGrowth$), is negative and significant at the 10% significance level. This indicates that population growth rate negatively moderates the impact of the BRI on renewable energy power generation. An increase in population growth rate tends to diminish the positive effects of the initiative on renewable energy generation. This could be attributed to the complexities and variabilities in infrastructure, legal frameworks, and regulations in regions with high population growth, potentially hindering the smooth implementation of projects under the initiative. Additionally, resources such as land and capital may be allocated more towards fulfilling basic living needs rather than investing in renewable energy infrastructure [16]. Government and societal focus might be more inclined towards short-term economic growth and employment rather than long-term renewable energy investments, which consequently attenuates the initiative's ability to foster renewable energy development in these regions. In column (b), after the integration of control variables, the coefficient for $BR\_PGrowth\_interaction$ remains negative and significant at the 5% significance level. Therefore, the null hypothesis 3 is rejected, however, confirming a significant moderating effect of population growth rate.

Table 4. Regression results after adding moderating variables.

	Hypothesis 2		Hypothesis 3	
	(a)	(b)	(a)	(b)
BR	0.1047***	0.1194***	0.1433***	0.1621***
Capacity	0.0012	0.0028	/	0.0047***
BR_Capacity_interaction	0.0059***	0.0046**	/	/
PGrowth	/	0.0175	0.0340	0.0574**
BR_PGrowth_interaction	/	/	-0.0507*	-0.0672**
GDP		0.1081		0.1764
EExport		0.0075**		0.0078***
ELoss		-0.0100*		-0.0134***
INV		0.0029		0.0041
Year	Yes	Yes	Yes	Yes
Country	Yes	Yes	Yes	Yes
F	750.3	690.3	731.2	694.5
R-squared	0.991	0.991	0.990	0.991
N	357	357	357	357

Note: The data in the table are the regression coefficients of the variables, ***, ** and * indicate that they are significant at the 1 per cent, 5 per cent and 10 per cent level of significance, respectively.

4.4 Robustness Test

In this study, all three hypotheses employ cluster robust standard errors, which account for potential correlations among error terms within the same group (as data from the same country may exhibit such correlations) while assuming that error terms between different groups remain independent. For robustness testing, the study substituted the HC3 heteroscedasticity robust standard errors. This approach specifically addresses heteroscedasticity at the individual data level, mitigating estimation bias resulting from heteroscedasticity by adjusting the residuals of each observation [17]. This method demonstrates enhanced robustness, particularly in scenarios involving small sample sizes (Ibid). The substitution ensures that the variance of errors across different observation points remains robust even under non-constant variance conditions.

The regression analysis reveals that, after incorporating control variables, the regression coefficient for the implementation of the BRI (BR) is 0.1609, with a p-value of 0.000. This finding maintains significance at the 1% level, aligning with the primary hypothesis and corroborating the robustness of the model.

5 Conclusion

This study investigates the correlation between the implementation of the Belt and Road initiative and national renewable energy power generation, utilizing national energy and development data spanning from 2011 to 2023. The analysis also considers the moderating influence of the installed capacity of power generation equipment and population growth rate, from the perspective of infrastructure development levels. The research has drawn the following conclusions.

(1) The BRI exerts a significant and positive influence on renewable energy power generation in countries along its route, thereby facilitating energy transition and promoting sustainable development in these regions.

(2) The installed capacity of power generation equipment serves as a positive moderating factor. The initiative potentially facilitates participating nations in accessing advanced renewable energy technologies and equipment, optimizing the exploitation of local natural resources, and enhancing renewable energy outputs.

(3) The population growth rate acts as a negative moderating factor. Contrary to conventional theories and expectations, while population growth stimulates demand and development for renewable energy, complexities and variations in national infrastructure development often result in a focus on short-term economic growth and resource allocation, at the expense of the long-term advancement of new energy sources.

Based on these research findings, several policy implications arise.

(1) It is recommended that countries along the Belt and Road engage proactively in energy cooperation projects within the framework of the initiative. By leveraging this platform, they can attract increased international investment and technical support, thus expediting the construction and enhancement of renewable energy infrastructure, and achieving energy structure transformation and green, sustainable development.

(2) Nations should foster collaboration with technologically advanced countries and enterprises, with an emphasis on importing and advancing efficient renewable energy generation equipment and related technologies. Furthermore, strategic policy support and financial incentives should be provided to augment installed capacity and elevate the overall technological competence, thereby optimizing the utilization of indigenous renewable resources.

(3) In strategizing developmental plans, nations should integrate renewable energy development into long-term strategic objectives, ensuring a balance between the economic growth imperatives brought about by short-term population increases and the prioritization of long-term energy transformation. This includes optimizing resource allocation by dedicating a portion of resources to long-term infrastructure development, ensuring sustained investment and focus on renewable energy, while concurrently addressing the exigencies of population growth.

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