

Article

Research on the Impact of Large-Scale Photovoltaic Development on Regional Economic Growth—A Case Study of Qinghai Province

Zhun Qu *  and Suchang Yang

School of Economics, Lanzhou University, Lanzhou 730000, China; suchang64@aliyun.com

* Correspondence: quzhun1989@163.com

Abstract: Large-scale photovoltaic (PV) development has been widely promoted in north-west China and has yielded notable economic and industrial outcomes. However, the existing literature has not adequately examined the relationship between large-scale PV development and regional economic growth, particularly in high-altitude and ecologically fragile areas. This study selects eight prefecture-level cities in Qinghai Province from 2014 to 2023 and employs a static fixed-effects panel regression model to empirically investigate the association between solar PV generation and regional economic performance. The findings indicate a significant positive correlation between PV power generation and regional GDP, with clear regional heterogeneity. In developed regions, the association is stronger, while in less developed regions, the effect is positive but comparatively weaker. Furthermore, the analysis reveals a nonlinear (inverted U-shaped) relationship between PV generation and economic growth in less developed areas, with a critical threshold beyond which the marginal economic benefit declines. These results provide empirical insights into optimizing PV development strategies based on local economic conditions. Notably, the study focuses on identifying statistical associations rather than establishing causality.

Keywords: large-scale photovoltaic development; economic growth; panel model



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1. Introduction

The development and utilization of solar energy and other green and clean energy is not only a key way to achieve the goal of “carbon peak” and “carbon neutral”, but also an important strategy to promote regional economic growth. Policy support and technological innovation have propelled the large-scale development of renewable energy generation [1]. As an important part of renewable energy, solar photovoltaic has developed rapidly in recent years and has an increasing impact on the regional economy. Based on this, this paper explores the mechanism of action of photovoltaic solar energy on the economy referring to the existing relevant research methods on the economic impact of renewable energy consumption. In much of the relevant literature, scholars have studied the relationship between renewable energy and economic growth and proposed that renewable energy consumption has a significantly positive impact on economic growth based on different mechanisms [2–6]. Abbasi et al. (2021) stated that a positive association between renewable electricity consumption and economic growth in Pakistan [7]. Based on the renewable energy data of 22 countries from 2001 to 2020, Wang et al. (2023) used linear and nonlinear panel research to conclude that wind, solar and hydro energy can effectively promote economic growth and reduce carbon emissions, among which wind energy has the most significant emission reduction effect, followed by solar energy and hydro energy has the

lowest effect [8]. Shahbaz et al. (2020) studied the impact of renewable energy consumption on economic growth in 38 renewable energy-consuming countries from 1990 to 2018. By applying dynamic ordinary least squares (DOLS), fully modified ordinary least squares (FMOLS), and non-causality methods, the empirical analysis validates the existence of a long-term positive association between renewable energy consumption and economic growth [9].

However, some scholars hold opposite opinions on this conclusion. Ocal et al. (2013) adopted the ARDL method and the Toda–Yamamoto causality test. The relationship between renewable energy consumption, capital, labor, and economic growth in Turkey during the period 1990 to 2010 was analyzed and it was found that renewable energy consumption has a negative impact on economic growth in Turkey [10]. By using panel data, Marques and Fuinhas (2012) analyzed the impact of various energy types on economic growth in 24 European countries from 1990 to 2007. The study found that although renewable energy is widely considered to contribute to environmental protection, its use in these countries has a negative impact on economic growth, mainly due to the excessive burden on the economy due to the high cost of renewable energy promotion [11]. The study of Moe (2010) similarly confirmed the negative impact of renewable energy costs on the economy [12]. Tsangyao et al. (2015) used the data of G7 countries from 1990 to 2013 to test the existence and direction of the causal relationship between renewable energy and GDP growth with the help of the panel Granger causality method and concluded that there is a unidirectional relationship between renewable energy consumption and economic growth. In particular, for France, Canada, and Japan, the existence of a negative impact relationship of renewable energy on GDP [13].

In addition, some scholars believe that renewable energy development has no significant impact on economic growth. Payne et al. (2009) used the annual data of the United States from 1949 to 2006 to compare and analyze the causal relationship between renewable energy and non-renewable energy consumption and real GDP and found that there is no Granger causality between energy consumption of any nature and real GDP, which indicates that changes in energy consumption do not directly affect economic growth [2]. Vaona (2012) analyzed the annual energy data of Italy from 1861 to 2000 and used the Granger causality test to study the relationship between energy consumption and economic output, and found that there was no significant causal relationship between economic growth and renewable energy consumption [14]. Bao and Xu (2019) explored the causal relationship between renewable energy consumption and urbanization and economic growth by analyzing the panel data of 30 provinces and 7 geographic regions in China from 1997 to 2015. Panel causality tests, cross-sectional correlation tests, and slope uniformity tests were used to find that China's renewable energy consumption, urbanization, and economic growth in one region may be affected by other regions. No causal relationship between renewable energy consumption and economic growth was found in 53% of the provinces and 43% of the geographical areas [15]. It can be seen that the research conclusions on the impact of renewable energy on economic growth vary greatly with different regions, methods, and research objects. Based on this, this paper focuses on the core scientific problem of the impact of large-scale photovoltaic development on the regional economy.

Based on economic theory and existing research results, this paper takes Qinghai Province, which has the highest large-scale photovoltaic power generation in China, as the research object, and adopts various analysis methods such as static panel data regression analysis, intermediary test, and threshold effect test. Scientifically evaluate the impact of large-scale photovoltaic development on the regional economy, and put forward relevant countermeasures and suggestions for the popularization of large-scale photovoltaic power stations in the future. Therefore, this paper proposes the following hypotheses:

H1. *Large-scale photovoltaic development (photovoltaic power generation) promotes regional economic growth.*

H1a. *There are regional differences (heterogeneity) in the impact of large-scale photovoltaic development (photovoltaic power generation) on the regional economy, and its impact on economic growth in developed regions is more significant than that in underdeveloped regions.*

H1b. *The impact of large-scale photovoltaic development (photovoltaic power generation) on the regional economy is nonlinear. When PV power generation is below the critical value, large-scale PV development has a significant impact on regional economic growth; when PV power generation is above the critical value, this impact is insignificant or has a negative impact.*

2. Study Area

Qinghai Province is located in the inland northwest of China, adjacent to Gansu Province in the north and east, Xinjiang Uygur Autonomous Region in the northwest, Tibet Autonomous Region in the south and southwest, and Sichuan Province in the southeast. With a total area of 722,300 square kilometers, the province has jurisdiction over two prefecture-level cities and six autonomous prefectures. By the end of 2023, the province's permanent population is 5.94 million. The terrain of Qinghai Province is generally high in the west and low in the east, high in the north and south, and low in the middle. The elevation in the west is high and steep, and it slopes to the east, descending in a ladder type. The eastern region is the transition zone from the Qinghai–Tibet Plateau to the Loess Plateau, with complex topography and diverse geomorphology. The mountains constitute the basic skeleton of the province's geomorphology. The total annual solar radiation of the province is second only to that of the Tibetan Plateau, with an average annual total radiation of 5860~7400 megajoules/m² and sunshine hours of 2336~3341 h. Qinghai Province has carried out large-scale PV development over the years benefiting from the abundant solar energy resources. This long-term project has not only achieved remarkable economic and industrial benefits but also promoted the sustainable development of the regional economy. By 2023, the province's installed capacity of new energy will reach 37.5429 million kW, with a new installed capacity of 9.3971 million kW that year [16]. Compared with 2015, the total installed capacity of new energy increased by more than six times, while the increase in new installed capacity was nearly 10 times. The overall trend of installed capacity shows rapid growth and increases year by year. Among them, the cumulative installed capacity of solar power generation has reached 25,612,100 kW, making it the largest type of power supply in Qinghai Province. In addition, the proportion of solar installed capacity in new energy remains above 65% all year round and reaches 68.2% in 2023, but the proportion shows a trend of decline year by year, mainly due to the rapid rise in wind power in the new energy structure, increasing from 7.6% in 2015 to 31.5% in 2023. In terms of power generation, according to the National Energy Administration, in 2023, the total power generation of Qinghai province will be 100.82 billion KWH, showing an annual growth rate of 1.6%. Specifically, hydropower generation was 39.83 billion kWh, down 6.7 percent from last year; thermal power generation reached 15.88 billion kWh, representing a year-on-year increase of 3%; solar power generation increased significantly to 29 billion kWh, up 13.3% year on year; wind power generated 16.1 billion kilowatt-hours, up 3.3 percent year on year. These data reflect that solar energy in Qinghai Province occupies a dominant position in the local new energy structure and continues to promote the optimization and development of the province's new energy structure. Figure 1 illustrates the annual trends in photovoltaic (PV) power generation (in billion kWh) and total regional GDP (in billion CNY) across all prefecture-level cities in Qinghai Province over the period 2014–2023. The figure reveals a steady and significant increase in both PV output and economic activity during the study

period. The synchronized upward trends suggest a potential linkage between the growth of renewable energy infrastructure and regional economic development. These observed patterns provide preliminary empirical support for the hypothesis that large-scale PV deployment contributes positively to regional economic performance, warranting further econometric investigation.

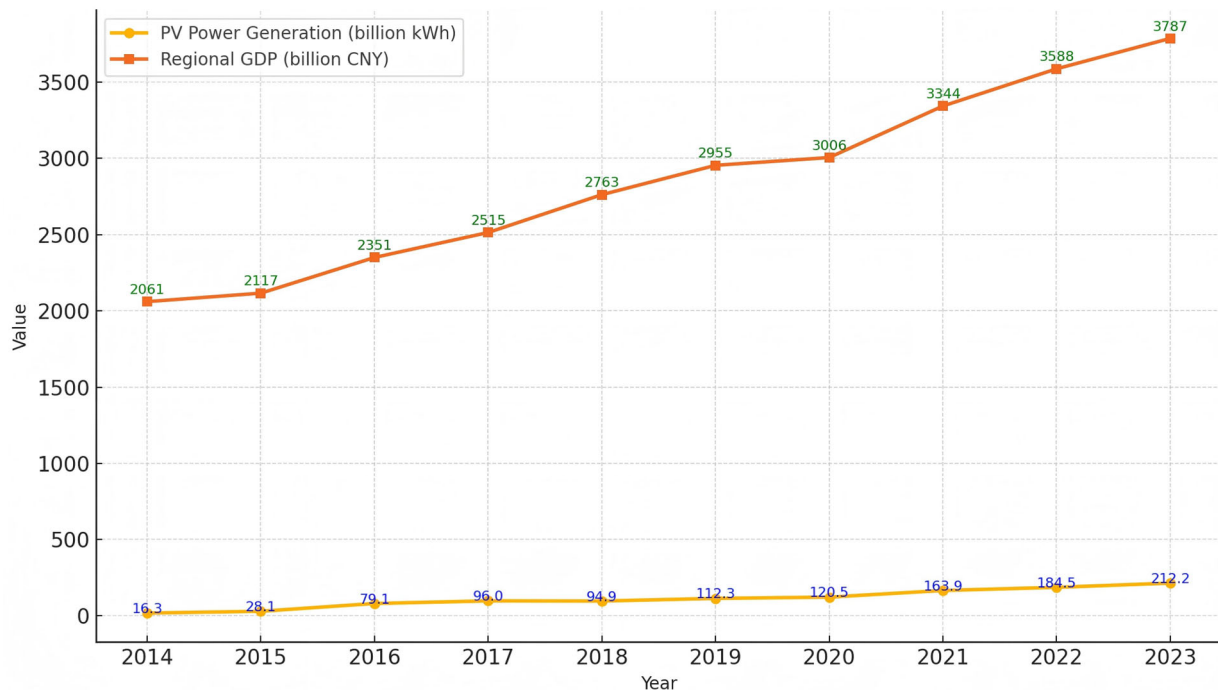


Figure 1. Trends in PV power generation and regional GDP in Qinghai province (2014–2023).

3. Methodology

3.1. Specification of Model

The existing literature mostly uses ordinary least squares (OLS), generalized method of moment estimation (GMM), panel threshold model, vector autoregressive model, and other calculation methods to study the impact of renewable energy development on regional economic growth [17,18]. Considering the possible bidirectional causal relationship between renewable energy consumption and economic growth [19], in order to solve the possible endogeneity problem, this study decides to use the static balanced panel linear regression model for empirical analysis. Compared with other research methods, the static panel data analysis can better deal with the individual effect [20]. Reduce the selection bias of small samples and improve the accuracy of estimation [21]. In this paper, stada16 is used for data processing and regression analysis. In addition, since the PV power generation in Qinghai Province has only begun to increase since 2015 with the completion of large-scale PV power station construction, the time span is relatively short, so it is not suitable for vector autoregression and other methods. Combined with the main research objectives of this paper and referring to the research methods of previous scholars [22–25], the static balanced panel linear regression model is selected for empirical analysis. The model is specifically expressed as:

$$Y_{it} = \beta_0 + \beta_1 X_{1it} + \beta_2 X_{2it} + \beta_3 X_{3it} + \dots + \beta_6 X_{6it} + \mu_{it} \quad (1)$$

where Y_{it} represents the explained variable regional GDP; t represents time (2014–2023); X_{it} sequentially represents explanatory variables and control variables; X_{1it} represents photovoltaic power generation; X_{2it} represents total import and export trade; X_{3it} represents

fixed asset investment growth rate; X_{4it} represents total fiscal revenue; X_{5it} represents local public fiscal budget revenue; X_{6it} represents female employment in non-private units; β_i is the regression coefficient of explanatory variables; and β_0 and μ_{it} are the constant term and the random disturbance term, respectively.

3.2. Data Sources, Sample Selection and Variable Description

In this paper, the data of prefecture-level cities in Qinghai Province from 2014 to 2023 come from the Statistical Yearbook of Qinghai Province, the Statistical Yearbooks of prefecture-level cities, and the Wind Database. Moreover, the sample size is 80 (including 10 years of data from 8 prefecture-level cities), which approximately follows the normal distribution.

This study aims to analyze the impact of large-scale PV development in Qinghai Province on the regional economy from 2014 to 2023. Considering the specific geographical and time scope of the study, eight prefecture-level cities in Qinghai Province were selected as the research objects. The sample size is determined based on the following three considerations. (1) Geographical coverage: there are eight prefecture-level cities in Qinghai Province, and this study chooses to include the data of all prefecture-level cities in the province to ensure the comprehensibility of geography. (2) Time span: the study covers nearly 10 years, which includes the initial stage to the mature stage of large-scale photovoltaic development in Qinghai Province. (3) Data integrity: The selected data are all the existing and available data of 8 prefecture-level cities in Qinghai Province during the study period. This ensures the integrity of the data and the stability of the data studied. Therefore, although the sample size of this paper is small (a total of 80 samples), the annual data of each prefecture-level city are included in the analysis, ensuring the representativeness and comprehensiveness of the data used in the research. In addition, since the data cover all available information, they have a certain reliability.

Since this paper focuses on the study of the relationship between large-scale development (photovoltaic power generation) and regional economic development in Qinghai province, it aims to study the impact of photovoltaic power generation in Qinghai province on regional economic development. Therefore, the index (gross regional product) characterizing the regional economic development of Qinghai Province in recent years is selected as the explained variable. Referring to the existing literature and considering the availability of data, the provincial photovoltaic power generation index is selected as the core explanatory variable to measure the large-scale photovoltaic development in the alpine region. Considering that there are other factors that may affect regional economic development, the following control variables are selected based on the existing literature:

Total import and export trade: Import and export trade can help increase foreign exchange earnings, expand production scale, increase employment opportunities, and improve the welfare and living standards of domestic consumers. Increasing the supply of goods and services helps to stabilize the domestic price level. In addition, import and export trade also helps to promote the upgrading and technological progress of domestic industries, improve the efficiency of resource allocation, and thus further promote economic growth. A large amount of the literature supports its significant role in promoting economic growth. Therefore, this paper chooses the total volume of import and export trade as one of the control variables.

Growth rate of fixed asset investment: The impact of fixed asset investment on economic growth is significant, involving capital formation, production efficiency, economic structure, job creation, and many other aspects. The economic growth of developed countries has experienced a significant stage of investment growth, and investment plays an important role in promoting the economic transition to the industrialization stage. In addi-

tion, the increase in the proportion of fixed asset investment is the key factor to promote economic development. Furthermore, the growth rate of fixed asset investment can reflect the changes in the investment level of a country or region in infrastructure and production capacity, so it is selected as a control variable.

Total fiscal revenue: Total fiscal revenue is the sum of funds obtained by the government from tax, non-tax revenue, and other sources. By adjusting taxes and government expenditures, fiscal policy can be used to regulate the economy and further influence economic growth, so it is used as a control variable and core explanatory variable.

Budget revenue of local public finance refers to the fiscal revenue obtained by a certain level of government through tax and non-tax revenue (excluding governmental fund revenue and transfer payment), which is included in public budget management. This part of the revenue is left to local governments after deducting the tax shared by higher governments, which is mainly used to manage local affairs and finance local construction projects. The budget revenue of local public finance is a key indicator to measure the financial strength of local governments, reflecting the scale of independent financial resources of local governments, which affects the regional economy through fiscal expenditure drive, investment, income distribution, and other aspects. By including it as a control variable, the actual effects of other variables in different fiscal capacity contexts can be assessed more accurately.

Female employees in non-private units: There is a mutually promoting relationship between female employment and economic growth. The employment status of women in non-private units is of great significance in promoting gender equality and economic inclusion, and may reflect the impact on macroeconomic and social policy changes. Especially in less developed regions, female employment in the non-private sector is relatively stable, which can directly reduce household poverty and help stabilize income and consumption. Therefore, the above data are selected as control variables. Table 1 shows the variables involved in the relevant empirical analysis and their corresponding descriptions.

Table 1. Variable type and variable description.

Variable Type	Variable Description
Dependent Variable:	
Regional Gross Domestic Product (Y)	Annual regional GDP amount for each area (unit: billion CNY)
Core Explanatory Variable:	
Solar PV Electricity Generation (X1)	Annual solar photovoltaic electricity generation in each area (unit: billion kWh)
Control Variables:	
Total Import and Export Trade Volume (X2)	Annual total import and export trade volume for each area (unit: ten million USD)
Fixed Asset Investment Growth Rate (X3)	Annual growth rate of fixed asset investment in each area (unit: percentage)
Total Fiscal Revenue (X4)	Annual total fiscal revenue for each area (unit: billion CNY)
Local Public Fiscal Budget Revenue (X5)	Annual local public fiscal budget revenue for each area (unit: billion CNY)
Non-Private Sector Female Employment (X6)	Annual number of women employed in non-private sectors in each area (unit: 10,000 persons)

3.3. Empirical Strategy and Identification

3.3.1. Descriptive Statistics Analysis

Descriptive statistical analysis, as part of data preprocessing, helps to identify outliers, missing values, and potential data entry errors in the data, ensuring the accuracy and reliability of subsequent analysis. Through descriptive statistics, the central tendency, the degree of dispersion, and the distribution pattern of the data can be better presented, thus providing a basis for more in-depth statistical inference or hypothesis testing. The descriptive statistical results of each variable are shown in Table 2 below.

Table 2. Descriptive statistics for variables in empirical analysis.

Variable Type	Observations	Mean	Standard Deviation	Minimum	Maximum
Dependent Variable:					
Regional Gross Domestic Product (Y)	80	356.1	423.4	35.70	1801
Core Explanatory Variable:					
Solar PV Electricity Generation (X1)	80	13.85	28.10	0	135.7
Control Variables:					
Total Import and Export Trade Volume (X2)	80	11.56	31.78	0	184.2
Fixed Asset Investment Growth Rate (X3)	80	7.086	17.85	−56.80	48.80
Total Fiscal Revenue (X4)	80	173.6	105.2	58.00	554.5
Local Public Fiscal Budget Revenue (X5)	80	29.05	40.64	1.892	153.9
Non-Private Sector Female Employment (X6)	80	3.199	4.069	0.516	14.78

3.3.2. Analysis of Correlation

In order to ensure the accuracy of multivariate analysis and avoid multicollinearity, this paper first uses the Pearson correlation coefficient test to evaluate the linear relationship between variables. A high Pearson coefficient indicates a strong linear correlation between variables, which may affect the accuracy of regression analysis because standard regression analysis requires that variables should be independent as much as possible to avoid collinearity problems. In addition, in order to exclude spurious regression and ensure the credibility of regression results, this paper uses Stata 15.0 software to conduct a correlation analysis on regional GDP and its potential influencing factors. The detailed results of the analysis are shown in Table 3, through which the stability of the model and the reliability of the results can be ensured, providing a solid foundation for the subsequent regression analysis. This section shows the explanatory variables and their degree of influence and correlation on the gross regional product.

Table 3. Correlation analysis of main variables.

Orrelation Coefficient	Regional GDP (Y)	Solar PV Electricity Generation (X1)	Total Import and Export Trade Volume (X2)	Fixed Asset Investment Growth Rate (X3)	Total Fiscal Revenue (X4)	Local Public Fiscal Budget Revenue (X5)	Non-Private Sector Female Employment (X6)
Regional GDP (Y)	1						
Solar PV Electricity Generation (X1)	0.2221 ***	1					
Total Import and Export Trade Volume (X2)	0.5713 **	0.1313 *	1				
Fixed Asset Investment Growth Rate (X3)	0.2146	0.0665 **	0.0239	1			
Total Fiscal Revenue (X4)	0.9285 **	0.0595 **	0.5344 *	−0.2295 *	1		
Local Public Fiscal Budget Revenue (X5)	0.7401 **	0.1501	0.5449 **	−0.1801 **	0.6671 *	1	
Non-Private Sector Female Employment (X6)	0.6387 **	−0.107 **	0.7361 **	−0.1581 **	0.6781 **	0.5590 ***	1

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed); * indicates significance at the 0.1 level (two-tailed).

According to the Pearson correlation analysis results in Table 3, it can be seen that the maximum absolute value of the correlation coefficient among explanatory variables is 0.6781. When the absolute value of the Pearson correlation coefficient among explanatory variables is lower than 0.7, it can be considered that the multicollinearity problem is not significant. This result indicates that there is no high linear correlation among the variables that can affect the multiple regression analysis, so all explanatory variables can be included in the same regression model for testing. This step ensures the stability of the model and the reliability of the regression results, allowing accurate statistical analysis of the impact of each explanatory variable.

In addition, according to the correlation analysis in the table, it can be seen that regional GDP is related to core explanatory variables and other control variables: The correlation coefficients of photovoltaic power generation, total import and export trade volume, fixed asset investment growth rate, total fiscal revenue, local public finance budget revenue, and female employment in non-private units are 0.2221, 0.5713, 0.2146, 0.9285, 0.7401, and 0.6387, respectively. The correlation coefficients between all explanatory variables (including control variables) and regional GDP have passed the statistical significance test, indicating that these variables have a significant correlation with regional GDP. It can be preliminarily determined that indicators such as photovoltaic power generation, fixed asset investment growth rate, total fiscal revenue, local public fiscal budget revenue (X5), and female employment in non-private units (X6) are positively correlated with regional GDP (Y), but further analysis and verification are needed.

Although the current analysis reveals the correlation between each explanatory variable and regional GDP, these results are limited to a single relationship between the variables and do not control the potential impact of other variables. To ensure the rigor of the analysis and further explore the real influence among the variables, multiple regression

analysis is needed. This will help to test the actual impact of each explanatory variable on regional GDP after controlling other variables and verify the reliability of the preliminary analysis results. Therefore, appropriate regression models will be used in subsequent studies to systematically evaluate the impact of these variables on the explained variables in order to obtain more accurate and comprehensive research conclusions.

3.3.3. Multicollinearity Diagnosis

To address concerns regarding multicollinearity due to the number of control variables relative to the sample size, we conducted a variance inflation factor (VIF) analysis. As shown in Table 4 of the revised manuscript, all VIF values are below the commonly accepted threshold of 10 (with the highest VIF being 8.066). This suggests that while some correlation exists—as expected in macroeconomic variables—it is within acceptable bounds and does not pose a serious threat to model validity.

Table 4. Variance inflation factor (VIF) test results.

Variable	Tolerance	VIF
Solar PV generation (X1)	0.124	8.066
Total import-export trade volume (X2)	0.140	7.124
Growth rate of fixed asset investment (X3)	0.144	6.965
Total fiscal revenue (X4)	0.156	6.405
Local public budget revenue (X5)	0.223	4.488
Female employment in non-private units (X6)	0.303	3.299

According to the collinearity test results in Table 4, the variance inflation factor (VIF) of all variables is lower than 9, which indicates that there is no serious multicollinearity problem in the model. This result ensures the reliability and stability of the model regression, and allows us to reasonably analyze the relationship between explanatory variables (such as photovoltaic power generation, total import and export trade volume, fixed asset investment growth rate, total fiscal revenue, and the number of female employment in non-private units) and explained variables (regional GDP). Therefore, the results of the model can be regarded as reflecting the actual economic relationship between the variables and having long-term robustness.

3.3.4. Panel Model Selection (F-Test, LM Test, Hausman Test)

To determine the most appropriate panel data model, this study first applies the F-test to assess whether a pooled OLS model or a fixed effects model is more suitable. In this context, the null hypothesis (H_0) assumes that the pooled model is appropriate and that there are no significant individual (cross-sectional) effects. The alternative hypothesis (H_1) supports the adoption of a fixed effects model. The procedure of the F-test—null hypothesis (H_0): if the p -value of the F-statistic is greater than the significance level (typically 0.05), there is insufficient evidence to reject the null hypothesis, and the pooled OLS model is preferred. Alternative hypothesis (H_1): if the p -value is less than 0.05, the null hypothesis is rejected, indicating that the fixed effects model is more appropriate. The F-test result shows F-statistic is 9.31, the p -value is less than 0.05.

To determine the appropriateness of a random effects model relative to the pooled OLS model, the Lagrange Multiplier (LM) test is applied. This test helps to assess whether unobserved individual effects are present and statistically significant. Null hypothesis (H_0): if the p -value of the chi-square statistic is greater than 0.05, the random effects are redundant, and the pooled model is preferred. Alternative hypothesis (H_1): if the p -value is

less than 0.05, the random effects model is more appropriate. The results of the LM test chi-square statistic is 23.78 with a p -value of 0.0013, which is far below the 0.05 threshold. This indicates strong evidence of significant random effects, thus rejecting the null hypothesis. Therefore, a random effects model is preferred over the pooled model.

To decide between the fixed effects model and the random effects model for panel data analysis, the Hausman test is conducted. This test evaluates whether the regressors are correlated with the unobserved individual effects, which would violate the assumptions of the random effects model. Null hypothesis (H_0): if the p -value is greater than 0.05, the random effects model is appropriate, as there is no correlation between the regressors and the unobserved effects. Alternative hypothesis (H_1): if the p -value is less than 0.05, the fixed effects model is more appropriate, indicating the presence of endogeneity between the regressors and the individual effects. The results of the Hausman test show the chi-square statistic is 33.45 with a p -value of 0.0000, well below the 0.05 threshold. This leads us to reject the null hypothesis and confirms that the fixed effects model is preferable to the random effects model. The result highlights the presence of a correlation between explanatory variables and unobserved effects, validating the fixed effects approach as it better controls for such individual-specific heterogeneity. To further ensure the reliability of the regression results, especially in light of potential heteroskedasticity, all subsequent estimations are performed using heteroskedasticity-robust standard errors. This enhances the stability and credibility of the statistical inference.

In order to ensure the high robustness of the regression results of this study, this paper not only chooses the fixed effect model for analysis but also adopts the standard procedures of panel data analysis, including the F-test, LM test and Hausman test, to determine the most suitable model type. Through these steps, the fixed effects model was identified as the most appropriate, mainly because it effectively controls for unobservable heterogeneity that does not change over time.

3.3.5. Robustness Test

In addition, in order to further verify the robustness of the model, this study adopts the least square dummy variable model to conduct additional regression analysis. The LSDV model is a type of fixed effects model that deals with unobservable individual effects by introducing dummy variables for each cross-sectional unit, which can more accurately capture the stability of the influence of explanatory variables on the explained variables. The robustness test can not only increase the accuracy of model prediction but also improve the credibility of the effect of explanatory variables. The results are in the following Table 5.

Through the robustness test, it can be seen that the influence of explanatory variables on explained variables shows stability and persistence. This result can further prove the reliability of the research conclusion, indicating that the relationship between explanatory variables and explained variables is highly robust under various model Settings.

Table 5. Robustness test of the model.

Variable Type	Coefficient	Standard Error	t-Statistic
Dependent Variable: Regional GDP (Y)			
Core Explanatory Variable:			
Solar PV Electricity Generation (X1)	1.708 ***	0.593	2.88
Control Variables:			
Total Import and Export Trade Volume (X2)	0.698 ***	0.219	3.18
Fixed Asset Investment Growth Rate (X3)	0.495	0.384	1.29
Total Fiscal Revenue (X4)	1.206 ***	0.419	2.88

Table 5. *Cont.*

Variable Type	Coefficient	Standard Error	t-Statistic
Local Public Fiscal Budget Revenue (X5)	1.628 **	0.790	2.06
Non-Private Sector Female Employment (X6)	5.474 **	2.401	2.28
Constant	108.09 ***	27.858	3.88
Sample Size (N)	80		
F-Statistic	67.36		
p-value	0.0000		
R-squared	0.8592		

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed).

3.3.6. Endogeneity Test of the Model

To assess whether the model suffers from endogeneity, we apply the Durbin–Wu–Hausman (DWH) test. Unlike the traditional Hausman test, which may not be valid under conditions of heteroskedasticity, the DWH test is more robust and generally recommended when such conditions are suspected.

When there is no endogeneity in the model, the ordinary least squares (OLS) estimation is more efficient and provides unbiased and consistent parameter estimates. In such a case, the explanatory variables are uncorrelated with the error term, and OLS remains valid. However, if one or more explanatory variables are endogenous—i.e., correlated with the error term—the OLS estimates become biased and inconsistent. In this situation, instrumental variable (IV) estimation methods such as two-stage least squares (2SLS) are required to obtain valid results. These methods use instruments that are correlated with the endogenous variables but uncorrelated with the error term, thereby correcting for endogeneity bias.

In this study, the Durbin–Wu–Hausman test is used to determine whether endogeneity is present. The test evaluates the significance of the difference between OLS and IV (e.g., 2SLS) estimates. Under the null hypothesis (H_0), all explanatory variables are exogenous, and OLS is consistent and efficient. If the null is rejected, it implies that at least one variable is endogenous and IV methods should be used instead. If the null is not rejected, it indicates that all variables can be considered exogenous, justifying the use of OLS. The results are presented in Table 6.

Table 6. Durbin–Wu–Hausman test for endogeneity.

Test Description	DW Statistic	p-Value
	2.118	0.489

As shown in Table 6, the DW statistic is 2.118, which is close to the ideal value of 2, indicating no significant autocorrelation in the residuals. The p-value of 0.489 is well above the conventional 0.05 significance threshold. Taken together, these results suggest no strong evidence of endogeneity in the model. Therefore, OLS estimation is deemed appropriate, and all explanatory variables—including both the core variable (solar PV generation) and control variables—can be treated as exogenous. The OLS results can thus be considered unbiased and consistent, providing a reliable foundation for economic interpretation and subsequent policy recommendations.

3.3.7. Test for Heteroskedasticity

To further ensure the robustness of the regression results and account for potential heteroskedasticity, the study employs the White test, which is a general test for heteroskedasticity in a regression model.

Under the null hypothesis (H_0), the model exhibits homoskedasticity (i.e., constant variance of the error term). The alternative hypothesis (H_1) posits the presence of heteroskedasticity. If the null hypothesis is rejected, it suggests that the variance of the residuals is not constant, which may affect the efficiency of OLS estimates and the validity of hypothesis testing. If the null cannot be rejected, it indicates that the model is homoskedastic and OLS inferences remain valid. The results are shown in Table 7.

Table 7. White test for heteroskedasticity.

chi2 (2)			6.640
Prob > chi2			0.062
Source	chi2	df	<i>p</i>
Heteroskedasticity	6.640	27	0.0538
Skewness	10.02	6	0.1239
Kurtosis	3.52	1	0.0809
Total	20.18	34	0.0598

As shown in Table 7, the test statistic for heteroskedasticity is 6.640 with 27 degrees of freedom, and the associated *p*-value is 0.0538, which is slightly above the conventional 0.05 threshold. The overall White test also yields a *p*-value of 0.0598. These results suggest that there is no strong evidence against homoskedasticity, though a mild presence of heteroskedasticity cannot be entirely ruled out.

Given the borderline significance, the model is considered to exhibit acceptable homoskedasticity, and the OLS estimations remain statistically valid. Nonetheless, to further enhance robustness, the study adopts heteroskedasticity-robust standard errors in subsequent estimations. This ensures that even if mild heteroskedasticity exists, the regression results remain reliable and efficient for inference.

4. Results

Empirical Results

The empirical analysis of this paper adopts Stata15.0 statistical software to perform fixed effect regression analysis, with the purpose of evaluating the overall impact of explanatory variables including core explanatory variables and control variables on regional GDP (*Y*). Through detailed regression analysis, the model shows that after all control variables are included,

The F-test value of 68.82 ($p < 0.01$) indicates that the regression model as a whole is statistically significant, meaning that the group of explanatory variables jointly explain variations in regional GDP at a high level of confidence. This does not imply individual causality but suggests that the model captures meaningful associations between the independent variables and regional economic outcomes. As shown in Table 8 below. In addition, the pseudo-judgment coefficient (R^2) of the model is 0.8622, which means that the variables included in the model can explain 86.22% of the variation in regional GDP, while the remaining 13.78% of the variation has not been explained by the model. This indicates that there may be other important variables or external factors not considered in the model, which may also have an impact on regional GDP. Despite this unexplained variation, the overall significance of the model ensures the validity and applicability of the chosen set of variables in explaining regional GDP.

Table 8. Regression analysis results.

Variable Type	Coefficient	Standard Error	t-Statistic
Dependent Variable: Regional GDP (Y)			
Core Explanatory Variable:			
Solar PV Electricity Generation (X1)	1.727 ***	0.535	3.230
Control Variables:			
Total Import and Export Trade Volume (X2)	0.674 ***	0.143	4.710
Fixed Asset Investment Growth Rate (X3)	0.487	0.451	1.080
Total Fiscal Revenue (X4)	1.156 ***	0.416	2.780
Local Public Fiscal Budget Revenue (X5)	1.658 ***	0.556	2.980
Non-Private Sector Female Employment (X6)	5.088 **	2.077	2.450
Constant	106.74 ***	29.005	3.680
Sample Size (N)	80		
F-Statistic	68.82		
p-value	0.0000		
R-squared	0.8622		

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed).

Firstly, according to the regression analysis in Table 8 above, regarding the influence of the core explanatory variable photovoltaic power generation (X1) on the regional GDP (Y) of each region in Qinghai Province, we observe that the regression coefficient of photovoltaic power generation is 1.727, which has a significant positive impact and is statistically significant at the level of 5%. This shows that when other conditions remain unchanged, each additional unit of PV power generation in each region of Qinghai Province will increase the regional GDP by 1.727 units on average. The reason may be that with the gradual rise and further development of photovoltaic power generation, photovoltaic power generation drives the scale of related industries to gradually increase, and then drives the improvement of local fiscal revenue and gross national product. In addition, the development of large-scale PV may be closely related to regional policy support, technological progress, and market demand growth, which together act on the upgrading of regional economic activities. With the expansion of the photovoltaic construction scale, the increase in photovoltaic power generation, and the gradual reduction in cost, photovoltaic power generation will become a key driving force to promote the optimization of economic structure and green and low-carbon development of Qinghai Province.

Secondly, in terms of the influence of the control variables of total import and export trade (X2) and fixed asset investment growth rate (X3) on the GDP of each region in Qinghai Province, this paper analyzes the influence of the two variables of total import and export trade (X2) and fixed asset investment growth rate (X3) on the GDP of each region in Qinghai Province. The regression coefficients of the total import and export trade volume and the growth rate of fixed asset investment are 0.674 and 0.487, respectively. With every unit increase in the total import and export trade of each region in Qinghai province, the GDP of each region in Qinghai province will increase by 0.674 units accordingly. However, the regression coefficient of the growth rate of fixed asset investment fails to pass the significance test, indicating that the growth rate of fixed asset investment is not the core cause of the changes in regional GDP. Thirdly, the regression coefficients of the influence of the total fiscal revenue (X4) and the local public budget revenue (X5) on the regional GDP of Qinghai Province are 1.156 and 1.658, respectively. It shows that the regression results of the variables of total fiscal revenue (X4) and local budget revenue of public finance (X5)

are significant, that is, both total fiscal revenue (X4) and local budget revenue of public finance have a significant positive impact on the GDP of all regions in Qinghai Province. Moreover, the influence degree of the local public finance budget revenue on the regional GDP of Qinghai Province is greater than that of the total fiscal revenue on the regional GDP of Qinghai Province. Finally, the influence of the control variable, the number of female employees in non-private units (X6), on the GDP of each region in Qinghai Province is analyzed. The regression coefficient of the number of female employees in non-private units is significantly positive, indicating that the higher the number of female employees in non-private units is, the higher the GDP of each region is.

In order to explore whether there are regional differences in the impact of provincial photovoltaic power generation on regional economic development, eight prefecture-level cities in Qinghai Province are divided into developed regions and underdeveloped regions according to the level of economic development and regional distribution, as shown in Table 9 below:

Table 9. The eight prefecture-level cities in Qinghai Province are divided by economic development degree.

Regional Distribution in Qinghai Province	Prefecture-Level Cities
Developed Areas	Xining City, Haidong City, Hainan Prefecture, Haixi Prefecture (4 cities)
Less Developed Areas	Haibei Prefecture, Huangnan Prefecture, Guoluo Prefecture, Yushu Prefecture (4 cities)

In order to further explore the impact of the level of regional economic development on the analysis results, this study divides the samples into two sub-samples according to the level of regional economic development: developed regions and underdeveloped regions. This subsample regression analysis method allows us to examine in detail how the level of economic development moderates the relationship between PV generation and gross regional product. Regression 1 and Regression 2 in Tables 10 and 11 below present the results of the regression analysis for developed and less developed regions, respectively. This sub-sample regression analysis can not only reveal the difference in the impact of photovoltaic power generation on regional GDP under different economic development backgrounds but also help to formulate more accurate regional economic policies. For example, if the economic benefits of photovoltaic power generation are found to be more significant in less developed regions, policy makers may consider increasing support for photovoltaic projects in these regions to promote rapid local economic development. On the contrary, if the contribution of PV to economic growth is greater in developed regions, it may be necessary to further optimize the energy mix and improve the application efficiency of PV technology in these regions. Through this sub-sample analysis, the regional economic effects of PV power generation can be more accurately identified and utilized to provide a basis for sustainable development policies.

According to the results of heterogeneity analysis in Tables 10 and 11, the positive impact of photovoltaic power generation on regional economic development is significantly different between developed and less developed regions. The regression coefficients of the core explanatory variable photovoltaic power generation in regression result 1 (developed regions) and regression Result 2 (underdeveloped regions) are 2.098 and 0.864, respectively, which indicates that each unit increase in photovoltaic power generation in developed regions can increase regional GDP by 2.098 units, while in underdeveloped regions, The same increase results in an increase of only 0.864 units in the gross product. This indicates that the economic utilization efficiency of PV energy is higher in more economically devel-

oped regions, which may benefit from a more mature market structure, more advanced technical support, and more efficient energy utilization strategies. In general, photovoltaic power generation has a significantly positive effect on regional economic development, in which provincial photovoltaic power generation in developed regions has a greater impact on regional economic development and provincial photovoltaic power generation in underdeveloped regions has a lower impact on regional economic development.

Table 10. Results of regression analysis of developed regions in Qinghai Province.

Variable Category	Regression Coefficient	Standard Error	t-Statistic
Core Explanatory Variable:			
Photovoltaic Power Output (X1)	2.098 ***	0.752	2.79
Control Variables:			
Total Import and Export Trade (X2)	0.903 ***	0.336	2.69
Growth Rate of Fixed Asset Investment (X3)	0.965 **	0.404	2.39
Total Fiscal Revenue (X4)	0.976 ***	0.328	2.98
Local Public Budget Revenue (X5)	1.464 ***	0.433	3.38
Number of Non-Private Sector Employed Women (X6)	4.867 *	2.535	1.92
Constant	122.38 ***	32.643	3.749
Sample Size (N)	40		
F-statistic	119.08		
p-value	0.0000		
R-squared	0.8809		

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed); * indicates significance at the 0.1 level (two-tailed).

Table 11. Results of regression analysis of undeveloped regions in Qinghai Province.

Variable Category	Regression Coefficient	Standard Error	t-Statistic
Core Explanatory Variable:			
Photovoltaic Power Output (X1)	0.864 *	0.457	1.890
Control Variables:			
Total Import and Export Trade (X2)	0.495 **	0.194	2.550
Growth Rate of Fixed Asset Investment (X3)	0.678	0.477	1.420
Total Fiscal Revenue (X4)	1.420 **	0.683	2.080
Local Public Budget Revenue (X5)	1.901 ***	0.548	3.470
Number of Non-Private Sector Employed Women (X6)	7.858 ***	2.535	3.110
Constant	117.348 ***	32.687	3.59
Sample Size (N)	40		
F-statistic	84.694		
p-value	0.0000		
R-squared	0.6198		

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed); * indicates significance at the 0.1 level (two-tailed).

The control variable analysis further reveals other drivers of regional economic development. In developed regions, the growth rate of fixed asset investment significantly contributed to economic growth, which may reflect that infrastructure and capital investment remain key drivers of economic growth in more mature economies. However, in less developed regions, although the growth rate of fixed asset investment does not have a significant positive economic impact, this may indicate that the economic growth of these regions depends more on other factors, such as labor cost advantage, natural resource utilization, or government policy support. Therefore, according to the results of the analysis, the PV development policy should be customized according to the economic development level and market conditions of the region to ensure the maximum benefit of PV energy investment. For developed regions, the energy structure should be optimized and the application efficiency of photovoltaic technology should be improved. For less developed regions, more attention may be needed to infrastructure construction and improve technical support and financial input for local photovoltaic projects to improve energy efficiency and economic growth potential in these regions.

In order to further explore whether there is a nonlinear relationship between photovoltaic power generation and regional economic development, the quadratic term of photovoltaic power generation is introduced into the model (photovoltaic power generation * photovoltaic power generation) to conduct regression analysis on the data again. The regression results are shown in Table 12 below.

Table 12. Results of the nonlinear relationship between photovoltaic power generation and regional economic development.

Variable Category	Regression Coefficient	Standard Error	t-Statistic
Core Explanatory Variables:			
Photovoltaic Power Output Squared (X1 ²)	−0.0611 **	0.029	−2.08
Photovoltaic Power Output (X1)	4.982 ***	1.562	3.19
Control Variables:			
Total Import and Export Trade (X2)	0.0093 **	0.004	2.16
Growth Rate of Fixed Asset Investment (X3)	1.688 ***	0.528	3.198
Total Fiscal Revenue (X4)	0.0019 ***	0.001	3.691
Local Public Budget Revenue (X5)	0.0002 ***	0.000	3.89
Number of Non-Private Sector Employed Women (X6)	0.0031 ***	0.001	2.87
Constant	116.0 ***	31.016	3.74
Sample Size (N)	80		
F-statistic	78.830		
p-value	0.0000		
R-squared	0.9356		

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed).

According to the regression coefficients of the quadratic term and photovoltaic power generation, it can be seen that the regression coefficients of the two variables are significant, which indicates that photovoltaic power generation has a significantly positive effect on regional economic development within a certain range. When the value of photovoltaic power generation is greater than a certain range, photovoltaic power generation has a significantly negative effect on regional economic development. The critical value is $(b/-2a) = (4.982/2/0.0611) = 40.77$, which indicates that when the photovoltaic power generation is less than 40.77, the photovoltaic power generation has a significantly positive effect on regional economic development. When the photovoltaic power generation is

greater than 40.77, the photovoltaic power generation has a significantly negative effect on regional economic development.

Further explore the results of regional differences in regional economic development according to the interaction item photovoltaic power generation * photovoltaic power generation, as follows:

According to the analysis results in Tables 13 and 14, the interaction term and photovoltaic power generation in regression result 1 (in more developed regions) are not significant, which means that there is no inverted U-shaped relationship between photovoltaic power generation and regional economic development. The interaction term and photovoltaic power generation in the regression results (in underdeveloped areas) are significant, which means that there is an inverted U-shaped relationship between photovoltaic power generation and regional economic development, and the critical value is $(b/-2a) = (48.19/2/11.6) = 2.08$.

Table 13. Results of the nonlinear relationship between PV generation and regional economic development in developed regions.

Variable Category	Regression Coefficient	Standard Error	t-Statistic
Core Explanatory Variables:			
Photovoltaic Power Output Squared ($X1^2$)	−0.0597	0.038	−1.581
Photovoltaic Power Output ($X1$)	1.741	1.079	1.614
Control Variables:			
Total Import and Export Trade ($X2$)	0.00865 ***	0.003	3.456
Growth Rate of Fixed Asset Investment ($X3$)	−3.9877 ***	1.528	−2.61
Total Fiscal Revenue ($X4$)	0.0003	0.000	0.93
Local Public Budget Revenue ($X5$)	0.00031 ***	0.000	2.64
Number of Non-Private Sector Employed Women ($X6$)	0.0076 ***	0.002	3.28
Constant	123.157	32.668	3.77
Sample Size (N)	40		
F-statistic	181.78		
p-value	0.0000		
R-squared	0.9408		

Note: *** indicates significance at the 0.01 level (two-tailed).

Table 14. Results of the nonlinear relationship between PV generation and regional economic development in non-developed regions.

Variable Category	Regression Coefficient	Standard Error	t-Statistic
Core Explanatory Variables:			
Photovoltaic Power Output Squared ($X1^2$)	−11.60 ***	3.021	−3.84
Photovoltaic Power Output ($X1$)	48.19 ***	11.233	4.29
Control Variables:			
Total Import and Export Trade ($X2$)	0.00573 ***	0.002	2.36
Growth Rate of Fixed Asset Investment ($X3$)	−0.0382	0.041	−0.940
Total Fiscal Revenue ($X4$)	0.00019 ***	0.00002	3.570

Table 14. Cont.

Variable Category	Regression Coefficient	Standard Error	t-Statistic
Local Public Budget Revenue (X5)	0.00039 **	0.00013	2.68
Number of Non-Private Sector Employed Women (X6)	0.01828 ***	0.005	3.638
Constant	101.01	22.497	4.49
Sample Size (N)	40		
F-statistic	171.94		
p-value	0.0000		
R-squared	0.9031		

Note: *** indicates significance at the 0.01 level (two-tailed); ** indicates significance at the 0.05 level (two-tailed).

5. Discussion

The results show that large-scale photovoltaic development (PV power generation) has a significant positive impact on regional economic development. Specifically, the regression coefficient of the impact of photovoltaic power generation (X1) on the economic value of the regional GDP (Y) of the eight prefecture-level cities in Qinghai Province is 1.727. The reason may be that photovoltaic power generation directly provides stable and low-cost energy supply and employment opportunities and indirectly promotes the comprehensive development of the regional economy by improving energy efficiency, promoting environmental protection, stimulating scientific and technological innovation and industrial upgrading, and improving social and economic infrastructure [26].

Further heterogeneity analysis reveals significant differences between developed and less developed regions: in developed regions, each unit increase in PV generation can increase regional GDP by 2.098 units, while in less developed regions, this figure is 0.864 units. The reason may be that in developed regions, due to more mature infrastructure and higher technology absorption capacity, photovoltaic power generation has a more significant role in promoting economic growth. However, in less developed regions, although the increase in PV power generation also promotes economic growth, its impact is relatively low, which may be due to the insufficient infrastructure and low technological absorption capacity in these regions that limit the impact role of PV development on the regional economy [27]. Developed regions, benefiting from more advanced power grid infrastructure and efficient energy management systems, are better equipped to integrate newly installed photovoltaic capacity and utilize the generated energy effectively. Moreover, these regions often possess more mature energy markets, which facilitate the commercialization and market-oriented development of photovoltaic electricity, thereby further stimulating economic activity [28]. In less developed regions, weak infrastructure often makes it difficult to effectively distribute and use the generated electricity, limiting the economic potential of photovoltaic power generation [29]. Secondly, differences in technological absorption and innovation capacity also play a critical role. Developed regions typically demonstrate a stronger ability to adopt and apply emerging technologies, supported by higher levels of educational attainment and greater investment in research and development. This enables them to more effectively leverage photovoltaic technologies and foster the growth of associated industries [30]. However, less developed regions may lack the necessary technical support and expertise to fully leverage the benefits of PV technology. Finally, differences in policy support and investment climate also play a key role in the economic impact of PV. Developed regions tend to have more active policy support and larger investment scales, which help promote the development of the

photovoltaic industry. In contrast, less developed regions may have insufficient policy and financial support, which restricts the widespread application of PV technology.

In addition, by introducing the square term of photovoltaic power generation for regression analysis, it is found that the impact of photovoltaic power generation on the regional economy shows an inverted U-shaped relationship. Specifically, an increase in PV power generation boosts economic growth in the initial period, but when it exceeds 40.77 units, the impact on the economy turns negative. This indicates that at higher PV generation levels, economic benefits may decrease due to factors such as misallocation of resources or market saturation. Especially in less developed regions, the inverted U-shaped relationship between photovoltaic power generation and regional economic development is more obvious, and its critical value reaches 2.08 units. That is, when the photovoltaic power generation in underdeveloped areas exceeds a certain range, its impact on the regional economy will turn from positive to negative. This may be due to the fact that in the early stage of large-scale PV development, its positive economic drive is mainly due to its lower marginal cost and new technological opportunities. For example, large-scale photovoltaic deployment has reduced the cost of electricity and promoted the rise in new industries and the increase in employment while driving the development of related manufacturing and service industries. However, when these technologies tend to mature and the market is close to saturation, the economic value added by the newly installed unit capacity will decrease due to the slowdown of technological progress and the decrease in market demand, which is in line with the characteristics of the factor substitution effect. In addition, since large-scale PV development and construction usually depends on specific geographical and environmental conditions, such as light conditions and land use area, its high-density development in a certain area may encounter natural resource bottlenecks, which will also lead to the weakening of substitution effect [31]. These increased environmental and social costs will offset their economic benefits to some extent. Further, as the proportion of renewable energy in the energy structure increases, its stability and ability to regulate the power grid become new challenges [32]. The intermittent and unpredictable nature of solar energy requires that the grid must have sufficient regulation capacity or reserve capacity to ensure the stability of power supply [33], which may require additional investments, such as the construction of energy storage facilities, or more complex grid management techniques. These factors, in aggregate, increase the cost of the overall energy system and may somewhat undermine the economic attractiveness of renewable energy promotion.

6. Conclusions and Policy Recommendations

Based on the panel data of eight prefecture-level cities in Qinghai Province from 2014 to 2023, a static balanced panel model is used to explore the impact of large-scale photovoltaic development on the regional economy. It is found that PV power generation has a significant positive effect on the GDP of each region in Qinghai Province. Its regression coefficient reaches 1.727. This means that for every additional unit of photovoltaic power generation, the regional GDP of Qinghai Province is expected to increase by 1.727 units. In addition, in order to deeply analyze the regional differences in provincial PV power generation on regional economic development, eight prefecture-level cities in Qinghai Province are divided into developed and underdeveloped regions.

Through the analysis of the difference between developed and less developed regions, it is found that the promotion effect of photovoltaic power generation on economic growth is more obvious in developed regions, and its coefficient is 2.098, while in less developed regions, the economic impact of the same growth is small, the coefficient is only 0.864. Furthermore, the study also finds that the influence of photovoltaic power generation on the regional economy has nonlinear characteristics and presents an inverted U-shaped

relationship. Specifically, when the value of photovoltaic power generation is less than 40.77, the photovoltaic power generation has a significantly positive effect on regional economic development. When the value is greater than this, photovoltaic power generation has a significantly negative effect on regional economic development. Moreover, the impact is more significant in less developed areas, when the photovoltaic power generation exceeds 2.08. Its positive effect on economic growth will turn into a negative effect. Developed regions do not show this inverted U-shaped relationship.

Based on the empirical findings, this study proposes a more focused and cost-sensitive policy framework that accounts for regional disparities and the diminishing marginal returns of large-scale photovoltaic (PV) deployment. First, PV development strategies should be tailored to regional conditions. In less developed areas, efforts should prioritize addressing infrastructural and technical constraints through targeted, time-bound support measures such as concessional financing and tax incentives, coupled with investments in grid access and labor capacity. Context-specific integration models, such as “PV + agriculture/livestock”, may offer additional socio-economic benefits but should be selectively promoted based on land suitability and local needs. In contrast, developed regions—where economic returns to PV are higher—should focus on advancing grid integration, encouraging technological innovation (e.g., energy storage), and expanding energy market mechanisms, including green certificates and carbon trading, to reduce reliance on long-term subsidies. Second, PV deployment should be rationalized in scale. The identified inverted U-shaped relationship between PV generation and economic growth, particularly in less developed regions, signals the risk of overexpansion. Excess capacity in areas lacking sufficient energy demand or grid absorption may lead to inefficiencies and resource misallocation. Therefore, deployment decisions must be aligned with local energy needs, land constraints, and market maturity. Third, policy design should balance environmental and economic objectives. While PV contributes to emission reductions, large-scale installations—especially in ecologically fragile regions—can impose environmental costs that must be internalized through better site planning and ecological safeguards. Lastly, governments must carefully manage fiscal trade-offs. Many interventions, such as infrastructure investment, R&D, and subsidies, involve substantial public expenditure. Prioritization through rigorous cost-benefit evaluation is essential to ensure that limited resources are directed toward measures with the highest marginal returns. Future research should support these goals by employing dynamic panel models to capture time-lagged effects, spatial econometrics to analyze spillovers, and micro-level surveys to assess distributional outcomes. Studies should also explore the interaction between PV development and ecological restoration, particularly in high-altitude areas, and compare Qinghai’s experience with other renewable-rich regions in western China to deepen understanding of the broader economic, social, and environmental implications of large-scale energy transitions.

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References

- Chen, H.; Chen, W. Status, trend, economic and environmental impacts of household solar photovoltaic development in China: Modelling from subnational perspective. *Appl. Energy* **2021**, *303*, 117616. (In Chinese) [\[CrossRef\]](#)
- Payne, J.E. On the dynamics of energy consumption and output in the US. *Appl. Energy* **2009**, *86*, 575–577. [\[CrossRef\]](#)
- Chen, Y.; Zhao, J.; Lai, Z.; Wang, Z.; Xia, H. Exploring the effects of economic growth, and renewable and non-renewable energy consumption on China's CO₂ emissions: Evidence from a regional panel analysis. *Renew. Energy* **2019**, *140*, 341–353. [\[CrossRef\]](#)
- Magnani, N.; Vaona, A. Regional spillover effects of renewable energy generation in Italy. *Energy Policy* **2013**, *56*, 663–671. [\[CrossRef\]](#)
- Ajmi, A.N.; Inglesi-Lotz, R. Biomass energy consumption and economic growth in exusin OECD countries: A panel analysis. *Renew. Energy* **2020**, *162*, 1649–1654. [\[CrossRef\]](#)
- Apergis, N.; Payne, J.E. Renewable and non-renewable energy consumption growth nexus: Evidence from a panel error correction model. *Energy Econ.* **2012**, *34*, 733–738. [\[CrossRef\]](#)
- Abbasi, K.R.; Shahbaz, M.; Jiao, Z.; Tufail, M. How energy consumption, Industrial growth, urbanization, and CO₂ emissions affect economic growth in Pakistan? A novel dynamic ARDL simulations approach. *Energy* **2021**, *221*, 119793. [\[CrossRef\]](#)
- Wang, Q.; Guo, J.; Li, R.R. Better renewable with economic growth without carbon growth: A comparative study of impact of turbine, photovoltaics, and hydropower on economy and carbon emission. *J. Clean. Prod.* **2023**, *426*, 139046. [\[CrossRef\]](#)
- Shahbaz, M.; Raghuftla, C.; Chittedi, K.R.; Jiao, Z.; Vo, X.V. The effect of renewable energy consumption on economic growth: Evidence from the renewable energy country attractiveness index. *Energy* **2020**, *207*, 118–162. [\[CrossRef\]](#)
- Ocal, O.; Aslan, A. Renewable energy consumption-economic growth nexus in Turkey. *Renew. Sustain. Energy Rev.* **2013**, *28*, 494–499. [\[CrossRef\]](#)
- Marques, A.C.; Fuinhas, J.A. Is renewable energy effective in promoting growth? *Energy Policy* **2012**, *46*, 434–442. [\[CrossRef\]](#)
- Moe, E. Energy, industry and politics: Energy, vested interests, and long-term economic growth and development. *Energy* **2010**, *35*, 1730–1740. [\[CrossRef\]](#)
- Chang, T.; Gupta, R.; Inglesi-Lotz, R.; Simo-Kengne, B.; Smithers, D.; Trembling, A. Renewable energy and growth: Evidence from heterogeneous panel of G7 countries using Granger causality. *Renew. Sustain. Energy Rev.* **2015**, *52*, 1405–1412. [\[CrossRef\]](#)
- Vaona, A. Granger non-causality tests between (non) renewable energy consumption and output in Italy since 1861: The (ir)relevance of structural breaks. *Energy Policy* **2012**, *45*, 226–236. [\[CrossRef\]](#)
- Bao, C.; Xu, M. Cause and effect of renewable energy consumption on urbanization and economic growth in China's provinces and regions. *J. Clean. Prod.* **2019**, *9*, 483–493. [\[CrossRef\]](#)
- State Grid New Energy Cloud. Development Overview. 3 April 2003. Available online: <https://sgnec.sgcc.com.cn/renewableEnergy/developmentsituation> (accessed on 25 May 2024). (In Chinese).
- You, F.; Wang, C. Research on basic theory, research method and development trend of ecological Economics. *China Soft Sci.* **2003**, 131–138. (In Chinese)
- Yi, Y. *China Renewable Energy Development Report*; General Institute of Hydropower Planning and Design: Beijing, China, 2023; pp. 15–20. (In Chinese)
- Apergis, N.; Payne, J.E.; Menyah, K.; Wolde-Rufael, Y. On the causal dynamics between emissions, nuclear energy, renewable energy and economic growth Ecological Economics. *Ecol. Econ.* **2010**, *69*, 2255–2260. [\[CrossRef\]](#)
- Hansen, B.E. Threshold effects in non-dynamic panels: Estimation, testing, and inference. *J. Econom.* **1999**, *93*, 345–368. [\[CrossRef\]](#)
- Hsiao, C. *Analysis of Panel Data*; Cambridge University Press: Cambridge, UK, 2022.
- Menegaki, A.N. Growth and renewable energy in Europe: A random effect model with evidence for neutrality hypothesis. *Energy Econ.* **2011**, *33*, 257–263. [\[CrossRef\]](#)
- Lee, C.C. Energy consumption and GDP in developing countries: A cointegrated panel analysis. *Energy Econ.* **2005**, *27*, 415–427. [\[CrossRef\]](#)
- Wang, H.; Shen, L. Research on the relationship between economic growth and energy consumption in China: An empirical test based on panel data of 30 provinces and cities in China. *J. Stat. Decis. Mak.* **2008**, 125–128.
- Cai, X.; Lai, C. An empirical test on the relationship between regional economic growth and energy consumption: Based on the panel data of eight economic regions in China. *J. Stat. Decis. Mak.* **2010**, 113–115.
- Semelane, S.; Nwulu, N.; Kambule, N.; Tazvinga, H. Evaluating economic impacts of utility scale solar photovoltaic localisation in South Africa. *Energy Sources Part B Econ. Plan. Policy* **2021**, *16*, 324–344. [\[CrossRef\]](#)
- Qu, Z.; Yang, S.; Xiao, J. Double carbon in northwest China under the background of the present situation in the construction of photovoltaic power station and the potential analysis. *J. Arid Zone Resour. Environ.* **2024**, *38*, 20–26. (In Chinese)
- Hu, D. Research on the Development Path of Regional Renewable Energy in China from the Perspective of Green Economy. Ph.D. Thesis, China University of Petroleum, Beijing, China, 2022. (In Chinese)
- Zou, M. Research on the integrated development of photovoltaic new energy system construction and rural economy under the background of “dual carbon”. *Shanxi Agric. Econ.* **2022**, 125–128. (In Chinese)

30. Li, N.; Zhang, G.L.; Zhou, Y.H.; Wu, W.J. Poverty reduction practice in China: Evaluation of social and economic benefits of “photovoltaic poverty alleviation” policy in rural areas. *J. China Agric. Univ.* **2022**, *27*, 294–310. (In Chinese)
31. Song, C.; Guo, Z.; Liu, Z.; Hongyun, Z.; Liu, R.; Zhang, H. Application of photovoltaics on different types of land in China: Opportunities, status and challenges. *Renew. Sustain. Energy Rev.* **2024**, *191*, 114146. [[CrossRef](#)]
32. Zhou, Q.; Yang, S. Summary and prospect of new energy development in Northwest China. *China Energy* **2018**, *40*, 25–32.
33. Wang, L.Q. Application of Research on Optimal Allocation of Energy Storage in Improving the Acceptance Capacity of Photovoltaic Power Generation. Master’s Thesis, Xi’an University of Technology, Xi’an, China, 2016; pp. 67–70.

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