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Study on the impact of demographic and economic changes on regional energy consumption

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Abstract: Energy is the foundation of civilization and economic development, closely related to human survival and social stability. The rational use of energy is also the main battlefield for achieving "carbon neutrality" and "carbon peak". Based on the linear regression model, stagnant growth model and time series model, we constructed an energy consumption forecasting model based on population and economic changes. On the basis of analyzing the impact of population and economic changes on energy consumption, the energy consumption is predicted by combining the population size and the forecast value of GDP. The year-end resident population, gross regional product and total energy consumption data of Sichuan Province from 2000 to 2021 are selected for example validation, and the total energy consumption of Sichuan Province from 2022 to 2026 is predicted by using the established energy consumption prediction model based on demographic and economic changes, and the results show that: the population and the economy are positively and negatively correlated with the energy consumption, and the total energy consumption is still in an upward trend. The total energy consumption is still in an upward trend. The results show that population, economy and energy consumption are positively and negatively correlated, respectively, and that total energy consumption is still on the rise.

1. Introduction

Energy is the material basis for human survival and an important driving force for economic development, and is crucial for national prosperity, social order stability, and people's well-being. Energy consumption and carbon emissions are inextricably linked [1].Through energy forecasting, it is possible to establish the relationship between energy consumption and environmental protection, and to make targeted adjustments to the energy structure and industrial layout. Forecasting total energy consumption is of broad and far-reaching significance for energy conservation and emission reduction to achieve "carbon neutrality" and "carbon peak". With the rapid economic and social development and the significant improvement of people's living standards, energy consumption shows a rising trend, so quantitatively analyzing the impact of demographic and economic changes on energy consumption and then forecasting energy consumption will lay a solid foundation for accomplishing the goals of energy conservation and emission reduction.

Scholars mainly conduct research on total energy consumption forecasting from the aspects of influencing factors and fitting accuracy. Gao Di et al take the energy consumption of fixed asset investment projects and production adjustment and technological reform as the forecasting idea, and use the idea of driver decomposition to construct the forecasting method based on scenario analysis, time series forecasting method, multi-layer feed-forward neural network forecasting and combined forecasting to forecast the total energy consumption of Shanghai [2]. Hao Yu et al used the scenario analysis method to predict the energy consumption of each industry under three different scenarios: optimistic, baseline and pessimistic [3]. Xuechun Wang screened the factors influencing the total energy consumption such as economic level, population size, energy intensity and so on according to the grey correlation law quantitatively, and then constructed a particle swarm algorithm optimized support vector machine model to predict the energy consumption [4]. Yang Zhang established a variable weight combination prediction model based on hybrid indicators to predict total energy consumption by considering two error indicators, namely, the sum of error squares and the absolute value of maximum error[5]. Changjian Wang et al analyzed the process of the development of energy consumption by using the input-output method to compile the sources of energy inputs and outputs into an input-output table [6]. Chen Hui et al used an autoregressive distributed lag model to estimate the parameters of the energy consumption forecasting model and combined it with a time series model to forecast the factors affecting energy consumption, and then substituted the predicted values of the factors and the estimated values of the parameters into the autoregressive distributed lag model to forecast the total and structural energy consumption [7].

In summary, scholars have made a lot of research on the forecast of energy consumption, which provides a theoretical basis for realizing the sustainable development of energy, but scholars have not studied the impact of population and economic changes on energy consumption enough. Therefore, through linear regression analysis to quantitatively analyze the impact of population and economic changes on energy consumption, a linear equation is derived, and combined with the stagnant growth model and the time series model to forecast the population and GDP of Sichuan Province in 2022-2026, based on which, the total energy consumption of Sichuan Province in 2022-2026 is forecasted based on the predicted values of the population and GDP. The projected value is helpful for relevant departments to formulate relevant policies and provide a basis for reducing energy waste and energy transformation.

2. Energy consumption forecasting model based on demographic and economic changes

2.1 Linear regression model

Linear regression model is suitable for fitting with less amount of data and influencing factors, so this paper uses linear regression model to analyze the relationship between population, economy and total energy consumption. Linear regression modeling is a regression analysis method to study the linear relationship between one or more independent variables and the dependent variable through a linear regression equation least square function [8]. In the analysis of the relationship between population and economy on energy consumption, the total energy consumption is used as the dependent variable Y, and the year-end resident population and GDP are used as the independent variables X_1 and X_2 for the multiple linear regression analysis, and the total energy consumption Y and the year-end resident population X_1 and GDP X_2 are used to construct the multiple linear regression model as shown below:

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 \tag{1}$$

Where: β_0 is the regression constant; β_1, β_2 are the regression coefficients of the year-end resident population X_1 and the gross regional product X_2; Based on the least squares method, the minimum β_0, β_1 and β_2 values of the sum of squared deviations are calculated as shown in equation (2):

$$\min = \left(\sum Y_i - \hat{\beta}_0 - \hat{\beta}_1 x_{i1} - \hat{\beta}_2 x_{i2} - \cdots - \hat{\beta}_p x_{ip}\right)^2 \tag{2}$$

The method assumes that the year-end resident population X_1 and gross regional product X_2 are independent of each other and have the same weights in equation (2).

2.2 Blocked Growth Model

Blocked growth model based on the exponential growth model to increase the correction factor, taking into account the environmental capacity, external resources and other real factors, commonly used in population forecasting. Logistic model is based on the exponential growth model to improve the formation of a S-shaped growth trend curve population forecasting method, its fitting trend shows that the population growth rate in the later stages of the gradual decline in growth rate and eventually tend to stabilize [9]. The model can be expressed as:

$$\begin{cases} \dfrac{dn}{dt} = r(n)n \\ n(0) = n_0 \end{cases} \tag{3}$$

Where: r is the population growth rate; n is the number of population; $r(n)$ is the growth rate r when the number of population is n. Based on the characteristics of policy and social and other factors population tends to stabilize, it is assumed that the relationship between r and n is a linear function, as shown in equation (4):

$$r(n) = r - an \tag{4}$$

There is when the population reaches its maximum capacity:

$$\begin{cases} r(n) = r - an \\ r(n_m) = 0 \end{cases} \rightarrow \begin{cases} \dfrac{dn}{dt} = \dfrac{r}{n_m}(n_m - n) \times n \\ n(0) = n_0 \end{cases} \tag{5}$$

Where: n_m is the value of the maximum population capacity; this leads to the final form of the Logistic population projection model:

$$n(t) = \frac{n_m}{1 + (\frac{n_m}{n_0} - 1) \times e^{-rt}} \tag{6}$$

The logistic population projection model helps to fit the reality by adding its own and external constraints and thus correcting the population growth rate.

2.3 Time series modeling

The time series (ARIMA) model is based on historical economic data to explore the operation law of time series, which has high practicality in the field of economy and finance. The time series (ARIMA) model is a statistical model that predicts future development based on past economic trends, with the advantages of small amount of required data and dynamic determination of parameters [10].The ARIMA model consists of an autoregressive model $AR(p)$, a difference-in-differences model $I(d)$, and a moving average $MA(q)$, where $AR(p)$ is the future forecast composed of the actual value of the past GDP time series and the noise term, and p is the order

$AR(p)$; $I(d)$ for the GDP data subtracted to stabilize, d for the order of $I(d)$, generally take the value of 0, 1, 2; $MA(q)$ to the past GDP time series as an error function to correct the future forecast, q for the order of $MA(q)$. ARIMA model in the time-series forecasts can be expressed as a lagged term and the random interference term of the current and lagged period of the linear function, that is, the model is shown in Equation (7):

$$Y_t = c + \alpha_1 Y_{t-1} + \cdots + \alpha_p Y_{t-p} + \varepsilon_t + \beta_1 \varepsilon_{t-1} + \cdots + \beta_q \varepsilon_{t-q} \tag{7}$$

The establishment of ARIMA model to forecast gross regional product can be divided into the following four steps:

Step 1: Based on the ADF test method to test the smoothness of the time series of gross regional product. If the series is non-stationary, it needs to be transformed into a stable time series through differential analysis.

Step 2: Based on the preliminary determination of the model order according to the autocorrelation coefficient and partial autocorrelation coefficient, the best model is selected by combining the AIC and BIC order criteria.

Step 3: Parameter estimation and diagnostic test by testing the parameter significance, model validity and testing whether the residual series is white noise series.

Step 4: Based on the ARIMA model constructed in the above steps, the gross regional product is forecasted.

3. Example Validation

Since the total energy consumption data of Sichuan Province in 2022 has not been released, the regional GDP, year-end resident population, and total energy consumption of Sichuan Province from 2000 to 2021 are used as data variables. The data is sourced from the China Statistical Yearbook from 2001 to 2022, the China Energy Statistical Yearbook from 2001 to 2021, and the Sichuan Provincial Statistical Yearbook from 2001 to 2022. Using a linear regression model to analyze the impact of regional GDP and year-end permanent population on total energy consumption, determine the formula of the linear regression model, and then combine the Logistic model to predict the year-end permanent population of Sichuan Province from 2022 to 2026 and the ARIMA model to predict the regional GDP of Sichuan Province from 2022 to 2026.

3.1 Impact relationship analysis

Table 1: Linear regression analysis

Variant	Unstandardized coefficient		Standardized coefficient	t	P	VIF	R^2	Adjustment R^2	F
	B	standard deviation	$Beta$						
Constant	219481	41510	-	5.287	0.000***	-	0.904	0.894	F=89.752 P=0.000***
Year-end resident population	-25.942	5.129	-0.51	-5.058	0.000***	2.016			
Gross regional product (GDP)	0.391	0.032	1.242	12.329	0.000***	2.016			

Note: ***, **, * represent 1%, 5%, and 10% significance levels, respectively.

By analyzing the value of significance test F and the degree of regression fit R^2 , we can analyze whether there is a linear relationship between the independent variable gross regional product, the year-end resident population and the dependent variable total energy consumption, and determine the degree of fit of the regression straight line and the linear model, the results of the linear regression analysis are shown in Table 1. In the table, R^2 is as large as possible in the range of $[0,1]$; VIF is the degree of multicollinearity, whose value should be less than 10; B is the coefficient in the presence of a constant; the standard error is the ratio of B to t; and the standardized coefficients are the coefficients that have been standardized.

From the F-test and R^2 results in Table 1, the significance P-value is 0.000***, showing significance at the level, there is a linear relationship between the variables and a good fit between the year-end resident population X_1, regional gross domestic product X_2 and total energy consumption Y. The model basically meets the requirements. The model formula is shown below:

$$Y = 219481.29 - 25.942 \times X_1 + 0.391 \times X_2$$

Meanwhile, for the covariate covariance performance, the VIF values are all less than 10, indicating that the constructed multiple linear regression model does not have the problem of multiple covariance and the model performs well.

3.2 Regional population projections

Based on the Sichuan Provincial Statistical Yearbook to obtain the year-end permanent population data of Sichuan Province from 2000 to 2021, and after several calculations, assuming that 2011 is t_0, combined with the year-end permanent population data of Sichuan Province from 2011 to 2021 based on the logistic prediction model under the natural conditions of the maximum population of Sichuan Province is 87,685,200 people, and the net relative growth rate is 0.0557. The forecast of the year-end resident population of Sichuan Province from 2011 to 2021 and the relative errors are shown in Table 2.

Table 2: Forecast results and relative errors of year-end resident population in Sichuan Province, 2011-2021

Vintages	Actual value (10,000 persons)	Forecast (10,000 persons)	Relative error (%)
2011	8064	8064.00	0.0000
2012	8085	8099.26	0.1764
2013	8109	8132.90	0.2948
2014	8139	8164.98	0.3192
2015	8196	8195.55	-0.0055
2016	8251	8224.67	-0.3191
2017	8289	8252.41	-0.4415
2018	8321	8278.81	-0.5070
2019	8351	8303.94	-0.5635
2020	8371	8327.86	-0.5154
2021	8372	8350.60	-0.2557

According to Table 2, it can be seen that the average relative error of the 2011-2021 population forecast results is 0.3089%, and the error range is [-0.5635%, 0.3192], indicating that the forecast model fits well. And then the forecast results of year-end resident population in Sichuan Province from 2022 to 2026 are shown in Table 3.

From Table 3, it can be seen that the value of the year-end resident population of Sichuan Province in 2022-2026 is still in an upward trend, and the number of population in 2026 will be 84,485,000 people, which is an increase of 979,000 people compared with 2021, which is in line with the national policy.

Table 3: Projected year-end resident population of Sichuan Province, 2022-2026

Vintages	2022	2023	2024	2025	2026
Year-end resident population projection (10,000)	8372.22	8392.78	8412.31	8430.87	8448.50

3.3 Regional economic projections

Based on the ARIMA model and combined with the regional GDP data of Sichuan Province from 2000 to 2021, predict the regional GDP from 2022 to 2026. By analyzing the ADF test, determine whether the actual sequence is stationary and whether the difference order can be transformed into a stationary sequence at 0, 1, and 2. The ADF test is shown in Table 4.

Table 4: ADF test

Vintages	Difference order	*t*	*P*	*AIC*	Threshold value		
					1%	5%	10%
Gross regional product (GDP)	0	8.103	1.000	167.639	-4.138	-3.155	-2.714
	1	-0.613	0.868	206.841	-3.859	-3.042	-2.661
	2	-2.967	0.038**	173.231	-4.223	-3.189	-2.73

If the significance is $P < 0.05$, it means that the series is a smooth time series. From Table 4, when the difference order is 2, the significance P value is 0.038** and the series is a smooth time series. Perform autocorrelation and partial autocorrelation analysis on the regional GDP sequence, and determine the order of the autoregressive model and moving average based on the truncation situation. The results of autocorrelation and partial autocorrelation of final difference data are shown in Figure 1.

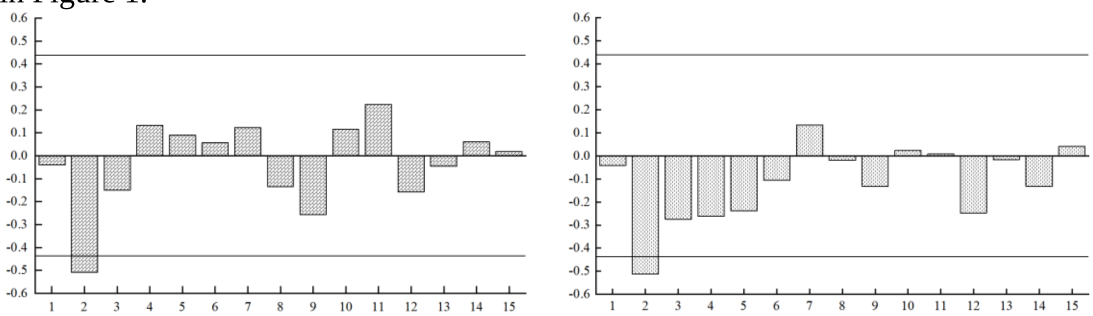

Figure 1: Autocorrelation plot of final differential data (left) and Bias autocorrelation plot of final differential data (right)

From Figure 1, it can be seen that the order of its autoregressive model and moving average is 2, 2. On this basis, since the ARIMA model needs to be purely stochastic, a white noise test is carried out based on the value of the Q statistic. The model white noise test results are shown in Table 5.

Table 5: ARIMA (2, 2, 2) model Q statistics

Q-statistic	Parameters
Q6 (P-value)	0.034(0.853)
Q12 (P-value)	0.936(0.988)
Q18 (P-value)	6.33(0.899)

From the results of Q statistics, it can be seen that based on the total regional production series, the P-values of Q6, Q12 and Q18 are all greater than 0.1, which do not show significance, so the residuals of the ARIMA (2, 2, 2) model are white noise, which is in line with the model requirements.The prediction fitting ability of 0.998 was obtained from the model superiority measure, and the model performance was excellent. By measuring the model superiority R^2 the prediction fitting ability is 0.998 and the model performance is excellent.

$$Y(t) = 204.396 + 0.14 \times Y(t-1) - 0.633 \times Y(t-2) - 0.505 \times \varepsilon(t-1) - 0.495 \times \varepsilon(t-2)$$

In turn, the GDP of Sichuan Province is forecasted from 2022 to 2026, and the forecast results show a rising trend year by year, and the forecast results are shown in Table 6.

Table 6: Forecast of Gross Regional Product of Sichuan Province, 2022-2026

Vintages	Forecast (billions of dollars)
2022	60637.69
2023	65185.41
2024	68814.19
2025	74035.90
2026	80367.65

Without considering the impact of policy changes and unforeseen events on the regional economy, Sichuan's GDP shows substantial growth from 2022 to 2026.

3.4 Forecast of energy consumption

According to the forecast results of year-end resident population and GDP of Sichuan Province in 2022-2026, combined with the relationship formula between year-end resident population, GDP and total energy consumption analyzed by the multiple linear regression model, the forecast value of total energy consumption in Sichuan Province in 2022-2026 can be derived, and the results are shown in Table 7.

Table 7: Forecast of Total Energy Consumption in Sichuan Province, Sichuan Province, 2022-2026

Vintages	Forecast (tons of standard coal)
2022	25998.4956
2023	27243.2866
2024	28155.4923
2025	29715.6974
2026	31734.0542

Combining Table 7 with the data of standardized quantity of coal fuel, standardized quantity of oil fuel, standardized quantity of natural gas, standardized quantity of primary electricity, standardized quantity of net inward and outward electricity transfer, and standardized quantity of other energy sources from 2000 to 2021, we can analyze the data to conclude that the consumption of energy sources is still in an upward trend, but the consumption of fossil fuels is gradually decreasing, and the consumption of clean energy sources is increasing, which is conducive to the protection of the ecological environment, and contributes to the "carbon neutrality" and the "carbon peaking".

4. Conclusion

Energy has an extremely important position in modern society and has a profound impact on people's life, economy and environment. In the study of regional energy consumption prediction based on population and economic changes, the linear regression model is used to explore the influence of population and economic changes on energy consumption in Sichuan Province from 2000 to 2021, and then the total energy consumption in Sichuan Province from 2022 to 2026 is predicted on the basis of the forecasts of population and GDP by combining with the stagnant growth model and the time series model. The results show that the population is negatively correlated with energy consumption, the economy is positively correlated with it, and energy consumption is still increasing year by year. The results of this study can provide a basis for the government to formulate energy-saving and emission reduction policies, thus laying a foundation for the realization of "carbon neutrality" and "carbon emission".

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