Chengdu carbon emission analysis and emission reduction countermeasure research in the context of the Double Carbon

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Abstract. In the context of global warming, low -carbon has become the focus of long -term concern for governments and all walks of life from all over the country. China proposed in 2020 to achieve the two goals of "carbon neutrality" and "carbon peaks". In recent years, it has achieved remarkable results in carbon emission reduction low carbon work. This study comprehensively evaluated the important carbon emissions indicators of Chengdu through the use of the TOPSIS Entropy Method and used the Gray Forecast Model and the Holt model to predict the total carbon emissions of Chengdu from 2023 to 2027. The largest weight of urban activities in various types of carbon emissions indicators in Chengdu is 0.3165. The total carbon emissions in Chengdu have increased in index before the 20th century, and it did not fluctuate slowly until recent years. The government should pay attention to the development and utilization of new energy and the transformation of energy efficiency. This study provides a reference for the direction of energy conservation and emission reduction policies of the Chengdu Municipal Government, and provides reference and samples for other cities around the world in promoting green low -carbon transformation.

Keywords: Carbon emissions, TOPSIS, Holt model, Gray Forecast Model.

1. Introduction

The 2015 Paris Agreement passed at the Paris Climate Change Conference, urging member states to work hard to control the average temperature. In 2017, 16 countries and 22 cities established the Carbon Sino -Hehe Alliance (CNC). China officially proposed in 2020 that it will achieve "carbon neutrality" in 2060. In 2021, China will formulate a carbon emissions operation plan before 2030, and the work of carbon emission reduction will enter the implementation stage. As the provincial capital of Sichuan Province, Chengdu City is not only an important economic center in the Southwest, but also an influential modern metropolis in the country and the world. In recent years, it has achieved remarkable results in carbon emissions and low -carbon work.

At present, for Chengdu, most domestic studies are aimed at specific aspects in some fields, such as clean energy pure electric vehicles and traditional fuel cars by more than 80%[1]. The construction of green parks has a significant effect on reducing carbon and carbon[2]. The trend of the good development of the land is greatly helpful for the reduction of carbon emissions [3]. However, in recent years, the overall carbon emission trends and prediction issues of Chengdu City have less research. It cannot clearly and intuitively show the impact of the Chinese government's emission reduction measures in recent years. Study the changes in carbon emissions in Chengdu and the achievements that may achieve the future.

This study has sorted out 7 important indicators for the main sources of carbon emissions in Chengdu in the past 20 years. They are transportation and construction, industrial production process, agricultural and forestry and land use changes, waste treatment, outsourcing power, heating and refrigeration, and carbon emissions of other cities' internal activities. First use the entropy authority to evaluate the weight of 7 indicators, and then use the TOPSIS Entropy Method to comprehensively score the carbon emissions from 2000-2021 and sort according to the score level. In addition, this study uses the Holt model and Gray Forecast Model to predict the total carbon emissions data of

Chengdu from 1970 to 2022 (2023-2027). Finally, it provides reasonable suggestions for the Chengdu government by comparing the results of the two predicted models.

The innovation points of this article are as follows: First of all, from the research content, this study visited the overall carbon emissions volume of Chengdu's overall carbon emissions, and intuitively and clearly showed that no emission reduction measures and emission reduction measures were obtained. The degree of influence provides the government with the basis for policy rationality and provides research samples for other cities. Secondly, from the research model, few studies have used different models to analyze the results and compare the results, and this study has repeatedly used the Gray Forecast Model and the Holt model to compare the results. The trend and result of total carbon emissions of the city provides new ideas and research directions for subsequent researchers.

2. Literature review

As the climate changes are becoming more intense, the problem of carbon emissions has also received more and more scholars' attention. Research on carbon emissions mainly includes the following aspects.

First, the research content of carbon emissions involves driving factor [4] [5], spatial characteristics [6], different regions [7], carbon emissions [8] and other aspects. Scholars have found that different urban areas are affected by different driving factors. For example, in the prefecture -level cities that are affected by the first industries in Shanxi Province, there are prefecture -level cities with greater influence of the first industry. There are prefecture -level cities in Datong City, Linfen City, Luliang City, Taiyuan City, Yuncheng City, Yangquan City, and Changzhi City; carbon emissions in Changzhi City and Taiyuan City are also affected by the green space area of the built -up area. Therefore, research on a certain local cities is necessary.

Second, influencing factors mostly involve large directions such as the construction industry [9], manufacturing [10] [11], and transportation. These contents are very large in carbon emissions, especially industrial and energy.

Thirdly, research methods often adopt scenario analysis, factors analysis, index decomposition method, etc. Liu Chao and other improving the backing analysis of the influencing factors of the long -term carbon emissions time and space changes in the return analysis of the StirPat model. Finally With the development of low -carbon in space, Hao Yaxing and Wang Jian used the Broad Di's Index to decompose and analyzed it, and the degree of quantitative factors contributed to the changes in the carbon emissions of the industry.

Fourthly, research standards are mainly concentrated in the country, region, provincial level [12], economic circle [13], and urban agglomerations. This is because the research of carbon emissions in a single city is limited to a small range and has no strong representativeness. At the same time, their research is more inclined to a specific field. There are fewer research on a single prefecture -level city. Carbon emissions and related indicators in Chengdu have been measured and predicted in the past 20 years, analyzing the differences in different indicators in Chengdu, found important carbon sources, proposed targeted countermeasures for Chengdu carbon development, and help achieve the "double carbon" goal.

3. Data Sources and Research Methods

3.1. Data Sources

By consulting materials from the Sichuan Provincial Bureau of Statistics, the Chengdu Statistical Yearbook, and the "General Guidelines for the Accounting and Reporting of Greenhouse Gas Emissions from Industrial Enterprises," we have identified the main sources of carbon emissions in Chengdu, selecting the seven most important indicators according to the proportion of carbon emissions of different indicators, namely activities outside the urban jurisdiction, including transportation and construction, industrial production processes, agriculture and forestry and land, waste management, purchased electricity, heating and cooling, and other urban internal activities. Subsequently, through data retrieval, we obtained the total carbon emission data for Chengdu from 1970 to 2022, as well as the carbon emission data for various prefecture-level cities from 2000 to 2021, from the "CEADs China Carbon Accounting Database" website. Based on this data, we plotted a line chart showing the average total carbon emissions every five years over time, as shown in Figure 1. The explanation of the carbon emission data indicators from 2000 to 2021 is provided in Table 1.

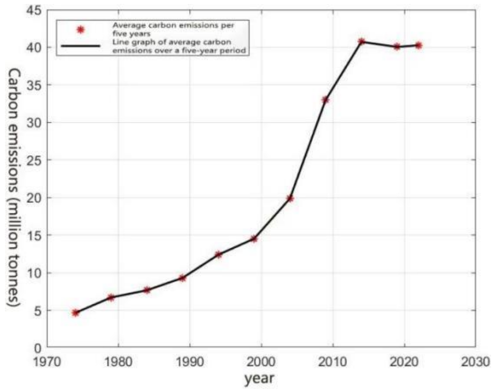

Figure.1. Line Chart of Average Carbon Emissions Every Five Years from 1970-2022

Table.1. Explanation of Carbon Emission Data Indicators

First-level Indicator	Second-level Indicator	Units	Attributes
Direct Carbon Emissions within City Limits	Carbon Emissions of Transportation and Building	Million tons	Negative
	Carbon Emissions of Industrial Production Process		
	Carbon Emissions of Agriculture, Forestry, and Land Use		
	Carbon Emissions of Waste Treatment		
Indirect Carbon Emissions outside City Limits	Carbon Emissions of Purchased Electricity		
	Carbon Emissions of Heating and Cooling		
Other City Internal Activity Carbon Emissions	Other Carbon Emissions Caused by Internal Activities Inducing Emission outside City Limits		

Data sources: China Carbon Accounting Database, Sichuan Provincial Bureau of Statistics, China Energy Statistical Yearbook, China Industrial Statistical Yearbook, China Agricultural Statistical Yearbook, China Animal Husbandry Yearbook, China Urban Statistical Yearbook, China Forestry and Grassland Statistical Yearbook.

3.2. Research Methods

Considering the complexity of "carbon sources" — three aspects and seven indicators of carbon emission data, we used the Distance Comprehensive Evaluation Method, Time Series Data Analysis Method, and Grey Pattern Mining Method to predict and analyze the carbon emission data from 1970 to 2022.

3.2.1 TOPSIS Entropy Method

The TOPSIS Entropy Method is a method that allocates weights based on the degree of change in indicators, reflecting the dispersion and uncertainty of data. According to the definition of information entropy, the larger the entropy value, the smaller the dispersion of the indicator, the less influence the indicator has on the comprehensive judgment, and the smaller the weight. The TOPSIS algorithm can solve the multi-objective decision-making problems of limited schemes in systems engineering. The central idea of this method is to first determine the positive ideal solution (best solution) and the negative ideal solution (worst solution) for each indicator, and then obtain the proximity of each scheme to the best solution as the standard for evaluating the quality of the scheme.

From the data acquisition and indicator analysis above, it is known that there are seven important indicators for carbon emissions in Chengdu, including transportation and construction, industrial production processes, agriculture and forestry and land, waste management, purchased electricity, heating and cooling, and other urban internal activities. Based on the complexity of carbon emission data indicators, we first conducted an independent weight analysis for the data of the seven indicators, performed normalization processing and proportion calculation respectively, and calculated the corresponding entropy value for each indicator based on the obtained proportions. The specific formula is:

$$e_j = -k \sum_{i=1}^{m} p_{ij} \cdot lnP_{ij} \; p_{ij} = \frac{r_{ij}}{\sum_{i=1}^{m} r_{ij}} \left(0 \le p_{ij} \le 1\right). \tag{1}$$

In the formula, P_{ij} is the prior probability of the carbon emission indicator value for the j-th carbon emission indicator in the i-th year,and the constant $k = \frac{1}{\ln m} > 0$;where represents the entropy value of the j-th carbon emission indicator.

The information utility value of an indicator depends on the difference between the information entropy e_j and 1. Its value directly affects the size of the weight. The larger the information utility value, the greater the importance of the evaluation, and the larger the weight. Based on the obtained information utility value, we calculated the entropy weight of each carbon emission data indicator. The specific formula is:

$$w_j = \frac{(1-e_j)}{\sum_{j=1}^{n}(1-e_j)} = \frac{d_j}{\sum_{j=1}^{n} d_j}. \tag{2}$$

In the formula,$d_j = 1 - e_j$,where$d_j$represents the information utility value.The weight calculation results are shown in Table 2.

Table.2. Indicator Weights

First-level Indicator	Weight	Second-level Indicator	Weight	Final Weight
Direct Carbon Emissions within City Limits	0.4250	Carbon Emissions of Transportation and Building	0.3192	0.1357
		Carbon Emissions of Industrial Production Process	0.2595	0.1103
		Carbon Emissions of Agriculture, Forestry, and Land Use	0.1911	0.0812
		Carbon Emissions of Waste Treatment	0.2302	0.0978
Indirect Carbon Emissions outside City Limits	0.2585	Carbon Emissions of Purchased Electricity	0.5364	0.1387
		Carbon Emissions of Heating and Cooling	0.4636	0.1198
Other City Internal Activity Carbon Emissions	0.3165	Other Carbon Emissions Caused by Internal Activities Inducing Emission outside City Limits	1.0000	0.3165

In the study of carbon emissions in Chengdu, the transportation and construction sectors show high carbon emissions and large fluctuations, highlighting their key role in carbon emission management with higher information entropy values. The purchased electricity indicator also has a relatively high weight due to the large use of fossil fuels in electricity production and needs to be emphasized in emission reduction strategies. In addition, the weight of emissions outside the jurisdiction caused by urban internal activities is 0.3165, indicating that this part of the data has high variability and requires special attention and further analysis.

Secondly, a complete multi-attribute decision-making on carbon emission data was conducted, and the distance between the optimal and worst values of carbon emission data was calculated based on the TOPSIS Entropy Method, and the relative closeness was calculated. The specific formula is:

$$C_i = \frac{D_i^+}{D_i^+ + D_i^-}. \tag{3}$$

Where $D_i^+ = \sqrt{\sum_j \left(z_{ij} - z_{ij}^+\right)^2}$, $D_i^- = \sqrt{\sum_j \left(z_{ij} - z_{ij}^-\right)^2}$, C_i is the relative closeness.

After obtaining the relative closeness based on the aforementioned formula, the indicators are sorted according to their relative closeness values. The larger the value of C_i, the closer the selected indicator is to the optimal value. The carbon emission scores and rankings of Chengdu from 2000 to 2021 are shown in Table 3.

Table.3. Comprehensive Evaluation Index and Rankings

Year	Total Carbon Emission (Million tons)	Comprehensive Evaluation Index	Ranking
2000	12.348	0.0728	1
2001	16.4808	0.0585	6
2002	16.4472	0.0590	8
2003	16.1828	0.0579	3
2004	17.688	0.0555	2
2005	15.165	0.0634	4
2006	18.9124	0.0530	5
2007	16.335	0.0602	12
2008	19.7792	0.0477	7
2009	23.084	0.0413	11
2010	18.516	0.0529	13
2011	19.5672	0.0530	9
2012	19.6608	0.0495	14
2013	22.1364	0.0428	10
2014	24.31	0.0339	21
2015	24.08	0.0342	16
2016	27.3672	0.0273	15
2017	28.157	0.0269	20
2018	28.044	0.0240	17
2019	25.5762	0.0315	18
2020	25.104	0.0353	19
2021	30.996	0.0194	22

The comprehensive evaluation index of carbon emissions in Chengdu demonstrates an increasing trend over time, with the highest index in 2000 indicating effective control of carbon emissions. From 2010 onwards, the comprehensive evaluation index has decreased due to rapid economic development and urbanization, suggesting an increase in energy consumption and carbon emissions. This trend highlights the challenge of balancing economic growth with carbon emission control and validates the data's effectiveness, providing a reliable basis for the formulation of emission reduction strategies, such as the optimization of the energy structure.

3.2.2 Holt Model

In order to visually preserve the trend of carbon emissions over time, the total carbon emissions of Chengdu from 1970 to 2022 were plotted using EXCEL to create a time series graph, as depicted in Figure 2.

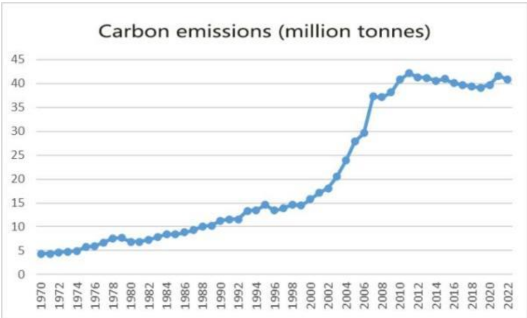

Figure.2. Time Series Plot of Carbon Emissions

From Figure 2, it can be observed that carbon emissions exhibit an increasing trend. Additionally, the volatility in the time series plot is quite pronounced. Consequently, this paper establishes a Holt model within the time series analysis.

Holt method is widely applied in forecasting and is considered an advanced form of exponential smoothing. The most notable advantage of this method is its ability to directly smooth trend data and predict the original time series without the need for double exponential smoothing, especially for time series with trend components. In this study, we employ this method to analyze and forecast the carbon emissions of Chengdu for the next five years.

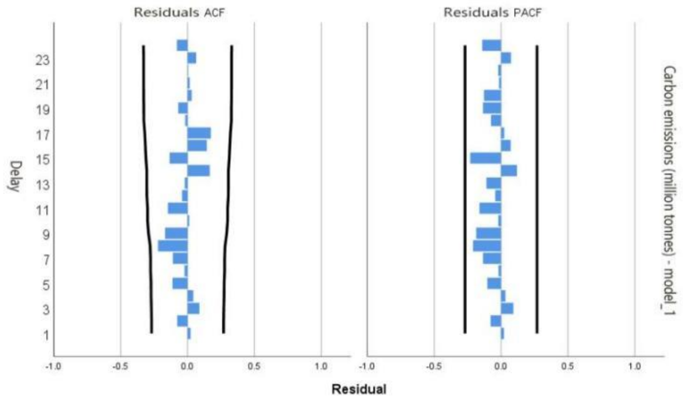

Figure.3. ACF and PACF Plots

By analyzing the autocorrelation (ACF) and partial autocorrelation (PACF) of the total carbon emissions data of Chengdu from 1970 to 2022, it was observed that as the lag order increases, the correlation indicators of the series fluctuate between positive and negative, showing dynamic changes. To effectively capture the trend in carbon emission data, the Holt model was assessed for its effectiveness, with the results presented in Table 4.

Table.4. Model Statistics

Model statistics					
Model	Predictor Variable Count	Model fitness statistics	Yang-Box Q (18)		
		Stable R square	Statistics	DF	Significance
Millions of tons CO2 (MTCO2) - model_1	0	0.455	16.797	16	0.399

① The number of predictive variables: 0, indicates that the model does not utilize any external variables for forecasting, relying solely on the time series data itself.

② Model fitting statistics: 0.455, which is close to 0.5, indicating that the model can better fit historical data.

③ Ljung-Box Q (18): 16.797, this value is used to test the autocorrelation of the residues, and the value is large, indicating that there is no auto-related in the residual, and the model is suitable.

④ The number of Outlier: 16, indicates that 16 points are considered to be outliers in the data set. These may affect the predictive accuracy of the model and require further analysis to determine their causes.

⑤ Stable R square: 0.399, this value indicates that the model can explain 39.9%of the data variability. Although the value of the smooth R square is not particularly high, it still indicates that the Holt model of this article has a certain interpretation ability.

⑥ Holt model parameters are shown in Table 5, including the estimated values, standard errors, T statistics, and prominentness of Alpha (level) and Gamma (trend).

Table.5. Model Parameters of Exponential Smoothing Method

Exponential Smoothing Model Parameter						
Model			Estimate	Standard error	t	Significance
Millions of tons CO2 (MTCO2) - model_1	Not convert	Alpha (Level)	0.548	0.133	4.135	0.000
		Gamma (Trend)	1.000	0.383	2.613	0.012

① Alpha (Level): 0.548, this value indicates that the model assigns a higher weight to the most recent observations, which helps to capture the recent changes in the data.

② Standard Error: 0.133, this is the standard error of the Alpha estimate, which is relatively small, indicating that the estimate is quite stable.

③ t-value: 4.135, this value is used to test the significance of the Alpha parameter. Since the t-value is large, it suggests that the Alpha parameter is significant.

④ Significance: 0.000, a very small p-value indicates that the estimate of the Alpha parameter is statistically significant.

⑤ Gamma (Trend): 1.000, this value indicates that the trend predicted by the model will continue indefinitely without showing any signs of leveling off.

⑥ Standard Error: 0.383, this is the standard error of the Gamma estimate.

⑦ t-value: 2.613, this value is used to test the significance of the Gamma parameter.

⑧ Significance: 0.012, indicating that the Gamma parameter is significant at the 5% significance level.

The evaluation results of the model show that the Holt model can effectively capture the trend of carbon emission data and has a high degree of predictive accuracy.

3.2.2 Grey model

The grey prediction model is based on the grey system theory, which is about uncovering the underlying regularities beneath objective appearances. The grey prediction model seeks to find the patterns of change by organizing raw data, ultimately generating a grey sequence. This article will use the cumulative generating operator. The process of successively accumulating data from each item (moment) in the sequence is called the cumulative generating process. The sequence obtained from the cumulative generating process is called the cumulative generating sequence. The specific formula is:

$$x^{(r)}(k) = \sum_{i=1}^{k} x^{(r-1)}(i) \quad (k = 1,2,\cdots,n, r \geq 1). \tag{4}$$

Firstly, the data used for prediction with the grey model should initially possess quasi-exponential regularity and smoothness ratio conditions. This paper has made judgments on both the condition that the ratio is greater than or equal to 2 and the smoothness ratio is greater than or equal to 0.5, and ultimately, the data meets the smoothness conditions and exponential growth patterns.

Secondly, the first-order differential equation model GM(1,1) was applied to carbon emission data from 1970 to 2022. The GM(1,1) model was used to analyze the carbon emission data of Chengdu from 1970 to 2022, and the forecasted values for the next five years are shown in Figure 4.

Lastly, to accurately assess the precision of the forecasted data, it is necessary to verify the predicted values. This involves sequentially calculating the average and standard deviation of the original carbon emission data, computing the prediction error and the corrected variance and standard deviation, and calculating the a posteriori difference ratio and judging the prediction accuracy. The calculated a posteriori difference ratio is 0.34, and according to the criteria, it can be known that the results predicted by the grey prediction model are of good precision.

4. Empirical Results

4.1. Holt Model Results

Based on the carbon emission data from 1970 to 2022 in Chengdu, the SPSS software was utilized to forecast the carbon emissions for Chengdu from 2023 to 2027, as shown in Table 6.

Table.6. Carbon Emission Forecast for the Years 2023-2027

Year	Carbon Emissions (Unit: Million tons)
2023	42.139040745504246
2024	42.869487375405990
2025	43.599934005307720
2026	44.330380635209465
2027	45.060827265111210

The forecast results are processed for visualization, as shown in Figure 4, which further demonstrates the fitting effect of the Holt model on historical data and the predicted trend of future carbon emissions. Through this intuitive display, the reliability of the model's predictions and the possible direction of future carbon emissions can be more clearly seen.

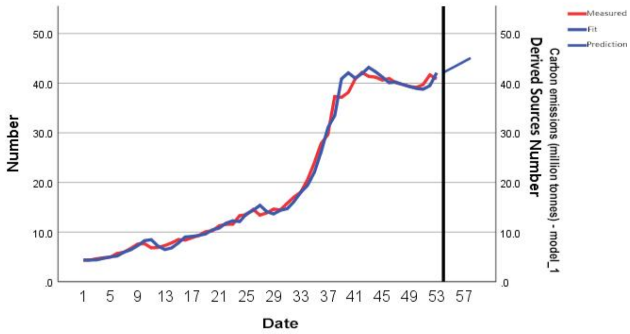

Figure.4. Holt Model Forecast Chart

4.2. Gray Forecast Model Results

The forecast values have been obtained and presented in Table 7. The fitting results of the grey prediction model are compared with the original data sequence and are depicted in the comparison chart, as shown in Figure 5.

Table.7. Grey Model Forecast of Carbon Emissions from 2023 to 2027

Year	Carbon Emissions (Unit: Million tons)
2023	61.032686
2024	63.739056
2025	66.565435
2026	69.517143
2027	72.599739

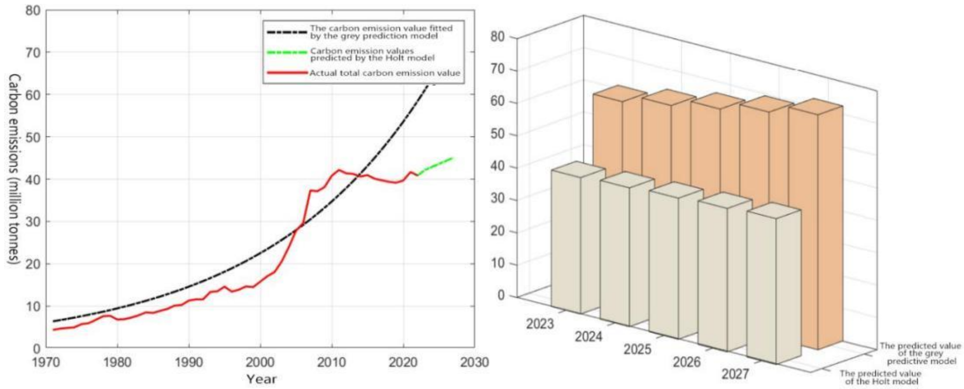

Figure.5. Comparison of Two Model Predictions

Analysis of Predictive Results

1.Annual Growth Trend: The forecasted data indicates that carbon emissions in Chengdu will continue to rise over the next five years. This is associated with factors such as the acceleration of urbanization, expansion of industrial production, and increased traffic volume.

2.Stable Growth Rate: From 2023 to 2027, the rate of increase in carbon emissions is relatively stable, with no significant growth between adjacent years. This suggests that, in the absence of new emission reduction measures, carbon emissions are likely to increase at a relatively stable rate

3.Policy Formulation Reference: These predictive results provide policymakers in Chengdu with a clear expectation of carbon emission growth, aiding them in setting quantitative benchmarks for emission reduction targets and measures.

4.Action Necessity: The annual increase in carbon emissions underscores the need for urgent and effective emission reduction actions to prevent greater negative environmental impacts.

5. Conclusions and Recommendations

5.1. Conclusions

Among various carbon emission indicators in Chengdu, urban activities significantly dominate. Prior to 2000, the total carbon emissions exhibited an exponential growth trend. However, with the government's continuous implementation of energy-saving and emission-reduction measures in recent years, the growth trend of total carbon emissions has noticeably decelerated. It is still predictable that the total carbon emissions in Chengdu from 2023 to 2027 will continue to trend upwards, necessitating stronger policy guidance from the government.

To achieve Chengdu's "low-carbon, zero-carbon" goals, it is imperative to align with the city's development prospects and the predictive analysis results of this study. Efforts should focus on transitioning to clean energy, improving energy efficiency, economic incentives and constraints, vigorously developing green transportation, and comprehensively enhancing environmental awareness. Firstly, the full utilization of renewable energy sources and the gradual phase-out of high-energy-consuming, high-polluting industries are essential. Government subsidies and tax incentives should promote renewable energy projects such as solar and hydroelectric power, gradually replacing inefficient coal-fired power plants. Secondly, energy conservation in construction, optimization of building materials, and reduction of construction consumption should be pursued. Implement energy-saving standards for buildings, promote efficient insulation materials, and intelligent control systems; in the industrial sector, reduce energy consumption through technological upgrades and process optimization. Then, continue to increase investment in public transportation and popularize the use of low-energy-consuming vehicles. Invest in public transportation systems to improve services, implement subsidies and other incentives to popularize electric vehicles, and reduce the use of traditional gasoline vehicles. Moreover, adjust carbon pricing and establish green finance. Implement carbon taxes and establish carbon trading markets, supporting energy-saving and emission-reduction projects through green financial instruments, such as the Green Development Fund established by the Chinese government. Lastly, enhance the effectiveness of public education and awareness campaigns, starting from practical actions. Raise public environmental awareness through education and advocacy for green lifestyles, while also strengthening forest protection and management, and implementing afforestation projects to increase carbon sinks.

5.2. Policy Recommendations

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Acknowledgments

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