A new model for carbon neutrality based on PV power generation

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Abstract. Energy issues has long been a significant problem perplexing multiple countries. Carbon neutrality is an essential area for power generation. The paper studies the feasibility and prospect of photovoltaic power generation through constructing mathematical models to forecast the electricity supply volume and the maximal PV power generation from 2024 to 2060, giving answer to the accessibility of carbon peak and carbon neutrality by 2060. Hence, we build a mathematical model to analyze different factors contributing to the electricity supply in China and predict its trend from the period 2024 to 2060. Combined with the model established in the paper for PV power generation, we reach the conclusion that China can realize carbon peak and carbon neutrality by 2060, which is much helpful for the government to make strategies.

Keywords: Regression, Time series prediction, ARIMA, GM, Photovoltaic power generation.

1. Introduction

The electric energy industry is supposed to develop under careful supervision. However, owing to global warming and other approaches to climate change as well as the hope to achieve carbon peaking and carbon neutrality in the near future, Chinese governments are attaching importance to alter its current structure where traditional means such as coal and oil will gradually be taken place by nascent and relatively cleaner ones, where solar energy is considered to be one of the most renewable and sustainable energy sources, and photovoltaic power generation has become an important research topic[1].

Based on electronic semiconductors, particularly but not exclusively, crystalline silicon or thin-film semiconductor materials, photovoltaic power technology is one of the optimum ways to utilize solar power to generate electricity by converting the sunlight to direct current in solar cells or PV cells[2]. Therefore, material scientists are dedicated to developing high-performance photovoltaic cells, so as to win the competition against other clean energy sources[3].

Hence, we build a mathematical model to analyze different factors contributing to the electricity supply in China and predict its trend from the period 2024 to 2060. Secondly, in terms of costs and benefits, geography and lightening conditions as well as other factors, select an area and build a model to examine the accessibility of constructing a photovoltaic power plant there. Then, build a mathematical model to calculate the potential maximum photovoltaic power generation in China, in which factors such as geographic resources, investment capacity and cost should be taken into account.

2. Preliminary

2.1. Assumptions

1.We assume that the marketization index (2020-2022) through SPSS platform is as same as the true value.

2.We assume the PV generation panels take up the same space as the under-constructed PV power plants and the average annual total horizontal irradiance ε is substituted for a certain place in Tianjin so that the model can be simplified[4].

3.We assume that the PV power plant comes into service as soon as the station is constructed, in order to calculate the cost and income of the first year[5].

4.We overlook the transportation cost and ageing of the PV panels.

2.2. Notations

The primary notations used in this paper are listed in Table 1.

Table 1 Notations

Symbol	Description
β	General term for coefficients of each function
y_t	Observed Time Series
β_c	Conversion Efficiency of PV Cells
$\varepsilon\ (W/m^2)$	Global Horizontal Irradiance
$P\ (W)$	Total Power of PV Generation Panels
$P_0(W)$	Power of PV Generation Panels per unit area
$C\ (dollor)$	Total Cost of PV Power Plant in Tianjin
$C_{TI}\ (dollor/KWh)$	Total Installation Cost of PV Power Plant in Tianjin
$C_{AG}\ (dollor/KWh)$	Average Generation Cost of PV Power Plant in Tianjin
$I\ (dollor)$	Total Income of PV Power Plant in Tianjin
$I_T\ (dollor)$	Other Income of the PV Power Plant
$S\ \ (hactor)$	PV Panel Area or Under-constructed Power Plant Area
$S'(hactor)$	Actual Area of PV Panel
$E\ (Wh/m^2)$	Irradiance Under Standard Conditions
$T\ (yuan/KWh)$	Electricity Price in Tianjin
t (Year)	Year
$H\ (1/h)$	Annual Full-load Equivalent Hour
$E(10^8 KWh)$	Maximum PV Power Generation

3. Electricity Supply Analysis and Prediction

3.1. Data Acquisition and Pre-processing Based on Cubic Function

From the background, it is certain that electricity supply in China is intimately bound up with factors such as economic status (GDP), household consumption expenditure, urbanization rate and marketization index. The majority of data was managed to obtain successfully, whereas last-three-year data (2020-2022) of the marketization index could not be found[6].

Hence, through analyzing the given statistics, our team found that the marketization index has demonstrated a trend, forming a cubic function. Subsequently, the coefficient of the function can be attained utilizing the SPSS platform[7]. Ultimately, our team managed to acquire the full data of the four factors, part of which is shown as follows, along with the missing data of the marketization index and the missing one is shown in Table 2 and Figure 1.

Table 2 Data Acquisition and Processing of Task I

Year	GDP/*10^9$	Household Consumption Expenditure/¥	Urbanization Rate	Marketization Index	Electricity Supply Quantity/*10^9Kwh
2019	142799.68	21559	60.6	8.19	74866
2020	146877.44	21210	63.89	8.82	77620
2021	178204.59	24100	64.72	9.27	85200
2022	179631.71	24538	65.22	9.81	86372

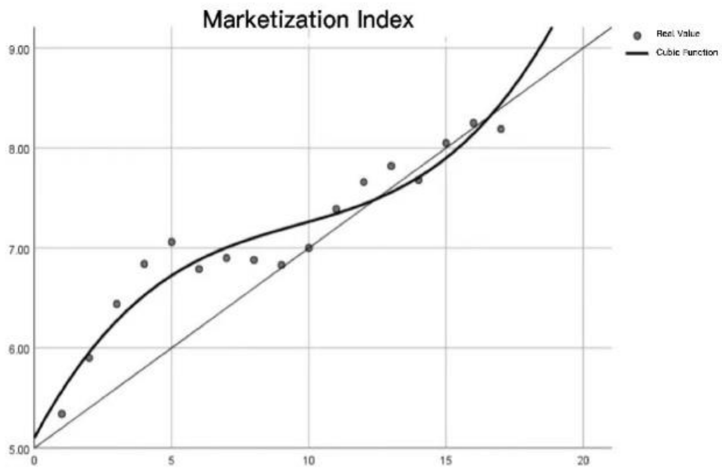

Figure 1 Cubic Function of Marketization Index

3.2. Analysis of results

Table 2 and Figure 1 demonstrate the coefficients of the cubic function together with T-test value and P-value, it can be learned that all variables have possessed a P-value of less than 0.05, meaning that every term has a prominent influence on this function and hence the function is stable. Moreover, the R-squared value can be obtained via SPSS which is 0.922 in this case. It is sufficient to derive that the module functions well since the value is approximate to 1 which is shown in Table 3.

Table 3 Coefficient of the Cubic Function Describing the Trend of Marketization Index

	Unstandardized Coefficients		Standardized Coefficients	T	P-value
	β	Normal Error	β		
x	0.512	0.141	3.276	3.633	0.003
x^2	-0.045	0.018	-5.375	-2.531	0.025
x^3	0.002	0.001	3.128	2.406	0.032
Constant	5.101	0.302		16.917	0.000

4. Electricity Supply Relationship Model based on MLR

4.1. Establishment of the MLR Model

In order to study the relationship between electricity supply and the four factors comprising GDP, household consumption expenditure, urbanization rate and marketization index[8], one terrific approach is to construct a multiple linear regression model, where the four factors serve as independent variables and electricity supply quantity is the dependent variable in this scenario. Utilizing the SPSS platform, coefficients of the four factors can be obtained respectively, along with the T-test value and P-value. The table is shown as follows, where coefficients are kept three decimal places. It is shown in Table 4.

Table 4 Coefficient of MLR Describing Relation between Electricity Supply and Four Factors

	Unstandardized Coefficients		Standardized Coefficients	T	P-value
	β	Normal Error	β		
GDP (x_1)	0.148	0.053	0.370	2.781	0.014
Household Consumption Expenditure (x_2)	0.472	0.401	0.152	1.178	0.257
Urbanization Rate (x_3)	1200.108	256.391	0.441	4.681	0.000
Marketization Index (x_4)	777.313	683.180	0.040	1.138	0.273
Constant	-37216.716	9599.571	-	-3.877	0.001

4.2. Analysis of the Result

Initially, through the T-test value and P-value in the MLR model, it can be seen that GDP and urbanization rate are imperative factors influencing electricity supple[9], due to the fact that the P-value of both is with the normal range of 0.05, whereas other two factors are not as significant as the former ones.

Secondly, the R-squared value of the model is 0.998, which also signifies the well-functioning of the model since the value is approximate to 1.

The coefficient correlation between four factors is shown in Table 5.

Table 5 Coefficient Correlation between four factors in the MLR Model

Coefficient Correlation	Marketization Index	Household Consumption Expenditure	Urbanization Rate	GDP
Marketization Index	1.000	0.014	-0.308	-0.048
Household Consumption Expenditure	0.014	1.000	-0.294	-0.766
Urbanization Rate	-0.308	-0.294	1.000	-0.340
GDP	-0.048	-0.766	-0.340	1.000

4.3. Electricity Supply Prediction Model based on ARIMA

The autoregressive integrated moving average (ARIMA) model is based on the principle of differencing stationary time series data to achieve stationarity, rendering it suitable for modeling[10]. In order to construct the ARIMA model, the first step is to build the AR model and the MA model, which assumes that the current value of a time series is a linear combination of its past values and its past white noise error terms respectively. Therefore, selecting the suitable value of $(\mathbf{p}, \mathbf{q}, \mathbf{d})$ becomes the key to construct a well-functioned ARIMA model. This process can be achieved utilizing programming in Python language.

4.4. Establishment of the ARIMA Model

Since every parameter of the ARIMA model has been identified, the model can be formally established. Fit the given electricity supply quantity data from the training set (part of which given below) into the model, and the function of the time series is obtained and shown in the figure below. It can be seen with bare eyes that the model functions remarkably well. Furthermore, it is worth mentioning that the fluctuation of the far left of the function is completely attributed to the lack of data (1995), which is not our fault. The results are shown in Table 6 and Figure 2.

Table 6 Excerpt of the Training Set

Year	Electricity
1995	10023
1996	10764
1997	11274
1998	11590

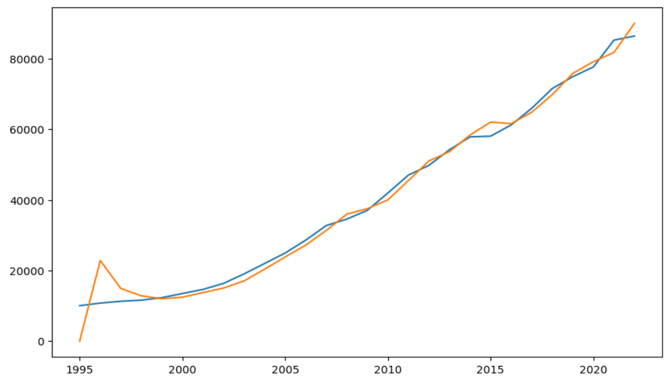

Figure 2 Fitting Function of the Time Series in Training Set

By summing up the forecasted results for wind power and photovoltaic generation obtained above, our team found that the combined result has already exceeded the predicted power supply quantity for the year 2060. Therefore, based on the vigorous development of the photovoltaic and wind power industries, the carbon neutrality goal for 2060 can be achieved.

4.5. Evaluation

The prediction for the 2024 environmental protection budget utilizes the Grey GM (1,1), achieving a relatively accurate prediction with a limited amount of data. Closely tied to reality, the prediction for the maximum photovoltaic power generation in 2024 is effectively made by gathering a large amount of data. What's more, the results are presented through visualization methods. We neglect the complexity of real-world situations, resulting in some influencing factors not being reflected in the forecasting process.

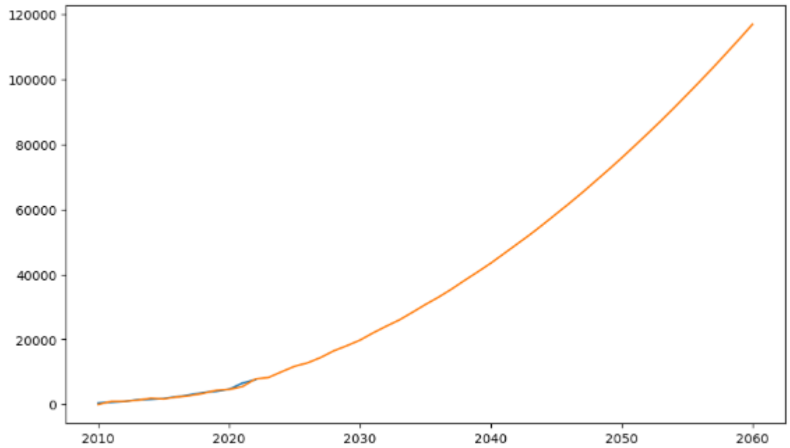

Figure 3 Prediction for Wing Power Supply (2023-2060)

Figure 3 shows the prediction of wing power supply. In terms of PV power generation, the electricity supply is approximately $\mathbf{973081371865.679}\ \boldsymbol{KWh}$ and $\mathbf{775448583991.794}\boldsymbol{KWh}$ respectively when conversion efficiency of PV Cells $\boldsymbol{\beta_c}$ is $\mathbf{25\%}$ and $\mathbf{20\%}$. Assuming conditions in Task III is also suitable for Task IV, the excessive quantity of PV power supply from 2023 to 2060 is $\mathbf{36004010759030.12}\boldsymbol{KWh}$ and $\mathbf{28691597607696.37}\boldsymbol{KWh}$ separately.

5. Conclusion

We proposed two different methods and models to evaluate the the prospect of Chinese photovoltaic power generation industry. Based on our research above, we sincerely come up with several suggestions toward the development of PV power industry. The MLR model demonstrates a good performance, effectively explaining the relationship between various factors and power supply quantity. By employing time series forecasting (ARIMA), the model is kept simple, reducing the impact of random factors. However, owing to the lack of sufficient data, Subjective assumptions of the Cost & Income model may result in error regarding the value of payback period of the power plant and the maximum PV power generation. Next, we shall consider more details about the specific industry problem using our models and provide more constructive suggestions.

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