A Mathematical model of Evolution and Prediction of Renewable Energy

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***Abstract*—How to describe the evolution of renewable energy scientifically and predict it in the future based on previous data has been a hot research. Considering the data released by the US MCM/ICM in 2018, and the consumption of non-renewable and renewable energy in some US states, ARIMA statistics model and BP-ARIMA model were established to analyze the evolution of renewable energy consumption in some US states from 1960 to 2009. Meanwhile, the process predicted the development of renewable energy by 2050. The results show that the proportion of renewable energy consumption to total energy consumption was not large from 1960 to 2009, but it was increasing year to year. And renewable energy will become the trend of future energy .**

Keywords-Renewable Energy, Energy Evolution, Energy Prediction, ARIMA Model, BP-ARIMA Model

I. Introduction

With the development of economy, the demand for energy in countries has risen sharply, while the conservative fossil fuel reserves are limited, which is impossible to meet industrial production for a long time. The world is miring down in "energy crisis" [1,2]. In order to develop economy sustainably, countries have not only developed advanced technology to improve the utilization rate of conservative energy, but also been gradually paying more and more attention to develop renewable energy. Compared with conservative energy, renewable energy has more advantages, like less pollution, rich reserves and so on. So researches on renewable energy have been important for countries[3].

The data released by the US MCM/ICM in 2018 is used in the paper to analyze the renewable energy evolution of the States of California (CA), the States of Arizona (AZ), the States of New Mexico(NM) and the States of Texas(TX) from 2000 to 2009 and to predict the renewable energy consumption of those states by 2050.

II. Classification of Energy

Energy can be classified into natural and artificial energy sources[4]. Natural energy, also called primary energy, can be subdivided into renewable and non-renewable energy sources. Renewable energy sources consist of solar, wind, water biomass energy and etc. And non-renewable energy sources are oil, natural gas and so on.

Artificial energy, the secondary energy, refers to the energy generated by the primary energy, such as electricity, heat and so on.

III. ARIMA Model: The Evolution of Renewable Energy Profile

3.1 ARIMA Model Design

Before establishing the ARIMA model[5,6,7], we firstly need to judge if the event sequence satisfies the stationary condition. If it is not satisfied, it needs to be stabilized by order difference. And it needs to be tested for white noise if the sequence is stable. Due to the fact that the ARIMA model is established for non-stationary time series, the ARIMA model can be divided into Auto-Regressive process $AR(p)$, moving average process $MA(q)$ and Auto-Regressive moving average process $ARIMA(p)$, as well as the Auto-Regressive Integrated Moving Average $ARIMA(p,d,q)$. For the stationary sequence after differential processing, we use the ARIMA model for describing the energy evolution and fitting prediction. The formula can be described as:

$$\Delta^d y_t = \theta_0 + \sum_{i=1}^{p} \phi_i \Delta^d y_{t-1} + \sum_{j=1}^{q} \theta_j \varepsilon_{t-1} \tag{1}$$

Where y_t is the time series, $\Delta^d y_t$ represents the stable sequence y_i after d order difference, ε_i as a zero-mean white noise random error sequence. $\phi_i (i = 1,2,\cdots, p)$ and $\theta_j (j = 1,2,\cdots,q)$ are estimated parameters, p and q are the order of the model.

3.2 Results And Analysis

We take use of EViews 8.0 and SPSS19.0 to fit the total energy consumption (TETCV) and renewable energy total consumption (RETCB) of each state and observe the 50 years of the energy evolution of each state from 1960-2009. Due to limited space, we take AZ total energy consumption as an example to describe the process of calculation.

Firstly, the data of TETCV and RETCB from 1960 to 2009 is imported into EViews 8.0 for stability testing. And The Prob. Value is 0.3669, which means the time series is unstable, so a differential operation is needed to achieve a steady state. When $d = 2$, Prob. Value is 0, and the original time series reaches a steady state. Then, followed by its AC map and ARC / SC criteria to select the appropriate value p,q ,we judge $p = 0, q = 2$. The curve fitting is done by using SPSS19.0. The goodness of curve fitting is 0.994, which shows that the fitting effect is very good. At the same time, residual test is done, and it passes

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the residual test within the specified range. The residual table is shown in Table.1.

Finally, the total energy consumption curve of Arizona and the curve of consumption of renewable energy are obtained, as shown in Fig.1.

From 1960 to 2009, Arizona ' s total energy consumption continued to rise, relying on conservative fossil fuels heavily. In the 1970s and 1980s, Arizona ' s total energy consumption growth was slow or even negative growth, which had a great relationship with the 1970 US energy crisis. At the same time, the consumption of cleaner and renewable energy fluctuated greatly. In 1960, Arizona ' s total cleaner and renewable energy consumption was 36383.45 Billion Btu, accounting for 12.78% of the total energy consumption, while the consumption of renewable energy reached 103,493.3 Billion Btu and in 50 years increased nearly 3 times. But the rate had fallen to 7.12%. In the 1980s and late 20th century, the consumption of renewable energy in Arizona showed a great fluctuation. In 1983, that accounted for 23.5309% of cleaner and renewable energy, and reached 12.0975% in 1987. However, all of them were short-lived and splendid, and it declined sharply after the peak. However, cleaner and renewable energy consumption was still growing, but its growth rate was far less than the total energy consumption

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IV. BP-ARIMA Model：Renewable Profile Prediction for 2025 and 2050

(A) BP-ARIMA Model Design

BP algorithm[8,9,10] is a typical learning algorithm of artificial neural network. Its main structure is composed of an input layer, one or more hidden layers, and an output layer. Each layer is composed of a number of neurons (nodes). The output values of each node are determined by the input value, the function and the threshold value to determine the learning process of the network. The objective function of network training is E_k, that is

$$E_k = \frac{1}{2N} 1 \sum_{k=1}^{n} (u_k - \hat{u}_k)^2 \tag{2}$$

N is the number of training samples, and u_k is the ideal output value of the network, $\hat{u}_k$ is the actual output value for the network.

When the neural network is trained, the conjugate gradient method is used. At the first time of the iteration, the direction of the negative gradient is taken as the search method, $S^{(0)} = \Delta E_k (W^{(k-1)}) + \beta_k S^{(k)}$ in the form of the iteration

$$\beta_k = \frac{[\Delta E_k (W^{(k-1)})]^T \Delta E_k (W^{(k-1)})}{[\Delta E_k (W^{(k)})]^T \Delta E_k (W^{(k)})} \tag{3}$$

$$S^{(0)} = \Delta E_k (W^{(k-1)}) + \beta_k S^{(k)} \tag{4}$$

（B）Results and Analysis

We choose the total energy consumption and the total consumption data of cleaner and renewable energy in 4 states in 1960-2009 years as the original time series, and use EViews 8.0, SPSS19.0 and MATLAB to solve the problem. In order to describe the changes in energy variables more intuitively, we have plotted the curves of the States from 1960 to 2050, such as Fig.2, Fig.3.We calculate the profile in 2025 and 2050, including total energy consumption and renewable energy consumption, such as Table 2.

V. Conclusions

In 2009, the energy consumption of the states relied mainly on those of traditional fossil fuels, but the development of renewable energy had fully attracted the attention of states leaders. From 1960 to 2009, most of Arizona ' s energy was coal, oil and natural gas. In the 1970s and 1980s, total energy consumption fluctuated due to the energy crisis. However, it continued to grow steadily after the recovery, and the proportion of renewable energy to total energy had been rising volatility. Establishing scientific models for medium and long term predictions, the development of renewable energy in Arizona will be greatly improved in 2025 and 2050, and the proportion of total energy consumption will increase..

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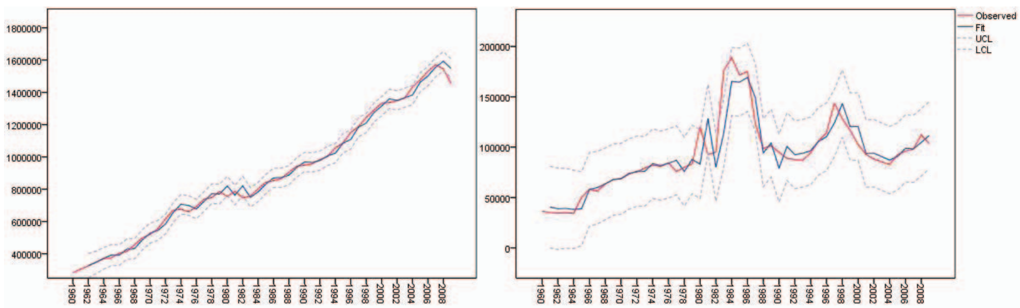
TABLE I. Model Statistics

Model	Number of Predictors	Model Fit statistics		Ljung-Box Q(18)			Number of Outliers
		Stationary R-squared	R-squared	Statistics	DF	Sig.	
ARIMA	1	.223	.994	16.444	16	.422	0



(a) (b)

Figure 1. The evolution of the energy total consumption and renewable source consumption(AZ)

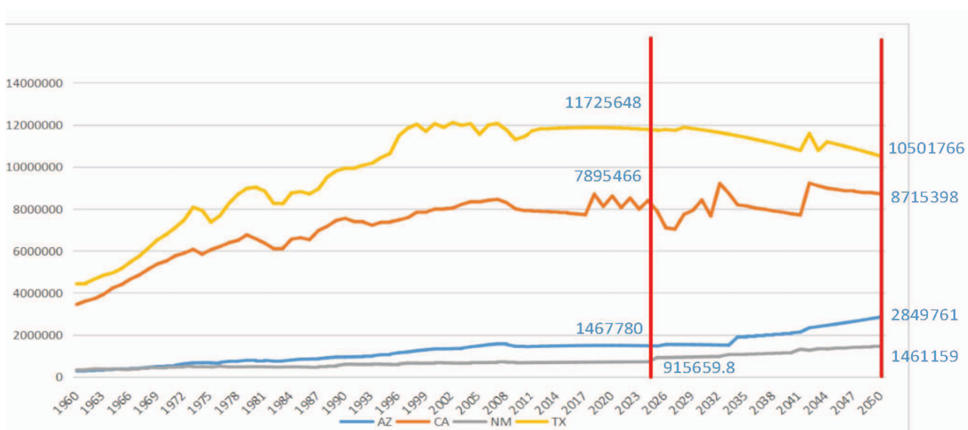


Figure 2. The tendency of energy total consumption

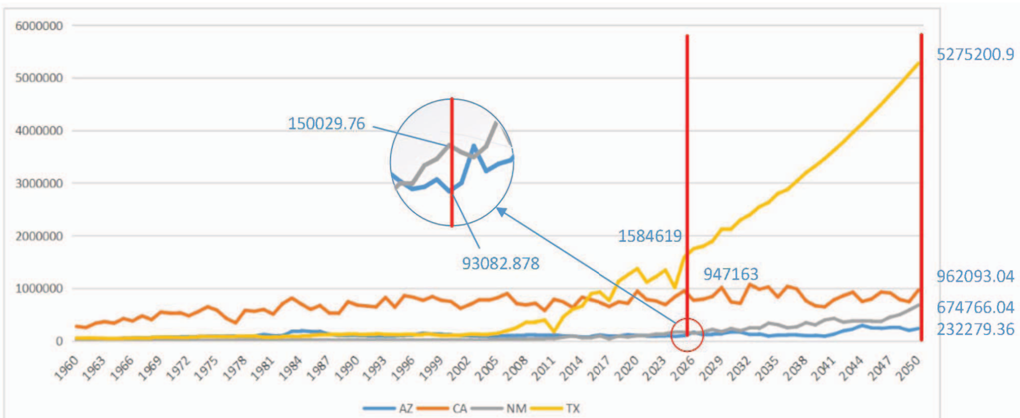


Figure 3. The tendency of renewable energy consumption

TABLE II. The energy prediction of 4 states in 2025 and 2050

States	Energy Total Consumption		Renewable Sources Consumption	
	2025	2050	2025	2050
AZ	1467780	2849761	93082.878	232279.36
CA	7895466	8715398	947163	962093.04
NM	91569.8	1461159	150029.76	674766.04
TX	11725648	10501766	1584619	5275200.9