Energy profile-Description, Evaluation and Prediction

Rongjie Jian[1], Youbo Liu[2], Licheng Zhao[3]

[1]Xiamen Huaxia University Fujian Xiamen;

[2]Fujian Normal University Fujian Fuzhou;

[3]Dalian Maritime University Liaoning Dalian

Keyword: Energy profile, grey model, principal component regression

Abstract: In order to describe and predict the energy profile of four states, we select the consumption of all sectors and all types of energy from the given worksheet, and then we aggregate them together. After mathematically and scientifically analysis, we decide to classify the data in two ways. In the first way, we divide the selected data into petroleum, natural gas, coal coke, renewable energy and else. In the second way, it is divided into industrial sector, transportation sector, commercial sector, electric power sector and residential sector. According to the classification, we draw several line charts to display the trend of energy usage in fifty years.

1. Background

Energy, water and food constitute the three main elements of human survival. Additionally, energy production and usage is a major portion of any economy. That is to say, it is of vital importance to research the profile and evaluation of energy. Now our team work as advisor for four states—California (CA), Arizona (AZ), New Mexico (NM), and Texas (TX). They all wish to form a realistic new energy compact focused on increased usage of renewable energy sources.

We are provided a worksheet which includes four states' energy production and consumption in the past fifty years, along with 605 variables. In order to clearly interpret the process to governors, we select some data which is typical to solve these problems. We aim to build models to depict the evaluation of energy and predict the energy profile of each state. Meanwhile, we take geography, industry and climate into consideration. Ultimately, it is natural for us to present some brilliant suggestions.

2. The tasks

After carefully analyzing the problem, we conclude six main sub-problems to tackle in our paper.

Describe the energy profile of each state.

Build a model to show the evolution of energy of four states from 1960 to 2009 and figure out the similarities and difference between the four states in the aspect of usage of renewable energy sources.

Based on the defined indexes determine the best profile for use of renewable energy in 2009.

Build a model to predict the energy profile of each state for 2025 and 2050 in the absence of policy changes by each governor's office.

Determine a reasonable renewable energy usage target for states and give some practical advises.

Present a one-page memo to governors for summarize this work.

3. Energy profile

In order to symbolically interpret the energy profile for each of the four states, we aggregate data in two ways. One is the types of energy; the other is the kind of sectors. We consider that consumption is the key index to show the profile, thus we choose the total consumption of different type of energy from the given worksheet.

  DOI: 10.25236/ssehr.2019.053

4. The basic model of energy evolution

In order to describe the evolution of each state's energy profile from 1960 to 2009, we categorized the data in terms of departments and categories. First, we extract the data of each state in each year, establish the Markov model, then use the optimization idea to calculate the probability transfer matrix, and explain the utilization of renewable energy in every state by using probability transfer matrix. Finally, we use possible factors to discuss the similarities and differences between the four states.

4.1 Hypotheses and definitions

We make the following assumptions:

Assuming that the current energy structure is mainly dependent on the state of the previous period, it has no direct relationship with its earlier situation, and it can only affect the latter stage.

Assuming that states' energy consumption meet with certain development laws and has continuity and stability.

Assuming that each governor does not change any policy about the usage of energy.

We make the following definitions:

$S_j^{(k+1)}$ The probability of being in a unified state after K+1 transfer

$S_i^{(k)}$ The probability of the state after the K transfer

P_{ij} The probability of being transferred from a state to a state for the first time

4.2 The model

According to the data provided, the energy structure of the four states is counted in a year. The state of energy structure in a certain period is affected only by the previous phase, and it can only affect the latter one. This change has the characteristics of randomness and no "aftereffect", which conforms to the Markov model[1].

Set $\left\{S_{(n)}, n = 0,1,2,\cdots\right\}$ is a discrete state space with a nonnegative random process (the state space is I). In the course of the development and change of the event, from a certain state, the possibility of transferring to another state at the next moment is called the state transfer probability. The state transition probability from the state S_i to the state S_j is

$$P(S_i \to S_j) = P(S_i / S_j) = P_{ij}$$

The initial state vector of the system is

$$S^{(0)} = (S_1^{(0)}, S_2^{(0)}, \cdots, S_n^{(0)})$$

If the K transfer is in the i state, the state of the j moment can be obtained by the Chapman-Kolmogorov equation:

$$S^{(0)} = (S_1^{(0)}, S_2^{(0)}, \cdots, S_n^{(0)})$$

The Markov prediction model is established, which is written as a vector form of

$$S^{(k+1)} = S^{(k)} \cdot P$$

By the recursive relation we can get:

$$S^{(1)} = S^{(0)} \cdot P$$

$$S^{(2)} = S^{(1)} \cdot P = S^{(0)} \cdot P^2$$

$$S^{(k+1)} = S^{(k)} \cdot P = S^{(0)} \cdot P^{k+1}$$

Because of the total amount of consumption from 1960 to 2009, we can use the optimal idea to obtain a more accurate one step state transfer probability matrix. Therefore, we need to calculate the minimum value of the sum of the error squared of the probability state of the theoretical state and the probability square of the actual state to construct the optimization model. We have $a(t)=\{p_t(1), p_t(2),\cdots, p_t(n)\}$, representing the probability vector of the time t system in the n state, $t=1,2,\cdots,m$, the next step state transfer matrix is

$$P=(p_{ij})_{n\times n}$$

In fact, because of the change of the objective conditions, the calculated value in theory is not exactly the same as the actual situation. Therefore, there is a total error between $a(t+1)$ and $a(t)P$. We establish the following optimization model based on the criterion of the minimum square sum of error:

$$\begin{aligned}\min\ f(P) &= \sum_{t=0}^{m-1}\left\|a(t+1)-a(t)P\right\|^2\\ &=\sum_{t=0}^{m-1}(a(t+1)-a(t)P)(a(t+1)-a(t)P)^T\end{aligned}$$

$$s.t.\begin{cases}\sum_{j=1}^{n} p_{ij}=1, i=1,2,\cdots,n\\ p_{ij}\ge 0,\ j=1,2,\cdots,n\end{cases}$$

The constraints are defined by the definition of a one-step transfer probability matrix and can be solved by MATLAB.

4.3 Results and analysis

Suppose the initial state probability vector classified according to the energy type is

$$S^{(0)}=\left(S_p^{(0)},S_g^{(0)},S_c^{(0)},S_n^{(0)},S_e^{(0)}\right)$$

It is assumed that the initial state probability vector of the division by sector is

$$S^{(0)}=\left(S_1^{(0)},S_2^{(0)},S_3^{(0)},S_4^{(0)},S_5^{(0)}\right)$$

Solving constrained optimization equations by MATLAB programming, we get the following results:

$$P_{AZ1}=\begin{bmatrix}0.9688 & 0.0252 & 0.0053 & 0 & 0.0007\\ 0.0379 & 0.9619 & 0 & 0 & 0.0001\\ 0.0116 & 0 & 0.9876 & 0 & 0.0008\\ 0.0010 & 0.0031 & 0.0005 & 0.9947 & 0.0007\\ 0.0021 & 0.0003 & 0.0410 & 0.0001 & 0.9565\end{bmatrix}$$

Figure1 (a)

$$P_{AZ2}=\begin{bmatrix}0.9369 & 0.0266 & 0.0260 & 0.0019 & 0.0085\\ 0.0264 & 0.9096 & 0.0272 & 0.0015 & 0.0354\\ 0.0030 & 0.0975 & 0.7011 & 0.0239 & 0.1745\\ 0.0003 & 0.0036 & 0.0251 & 0.9501 & 0.0209\\ 0.0014 & 0.0092 & 0.1476 & 0.1209 & 0.7209\end{bmatrix}$$

Figure1 (b)

$$P_{CA1}=\begin{bmatrix}0.9474 & 0.0418 & 0.0007 & 0.0010 & 0.0090\\ 0.0645 & 0.9278 & 0.0059 & 0.0004 & 0.0014\\ 0.0460 & 0.3266 & 0.5842 & 0.0112 & 0.0320\\ 0.0419 & 0.0043 & 0.0025 & 0.9475 & 0.0039\\ 0.0415 & 0.1070 & 0.0814 & 0.0177 & 0.7524\end{bmatrix}$$

Figure2 (a)

$$P_{CA2}=\begin{bmatrix}0.8835 & 0.0072 & 0.0040 & 0.0434 & 0.0620\\ 0.0086 & 0.7720 & 0.0816 & 0.0805 & 0.0573\\ 0.0078 & 0.1910 & 0.7507 & 0.0255 & 0.0249\\ 0.0304 & 0.1893 & 0.0293 & 0.6566 & 0.0944\\ 0.1101 & 0.0515 & 0.0193 & 0.1569 & 0.1569\end{bmatrix}$$

Figure2 (b)

$$P_{NM1}=\begin{bmatrix}0.8371 & 0.0651 & 0.0971 & 0 & 0.0007\\ 0.0762 & 0.9237 & 0.0001 & 0 & 0\\ 0.0727 & 0.0001 & 0.9261 & 0 & 0.0011\\ 0.0512 & 0.0341 & 0.0359 & 0.8404 & 0.0384\\ 0.0017 & 0.0745 & 0.0041 & 0.0003 & 0.9193\end{bmatrix}$$

Figure3 (a)

$$P_{NM2}=\begin{bmatrix}0.8581 & 0.0878 & 0.0062 & 0.0071 & 0.0407\\ 0.0924 & 0.7461 & 0.0201 & 0.0999 & 0.0414\\ 0.0199 & 0.1549 & 0.6427 & 0.1576 & 0.0249\\ 0.0069 & 0.0416 & 0.0741 & 0.8509 & 0.0265\\ 0.0494 & 0.0656 & 0.0969 & 0.0985 & 0.6896\end{bmatrix}$$

Figure3 (b)

$$P_{TX1}=\begin{bmatrix}0.9953 & 0 & 0.0033 & 0 & 0.0014\\ 0.0147 & 0.9834 & 0 & 0 & 0.0019\\ 0.0013 & 0 & 0.9938 & 0.0006 & 0.0043\\ 0.0005 & 0.2276 & 0.0004 & 0.7709 & 0.0006\\ 0.0008 & 0.2193 & 0.0004 & 0.0001 & 0.7795\end{bmatrix}$$

Figure4 (a)

$$P_{TX2}=\begin{bmatrix}0.8882 & 0.0114 & 0.0114 & 0.0084 & 0.0870\\ 0.0036 & 0.9087 & 0.0048 & 0.0166 & 0.0664\\ 0.0031 & 0.0241 & 0.6733 & 0.1345 & 0.1649\\ 0.0008 & 0.0052 & 0.0856 & 0.9052 & 0.0032\\ 0.0046 & 0.1275 & 0.0770 & 0.0676 & 0.7233\end{bmatrix}$$

Figure4 (b)

Figure 1: (a) Probability transfer matrix based on energy type of Arizona. (b) Probability transfer matrix based on sector type of Arizona

Figure 2: (a) Probability transfer matrix based on energy type of California. (b) Probability transfer matrix based on sector type of California.

Figure 3: (a) Probability transfer matrix based on energy type of New Mexico. (b) Probability transfer matrix based on sector type of New Mexico.

Figure 4: (a) Probability transfer matrix based on energy type of Texas. (b) Probability transfer matrix based on sector type of Texas.

Based on the above probability transfer matrix, we can get the probability that non-renewable energy transfer to renewable energy and the probability transfer from renewable energy to non-renewable energy. This is as follows:

Table1. Transfer probability of non-renewable energy to renewable energy

States	$X_1 \to X_4$	$X_2 \to X_4$	$X_3 \to X_4$	$X_5 \to X_4$
AZ	0%	0%	0%	0.01%
CA	0.1%	0.04%	1.12%	1.77%
NM	0%	0%	0%	0.03%
TX	0%	0%	0.06%	0.01%

Table2. Transfer probability of renewable energy to non-renewable energy

states	$X_4 \to X_1$	$X_4 \to X_2$	$X_4 \to X_3$	$X_4 \to X_5$
AZ	0.1%	0.31%	0.05%	0.07%
CA	4.19%	0.43%	0.25%	0.39%
NM	5.12%	3.41%	3.59%	3.84%
TX	0.05%	22.76%	0.04%	0.06%

Definitions: : X_1 Petroleum X_2: Natural gas X_3: Coal coke X_4: Renewable energy X_5: Else

At the same time, we get the highest and lowest value of the transfer probability between each sector.

(1) In Arizona, the highest probability of the transfer of the commercial sector to the housing sector is 17.45%, and the lowest probability of transferring the power sector to the industrial sector is 0.03%.

(2) In California, the highest probability of the transfer of the business sector to the transport sector is 19.1%, and the lowest probability of the transfer of the industrial sector to the commercial sector is 0.4%.

(3) In New Mexico, the business sector to transfer probability of the power sector up to 15.76%, the industrial sector transferred to the business sector for a minimum of 0.62% probability;

(4) In Texas, the highest probability of the transfer of the commercial sector to the residential sector is 16.49%, and the lowest probability of transferring the power sector to the industrial sector is 0.08%.

From the above analysis, we can see that if the present situation is developing, California has the highest probability of using renewable energy, and New Mexico has the lowest use of renewable energy.

4.4 The comparison between four states

Similarities:

In Arizona and New Mexico, the probability of their oil, natural gas and coal to renewable energy for 0%; probability of other energy transfer to renewable energy for 0.01% and 0.03% respectively. The reason is that the two states are in the southwestern part of the United States, with a similar geographical environment, mostly plain and desert landforms and rich in mineral resources. They mainly use oil, natural gas, coal, and less use of clean renewable energy.

In Arizona and Texas, their business department transferred to the housing sector that has the highest probability were 17.45% and 16.49%; in California and New Mexico, the lowest probability of their industry department transfer to the commercial sector, were 0.4% and 0.62%; in Arizona and Texas, the lowest probability of power department of their transfer to the industrial sector, respectively 0.03% and 0.08%.

Difference:

(1) Compared with the other three states, the probability of transferring oil, natural gas, coal and other energy to renewable energy in California is 0.1%, 0.04%, 1.12% and 1.77% respectively. The reason is that its geographical environment is superior and the industries are more developed. In a short period of 150 years, California's economy has undergone transformation from the primary industry to the second industry and then to the third industry.

(2) The probability of transferring oil and natural gas to renewable energy in Texas is 0%; the probability of transferring coal coke and other energy to renewable energy is 0.06% and 0.01%; the commercial sector in Arizona has the highest probability of transferring to residential sector. California has the highest probability of transferring the business sector to the transport sector, indicating that Arizona pays more attention to the real estate industry, and California pays more attention to the development of transportation industry.

5. The prediction model of energy profile

Based on the above analysis, we choose the grey prediction model[4] to predict the consumption of energy.

5.1 Grey Model

At first, we reference that the original sequence of $GM(1,1)$ is

$$X^{(0)} = \left\{ X^{(0)}(1), X^{(0)}(2), \cdots, X^{(0)}(n) \right\}$$

We should predict the value of $n+1, n+2, \cdots\cdots$, thus define them as $X^{(0)}(n+1), X^{(0)}(n+2), \ldots\ldots$, and the relevant sequence of prediction model is

$$\hat{X}^{(0)} = \left(\hat{X}^{(0)}(1), \hat{X}^{(0)}(2), \cdots, \hat{X}^{(0)}(n) \right)$$

Then we assume $X^{(1)}$ is a accumulative sequence of $X^{(0)}$, where is

$$X^{(1)} = \left\{ \sum_{m=1}^{1} X^{(0)}(m), \sum_{m=1}^{2} X^{(0)}(m), \cdots, \sum_{m=1}^{n} X^{(0)}(m) \right\}$$

Build the first order linear differential equations of $X^{(1)}$:

$$\frac{dX^{(1)}}{dt}+aX^{(1)}=u$$

Where a is called the development coefficient, u is called grey model action quantity. And if we get the value of a and u, the predict value of $X^{(1)}$ can be calculate. Then we assume matrix B and constant vector Y_n, where is

$$B=\begin{bmatrix} -0.5\left[x^{(1)}(1)+x^{(1)}(2)\right] & 1 \\ -0.5\left[x^{(1)}(2)+x^{(1)}(3)\right] & 1 \\ \vdots & \vdots \\ -0.5\left[x^{(1)}(n-1)+x^{(1)}(n)\right] & 1 \end{bmatrix},\quad Y_n=(x^{(0)}(2),x^{(0)}(3),\ldots x^{(0)}(n))^T$$

Based on the above formula, we let

$$\hat{U}=\begin{pmatrix}\hat{a}\\ \hat{u}\end{pmatrix}=(B^TB)^{-1}B^TY_n$$

and by calculating we obtain the grey model:

$$\hat{X}^{(1)}(i+1)=\left[X^{(1)}(1)-\frac{\hat{u}}{\hat{a}}\right]e^{-\hat{a}i}+\frac{\hat{u}}{\hat{a}}$$

To test the established grey model, we should calculate variance ratio, which is

$$C=\frac{s_2}{s_1}$$

And calculate Small error probability, which is

$$P=P\{|e(t)|<0.6745s_1\}$$

The value of P and C should satisfy the accuracy test table of grey model, which is

Table 3. Comparison table of accuracy test of grey model

Class	Variance ratio C	Small error probability P
I	< 0.35	> 0.95
II	< 0.50	> 0.80
III	< 0.65	> 0.70
IV	≥0.65	≤0.70

5.2 Results and analysis

We use MATLAB to solve the grey model and Markov prediction model, the results are as follows:

Table 4. The test of grey model

States	Classification method	Value of P	Value of C	Class
AZ	Classified in energy type	1	0.1999	I
	Classified in sector type	1	0.152	I
CA	Classified in energy type	0.8980	0.4019	II
	Classified in sector type	0.9388	0.3215	II
NM	Classified in energy type	0.9796	0.3413	I
	Classified in sector type	1	0.2468	I
TX	Classified in energy type	0.9796	0.3375	I
	Classified in sector type	1	0.2383	I

From the above chart, we can know that all the value of P and C are above class II. It seems that the use of grey model is true and all the data are liable, therefore, the result is true and successful.

Table 5. Predicted total energy consumption in 2025 and 2050

States	Classification method	The year 2025	The year 2050
AZ	Classified in energy type	2469024.908	5097824.619
	Classified in sector type	5247247.133	12229421.110
CA	Classified in energy type	8205933.336	10499718.321
	Classified in sector type	13621246.247	18912249.585
NM	Classified in energy type	1111143.141	1564407.212
	Classified in sector type	1543350.058	2375646.889
TX	Classified in energy type	16518006.759	24476520.216
	Classified in sector type	17099976.130	32446691.509

Table 6. Predicted ratio of consumption of each energy type in 2025 and 2050

States	year	Petroleum	Natural gas	Coal coke	Renewable energy	Else
AZ	2025	41.39%	27.30%	28.53%	1.66%	1.12%
	2050	42.70%	27.76%	26.76%	1.45%	1.22%
CA	2025	51.78%	42.34%	1.23%	2.51%	2.37%
	2050	53.83%	40.16%	1.20%	2.43%	2.40%
NM	2025	31.06%	28.57%	39.25%	0.11%	1.01%
	2050	31.01%	27.54%	40.60%	0	0.85%
TX	2025	43.42%	25.94%	29.45%	0.12%	1.07%
	2050	47.87%	22.22%	28.75%	0.09%	1.07%

Table 7. Predicted ratio of consumption of each sector in 2025 and 2050

States	Year	Industry	transportation	commerce	Electricity	Residency
AZ	2025	9.13%	20.26%	13.40%	42.75%	14.46%
	2050	9.54%	20.33%	13.34%	42.41%	14.38%
CA	2025	21.84%	30.93%	13.88%	18.04%	15.31%
	2050	22.35%	30.61%	13.68%	18.02%	15.34%
NM	2025	22.92%	22.87%	11.09%	33.26%	9.85%
	2050	21.49%	22.58%	11.49%	34.69%	9.75%
TX	2025	9.67%	32.27%	11.64%	27.75%	18.67%
	2050	2.70%	30.21%	13.91%	36.32%	16.86%

From the above charts, we can know that the total consumption will keep steady increase in 2025 and 2050, and the consumption in 2050 is one or two times than in 2025. In the future, petroleum will still play the dominate role in the energy structure. In Texas, the consumption of industrial sector will transfer to electric power sector. As a result of saturation of development, the consumption of transportation sector, commercial sector and residential sector will be stable.

6. Strengths and weakness

6.1 Strengths

The data we selected are based on annual statistics. And we are classified according to categories and departments, which is in line with Markov model. The state transition probability matrix calculated by MATLAB program meets the accuracy requirements.

In determining the best use of renewable energy, we carry out the principal component regression and all the indicators have reached our requirements.

The Grey prediction model and Markov model are used to establish a reasonable model with reasonable error.

6.2 Weakness

In the processing of data, we only selected some important indicators.

The evolution of the energy profile of each state during the period of 1960-2009 years, we selected only the data of the consumption of various departments and categories.

References

[1] Chen Yanchao, Niu Dongxiao. Prediction of the proportion of terminal energy structure in Jilin Province based on Markov chain[J]. Northeast Power Technology, 2014, 35(6):49-51.

[2] Wu Kaiyao, Zhu Qigui, Duan Jihong. Data Statistics of Energy Index System for Sustainable Development [J]. Shanghai Management Science, 2010, 32(1):32-37.

[3] Jin Enhui, Wang Yaomin, Mao Xiao, et al. Establishment of Black Tea Evaluation Model Based on Principal Component Regression Analysis[J]. Chinese Journal of Food, 2016(12).

[4] Yan Xueqing. Research on supply and demand forecasting of Guangdong high-skilled logistics talents based on Grey model[J]. Practice and understanding of mathematics, 2017(17):315-322.