Energy’s Development and Evaluation of Four American States

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Abstract. Energy is an important material basis for the survival and development of human society. With development of economic, people have a great demand of energy, clean energy plays an important role increasingly. Based on the energy data from 1960 to 2009 in four states of California (CA), Arizona (AZ), New Mexico (NM) and Texas (TX), an autoregressive model is used to derive energy changes curve fitting. Using principal component analysis to analyse the best use of clean energy, we concluded that clean energy use was most effective in four states in Arizona in 2009.

Keywords. Energy; autoregressive model; principal component analysis.

1. Introduction
Energy is an important material basis for economic growth and social development. With the development of economy, the demand for energy is growing. As the world's number one energy power [1], the energy structure of the United States is dominated by the initial coal (1885-1949), then it became the era of oil and natural gas (1950-present). Since the traditional energy sources are drastically reduced due to heavy consumption and non-renewable, new energy sources are beginning to play an increasingly important role. Now the United States has entered a process in which traditional and renewable sources go hand in hand New Era. Therefore, it is important to study and analyze changes in the energy development trend in the United States.

In this paper, based on energy data [2] from 1960 to 2009 in the four states of California (CA), Arizona (AZ), New Mexico (NM), and Texas (TX), we use the autoregressive model to fit four State energy curve to analyze energy changes in each state and then analyzed by principal component analysis that in 2009, Arizona had the best clean energy use among the four states.

2. Energy’s development of four American states

2.1. Introduction of autoregressive model.
Autoregressive model (AR model) [3] is a statistical method to deal with time series, with the same variables \( x \) before the period, that is \( x_i \) to \( x_{i-1} \) predict the current performance of \( x_i \). And assume they are a linear relationship.
2.2. Applying.
According to the processed data file, we can get proportion of four energy consumption (coal, all petroleum products, natural gas, clear and renewable energy) to total energy consumption per year from 1960 to 2009. Then, we take annual consumption proportion of four types of energy as variables, sort them by time to get a time sequence. We apply autoregressive model to find out mathematical relationship between the time sequences after handled. Autoregressive model we use can be shown as the following form:

\[ y_t = c_1 y_{t-1} + c_2 y_{t-2} + c_3 y_{t-3} + \varepsilon_t \] (1)

Where:
- \( y_t \): Current variables
- \( y_{t-1} \): The first variable before the current variable
- \( y_{t-2} \): The second variable before the current variable
- \( y_{t-3} \): The third variable before the current variable
- \( c_1, c_2, c_3 \): The corresponding coefficient

This mathematical relationship can be characterized sixteen difference linear equations. These equations can predict the four kinds of energy’s consumption in the future. Equations are expressed in matrix form as below:

\[
\begin{bmatrix}
  y_{CL-AZ} \\
  y_{CL-CA} \\
  y_{CL-NM} \\
  y_{CL-TX}
\end{bmatrix} =
\begin{bmatrix}
  -0.2279 & 0.2120 & 0.9570 \\
  0.0091 & -0.0116 & 0.7331 \\
  -0.0905 & 0.1641 & 0.8406 \\
  -0.4701 & 0.2873 & 1.1618
\end{bmatrix}
\begin{bmatrix}
  y_{CL-3} \\
  y_{CL-2} \\
  y_{CL-1}
\end{bmatrix}
+ \varepsilon_t \] (3)

Where:
The left column vector, from top to bottom, respectively, shows the proportion of coal used by Arizona, California, New Mexico and Texas in that year.
The right column vector, from top to bottom, respectively, shows the proportion of coal used three years ago, two years ago and one year ago.

\[
\begin{bmatrix}
  y_{PA-AZ} \\
  y_{PA-CA} \\
  y_{PA-NM} \\
  y_{PA-TX}
\end{bmatrix} =
\begin{bmatrix}
  -0.1380 & 0.1566 & 0.9215 \\
  -0.3363 & 0.2312 & 0.9332 \\
  -0.0357 & 0.1083 & 0.4760 \\
  -0.1060 & 0.1701 & 0.8715
\end{bmatrix}
\begin{bmatrix}
  y_{PA-3} \\
  y_{PA-2} \\
  y_{PA-1}
\end{bmatrix}
+ \varepsilon_t \] (4)

Where:
The left column vector, from top to bottom, respectively, shows the proportion of all petroleum products used by Arizona, California, New Mexico and Texas in that year.
The right column vector, from top to bottom, respectively, shows the proportion of all petroleum products used three years ago, two years ago and one year ago.

\[
\begin{bmatrix}
  y_{CL-AZ} \\
  y_{CL-CA} \\
  y_{CL-NM} \\
  y_{CL-TX}
\end{bmatrix} =
\begin{bmatrix}
  -0.2279 & 0.2120 & 0.9570 \\
  0.0091 & -0.0116 & 0.7331 \\
  -0.0905 & 0.1641 & 0.8406 \\
  -0.4701 & 0.2873 & 1.1618
\end{bmatrix}
\begin{bmatrix}
  y_{CL-3} \\
  y_{CL-2} \\
  y_{CL-1}
\end{bmatrix}
+ \varepsilon_t \] (5)
Where:
The left column vector, from top to bottom, respectively, shows the proportion of natural gas used by Arizona, California, New Mexico and Texas in that year.
The right column vector, from top to bottom, respectively, shows the proportion of natural gas used three years ago, two years ago and one year ago.

\[
\begin{bmatrix}
    y_{CL-AZt} \\
    y_{CL-CAt} \\
    y_{CL-NMt} \\
    y_{CL-TXt}
\end{bmatrix}
= 
\begin{bmatrix}
    -0.2279 & 0.2120 & 0.9570 \\
    0.0091 & -0.0116 & 0.7331 \\
    -0.0905 & 0.1641 & 0.8406 \\
    -0.4701 & 0.2873 & 1.1618
\end{bmatrix}
+ \varepsilon_i
\]  

Where:
The left column vector, from top to bottom, respectively, shows the proportion of clean, renewable energy used by Arizona, California, New Mexico and Texas in that year.
The right column vector, from top to bottom, respectively, shows the proportion of clean, renewable energy used three years ago, two years ago and one year ago.

Based on above equations, we can compare the curve of the original data with the curve fitted according to the equation. Then we choose Arizona’s results to give an example to explain, which are shown from figure 1 to 4 following:

**Figure 1.** Proportion of coal consumption
Figure 2. Proportion of petroleum products consumption

Figure 3. Proportion of natural gas consumption
Figure 4. Proportion of clean energy consumption

As can be seen from the above Figures, the actual value and the predict value roughly agree. So, it illustrates that the fitting is better. The situation in the remaining three states is the same as that for Arizona, and all show well-fitting results.

2.3. Energy Profile Analysis

Now, we can use these equations and the fitted curves to describe how the energy profile of each of the four states evolved from 1960 to 2009. The variables are proportion of four kinds of energy consumption and we use the names of energy as simple replacements of variables.

In Arizona, coal increased sharply at first and then declined gently. All petroleum products had a rapid growth first and a sharp decline then. At last, it shows fluctuations. As for natural gas, it had been declining, then gradually picked up, but it couldn’t reach the initial weight. As to clean energy, although there was volatility, but it rose rapidly all the time.

In California, coal had two major fluctuations, and finally show a sharp downward trend, much smaller than the initial ratio. All petroleum products increase sharply at first and then had two reductions. It returned to the original roughly the ratio eventually. Natural gas had a big ratio first, then reduced quickly, slowly increased volatility at last, much fewer than the initial data. While, clean, renewable energy went up rapidly all the time and reach a very large proportion finally.

In New Mexico, coal had a steady growth at all time. All petroleum products had been volatile, little change. The overall trend of natural gas was sharp shelves. Clean, renewable energy followed rapid growth.

In Texas, coal increased sharply during a short time and then became steady. All petroleum products had two drastic growths and there was a period of steady fluctuation between them. Natural gas always declined. Clear, renewable energy rose rapidly and continuously.

3. Evaluate clean, renewable energy usage in 2009

We apply Principal Component Analysis [4] to evaluate the use of clean, renewable energy in 2009. Because coal, petroleum, natural gas and clean energy are the main energy consumers, we choose per capita all petroleum products consumption, per capita coal consumption, per capita natural gas consumption and per capita clean energy consumption as indicators. In addition, we want to evaluate
the use of clean energy, so we choose the total growth of clean energy in the last 50 years and the ratio of clean energy to total energy as indicators.

First, standardize raw data. Then, calculate the correlation coefficient matrix. After it, calculate eigenvalues, contribution rate and cumulative contribution rate. So we can get principal component analysis results as below:

Table 1 Principal component analysis results

| Components | Characteristic Root | Contribution Rate | Accumulated Contribution Rate |
|------------|---------------------|-------------------|-------------------------------|
| 1          | 3.2721              | 53.3864           | 53.3864                       |
| 2          | 1.8486              | 30.8102           | 84.1966                       |
| 3          | 0.8793              | 14.6548           | 98.8514                       |
| 4          | 0.0071              | 0.4842            | 99.3356                       |
| 5          | 0.0027              | 0.4138            | 99.7494                       |
| 6          | 0.0007              | 0.2506            | 100                           |

Where:
1: per capita all petroleum products consumption
2: per capita coal consumption
3: per capita natural gas consumption
4: per capita clean energy consumption
5: the total growth of clean energy in the last 50 years
6: the ratio of clean energy to total energy

Because the cumulative contribution rate of the first three eigenvalues is above 98%, the principal component analysis is very effective, so we select the first three principal components to do comprehensive evaluation. The feature vectors corresponding to the first three eigenvalues are shown in table 2.

Table 2 Three principal components of the normalized variables

| Components | X1    | X2    | X3    | X4    | X5    | X6    |
|------------|-------|-------|-------|-------|-------|-------|
| 1          | -0.3598 | -0.3118 | -0.4994 | 0.4041 | 0.2348 | 0.5528 |
| 2          | 0.4514  | 0.1269 | 0.3139 | 0.4900 | 0.6644 | 0.0086 |
| 3          | -0.4766 | 0.8612 | -0.0458 | 0.1575 | 0.0649 | -0.0086 |

Then, we get the three main components which are shown as following equations:

\[ y_1 = -0.3598x_1 - 0.3118x_2 - \cdots + 0.2348x_6 \]  \( (7) \)

\[ y_2 = 0.4514x_1 + 0.1269x_2 + \cdots + 0.0086x_6 \]  \( (8) \)

\[ y_3 = -0.4766x_1 + 0.8612x_2 + \cdots + 0.0649x_6 \]  \( (9) \)

After that, take the contribution rate of the three principal components as the weight respectively, a comprehensive evaluation model of the principal components is formed as below:

\[ Z = 0.5339y_1 + 0.3081y_2 + 0.1465y_3 \]  \( (10) \)

By substituting the three principal components of each state into equation 10, we can get the rankings and the comprehensive evaluation results for each state as shown in Table 3:

Table 3 Comprehensive evaluation results and ranking

| State     | Arizona | California | New Mexico | Texas |
|-----------|---------|------------|------------|-------|
| Evaluation Values | 1.5424  | -0.2924    | -0.9834    | -0.2667 |
| Ranking   | 1       | 3          | 4          | 2     |
According to table 3, we know that Arizona has the highest fraction, so this state has the “best” profile for use of cleaner, renewable energy in 2009.

4. Summary
According to the analysis of this article, we can know that from 1960 to 2009, the proportion of using clean energy in the four states in the United States was growing, despite fluctuating sometimes which indicated that more and more clean energy is used. By comparing the energy use of the four states in 2009 through principal component analysis, we conclude Arizona has a good effort of using clean energy.

References
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