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T4 ________	**C**	F4 ________

2018
MCM/ICM
Summary Sheet

To be "green" together

Summary

With the deterioration of the environment and the shortage of energy, a better interstate energy compact among California , Arizona, New Mexico, and Texas should be made to increase the usage of cleaner, renewable energy sources. We established several models and provided some suggestions for the governments.

The first stage, we screened valuable data from the original dataset, created an energy profile for each of the four states and obtained the similarities and differences among the four states. Then we worked out some correlation analysis, analyzing several factors (e.g. population, GDP, geography, resource consumption structure) that may affect the energy profiles. So ,we can get better understanding of the energy distribution of different states more accurately.

The second stage, AHP was used to analyze the weight of various energy sources in terms of clean and renewable energy.Then we could get the state environmental index , which make it easy for us to compare the cleanliness of the four states. Also, it provides a reference for the future formulation of energy interstate compact.

Finally, we established optimized gray model to predict the future energy profile in the absence of any policy changes by each governor's office. The predicted results is not optimistic. By analyzing the results of the prediction model and drawing on the experience of other countries, we set up the goals for the use of renewable energy. We hoped governors can recognize the strengths and weaknesses of their state and promote interstate cooperation, improve the energy structure and so on.

Keywords:

Grey Prediction model;Energy profile;Interstate energy compact;Renewable energy

Contents

1 Introduction

1.1 Background

Energy policy is the combination of governmental actions that establish the framework for energy production, distribution, and consumption. This framework can be quite complex, as it is crafted from many entities and must take into account many different factors. In the United States alone there are multiple federal agencies, fifty states each with multiple agencies, and thousands of cities with their own arms of government that determine energy policy in many forms. Overall, the energy policy situation is a complicated, multilayered quilt of policy-making bodies interacting at many levels, from local to national.[1]

In 1970, 12 western states in the U.S. formed the Western Interstate Energy Compact (WIEC), whose mission focused on fostering cooperation between these states for the development and management of nuclear energy technologies. An interstate compact is a contractual arrangement made between two or more states in which these states agree on a specific policy issue and either adopt a set of standards or cooperate with one another on a particular regional or national matter.

1.2 Our Work

We are required to create an energy profile for each of the four states above.Then we establish a model to analyze the energy profile of these states from 1960 to 2009,including influential factors such as population and GDP.In the absence of any policy changes,we apply the Gray Prediction model to predict the energy profile of each state in 2025 and 2050.

Base on the energy consumption of the four states in 2009,we apply the AHP model to analyze the "Environmental weights" of each energy consumption.Thus we can calculate the environmental scores to determine which state appear to have the "best" profile for use of cleaner,renewable energy.

According to the results of the prediction and the information we have consulted, we propose the goals of renewable energy in 2025 and 2050.And also,we make some suggestions to the governors.These suggestions range from technological to interstate cooperation,which will optimize these's energy structure.

2 Assumptions

To simplify our problems, we make the following basic assumptions, each of which is properly justified.

1.The data from 1960 to 2009 is real and reliable.

2.In the next few decades,there are no natural disasters, war and so on.

3.Factors beyond the policies will not cause a sudden change in the evolution of energy resource.

4.The climate, location and characteristics of these states will not change significantly.

5.The governors are willing to make policy adjustments to our suggestions.

6.The policies will not change when we apply the Grey Prediction model to predict the energy structure in 2025 and 2050.

3 Notation

Abbreviation	Description
$\rho_{X,Y}$	Correlation coefficient
W_i	The weights of the ith energy in renewable energy usage
$x^{(0)}(m)$	the original series
$x^{(1)}(m)$	the generating series
B	Accumulated original data matrix
Y_N	Constant term matrix
RPE	Relative percentage error
ARPE	average relative percentage error
RGM	rolling grey model error

4 Model Theory

4.1 Original Energy Profile

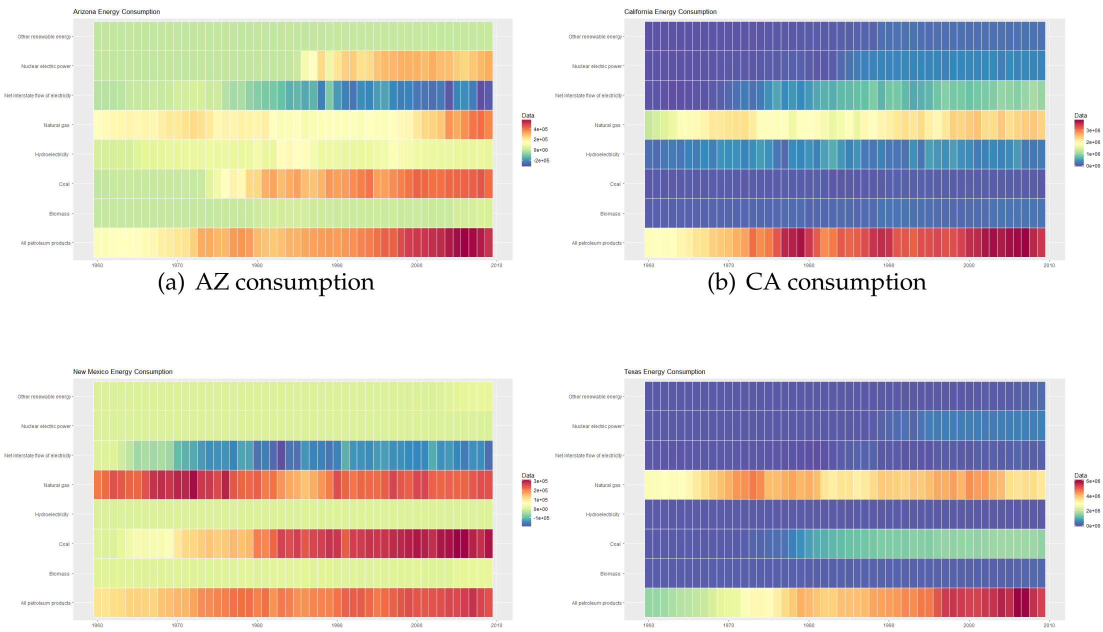
4.1.1 Energy Consumption Profile

By sorting the data provided,we get 8 characteristic parameters to show the energy consumption profile of each state.The parameters are:

- **Other renewable energy consumption:** SOTCB+GETCB+WYTCB
- **Nuclear electric power consumption:** NUETB
- **Net interstate flow of electricity:** ELNIB+ELISB
- **Natural gas consumption:** NNTCB
- **Hydroelectricity consumption:** HYTCB
- **Coal consumption:** CLTCB
- **Biomass consumption:** BMTCB
- **NAll petroleum products consumption:** PMTCB

Y-axis direction in the diagram below from the bottom to the top.

The X-axis represents the year from 1960 to 2009.In addition,we use different color to represent the consumption of each kind energy consumption.The more warm color,the greater consumption are.



(a) AZ consumption

(b) CA consumption

(c) NM consumption

(d) TX consumption

Figure1:State energy consumption diagram

As can be seen from the figure above,each state's energy consumption has been increasing.The structure of energy consumption is roughly the same in each state.And the fossil fuels consumption takes the largest part in the energy consumption,especially the petroleum products.The usage of nuclear power is on the rise.For decades,the states have not been able to develop renewable energy sources,and their growth is not obvious.

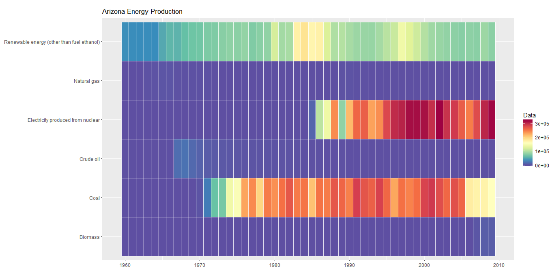
4.1.2 Energy Production Profile

Using the same sorting method above,we get 6 characteristic parameters to show the energy production profile of each state.The parameters are:

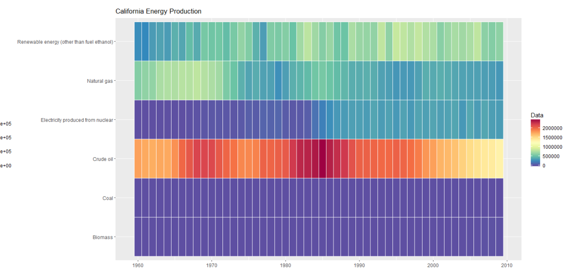
- **Renewable energy production:** ROPRB
- **Natural gas production:** NGMPB
- **Electricity produced from nuclear:** NUECB
- **Crude oil production:** PAPRB
- **Coal production:** CLPRB
- **Biomass production:** EMFDB

Y-axis direction in the diagram below from the bottom to the top.

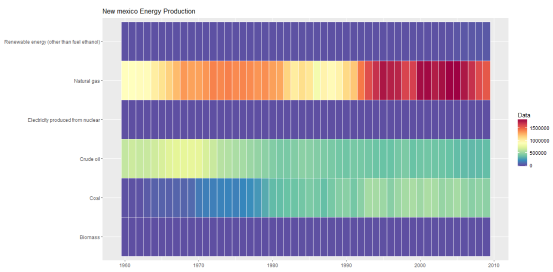
The X-axis represents the year from 1960 to 2009.In addition,we use different color to represent the production of each kind energy production.The more warm color,the greater production are.



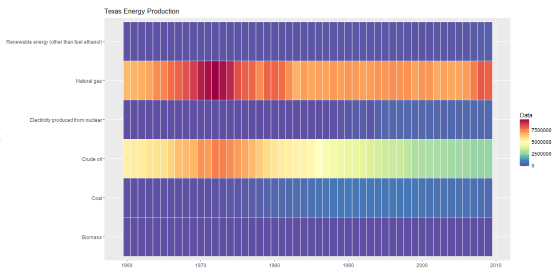
(e) AZ production



(f) CA production



(g) NM production



(h) TX production

Figure2:State energy production diagram

As can be seen from the figure above, energy output in all states increased first and then decreased. The structure of energy production are different among each state. New Mexico and Texas are rich in natural gas,while Arizona is rich in coal and nuclear power and California is rich in crude oil.It is worth mentioning that nuclear power production in California and Arizona is growing rapidly.The production of fossil fuels in all states has been declining in recent years, but it still takes the largest part in the energy production. The output of renewable energy is less, and the change is not obvious

4.1.3 Consumption and Production Contrast

Comparing the total annual energy consumption of four states,it can be concluded that energy consumption has been on the rise,and the growth rate has been declining in recent years.The energy consumption of CA and TX is obviously more than that of AZ and NM.

Comparing the total annual energy production of four states,it can be concluded that energy production peaked in the 1970s and then began to decline year by year,which is obvious in TX. Energy production in other states did not change significantly.

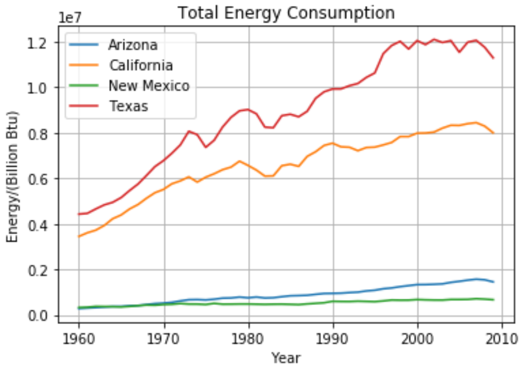


Figure3:Total energy consumption

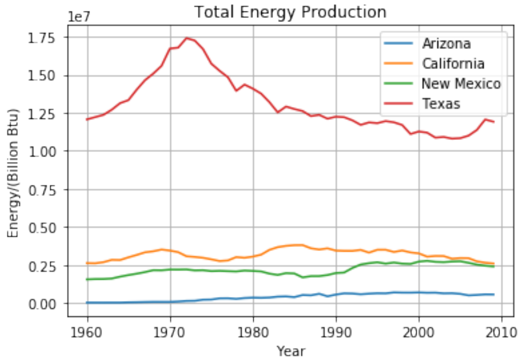


Figure4:Total Energy production

There are some possible influential factors which may cause the difference of energy profile in the four states.

Factor1: population,GDP

In order to find out the relationship between FFTCB/TETCB,Industry Proportion,GDP,Population,Total energy consumption,Total energy production,we create a pearson correlation coefficient matrix.

Correlation coefficient:

$$\rho_{X,Y} = \frac{\sum XY - \frac{\sum X \sum Y}{N}}{\sqrt{(\sum X^2 - \frac{(\sum X)^2}{N})(\sum Y^2 - \frac{(\sum Y)^2}{N})}}$$

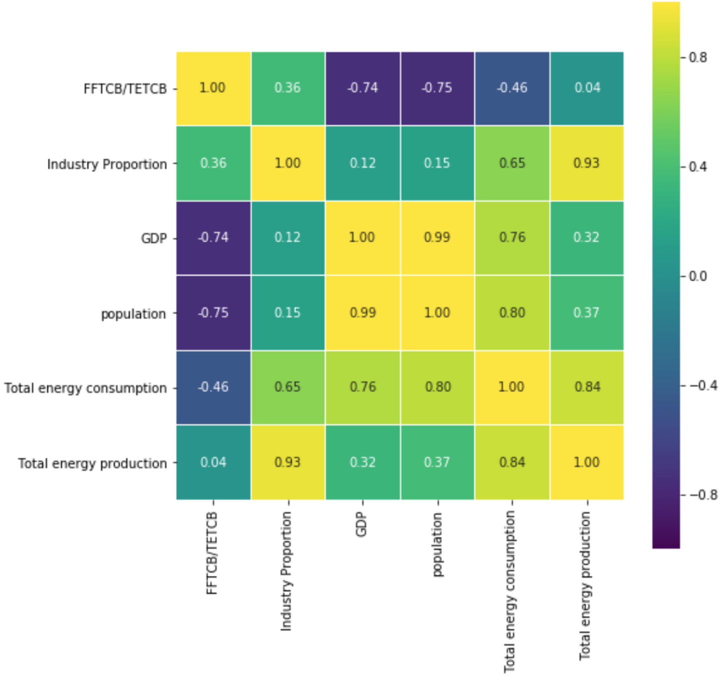


Figure5:correlation coefficient matrix

where the color represents how strong the relationships are.

Conclusion:

- Energy consumption has a strong relationship with population and GDP. California and Texas have far more population and GDP than Arizona and New Mexico, which is in accordance with the truth that they consumed far more energy. However, the production of energy is less related to the GDP,population, because energy production depends mainly on geographical factors such as the resource distribution in the region.
- The ratio of fossil fuel consumption to total energy consumption is positively related to industrial GDP, which shows that industrial development is often accompanied with high fossil energy consumption.Texas is a good example.Industry in Texas is well developed, and it's fossil fuel consumption is more than California, even though it's total energy consumption is less.

Factor2: geography

The geographical conditions in the four states are also an important factor affecting the energy profile.

We collected some major energy distributions in the US. The geographical differences between the four states are obvious. Texas is rich in resources ,so it has the most production and consumption of fossil fuels. New Mexico's resources are relatively small.So,they have the least energy consumption . The advantage of California and Arizona is that they have good wind and hydraulic conditions .It makes their energy structure cleaner. Geography plays an important role in the analysis and prediction of energy structure.

Resource distribution in the US[2]:

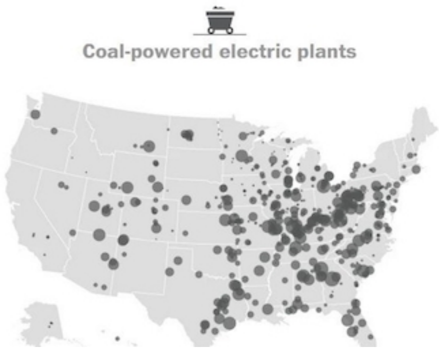


Figure6:Coal powered plants distribution

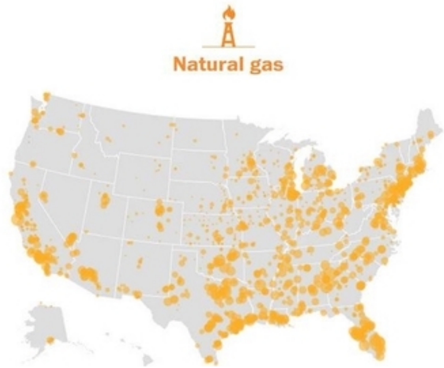


Figure7:Natural gas distribution

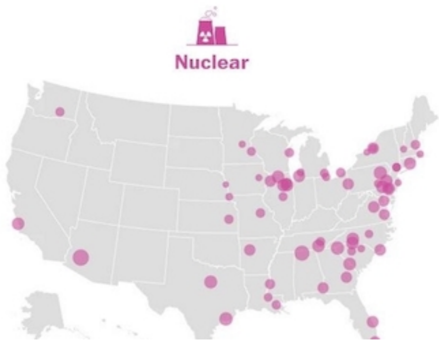


Figure8:Nuclear distribution

Figure9:Oil distribution

Factor3: Use of energy

Based on the data collected, we can see the similarities and differences in energy use among the four states. Texas uses more than half of its energy in industry. This indicates that they rely more on fossil fuels for industrial production. Texas also consumes greatest energy in all four states. Several states are focusing on the development of the transportation industry. This creates the environment for economic exchanges and resource sharing between states.

	Residential	Commercial	Industrial	Transportation
California	0.176826249	0.190873316	0.239412577	0.392887858
Arizona	0.266620354	0.241264328	0.163320597	0.32879472
New Mexico	0.169529168	0.18492745	0.332543678	0.312999704
Texas	0.131539971	0.123483021	0.500825857	0.244151151

Figure10:Energy Consumption by End-Use Sector,2015

The data highlighted in red indicates a high proportion of energy consumption,while the green indicates a low proportion.

4.2 Determine the best profile for renewable energy usage

4.2.1 Statement of AHP model

The Analytic Hierarchy Process (AHP) is a theory of measurement through pairwise comparisons and relies on the judgements of experts to derive priority scales. We can use this model to analyze the "Environmental weights" of each energy consumption, and thus calculate the environmental scores to determine which of the four states appeared to have the "best" profile for use of cleaner, renewable energy in 2009.

4.2.2 Establish a Hierarchical Model

First,we divide the total energy consumption(TETCB) into eight parts: fossil fuels(PMTCB,NNTCB,CLTCB),Renewable energy(HYTCB,BMTCB,Others), nuclear electric power(NUETB) and net interstate flow of electricity(ELNIB+ELISB).

When assessing the level of environmental protection of individual energy sources, the factors below are of great importance:

(1) Is the resource more renewable?

(2) the resource cleaner?

(3) the resource have better energy efficiency and economic effects?

Through above analysis of the three main criterion, which affect evaluation significantly,hierarchy figure is shown in Figure5.

In Figure5 we let the three main criterion to be Index B1 to B3; the eight parts of energy to be Index C1 to C8.

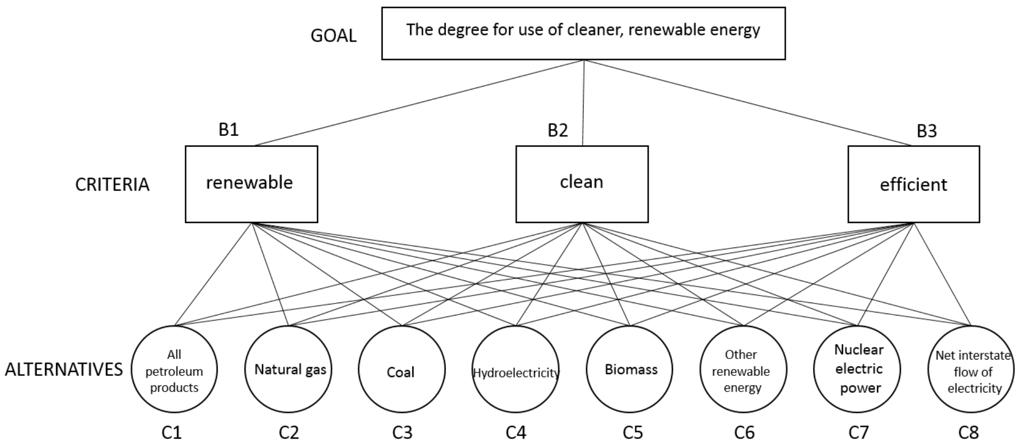


Figure11:Hierarchy figure

4.2.3 The analytic hierarchy process

To make comparisons, we need a scale of numbers that indicates how many times more important or dominant one element is over another element with respect to the criterion or property with respect to which they are compared.[3] Figure 6 exhibits how the scale are.

scale	Definition	Explanation
1	Equal Importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation
2,4,6,8	Intermediate preferences	

Figure12:The fundamental scale of absolute numbers

First,constructing comparison matrix by scale of 1-7,we get the weights of Hierarchy I-II:

A	B1	B2	B3	Weight
B1	1	1	3	0.428571
B2	1	1	3	0.428571
B3	1/3	1/3	1	0.142857

Figure13:Pairwise Comparison Matrix of Hierarchy I-II

Second,according the weights of Hierarchy I-II and the scale of 1-7,we get the weights of Hierarchy II-III.

Finally,Merging three Comparison matrix above,we can get the weight of C1-C8:

Criteria		B1	B2	B3	Weight
Weight		0.428571429	0.428571429	0.142857143	
Alternatives	C1	0.044081045	0.033962392	0.21801653	0.067847012
	C2	0.044081045	0.076175966	0.21801653	0.085938544
	C3	0.044081045	0.033962392	0.21801653	0.067847012
	C4	0.238358228	0.194930821	0.078171297	0.203003496
	C5	0.238358228	0.194930821	0.078171297	0.203003496
	C6	0.238358228	0.194930821	0.033265222	0.195840226
	C7	0.044081045	0.076175966	0.078171297	0.066394273
	C8	0.108601137	0.194930821	0.078171297	0.11012594

Figure14:Weight of each energy consumption

The derived scale based on the judgements in the matrix is:

$$W_i = \{0.067847, 0.085939, 0.067847, 0.203003, 0.203003, 0.19584, 0.066394, 0.11013\}, i = 1, 2, \cdots, 8$$

With a consistency ratio of 0.0052.

4.2.4 Calculate the Environmental Scores

Normalizing the data, We multiply the energy consumption by the weight,and get the environmental scores of each state.

States	Total energy	Source										score
		Fossil fuels				Renewable energy				Nuclear electric power	Net interstate flow of electricity	
		Petroleum	Natural gas	Coal	Total	Hydroelectricity	Biomass	Other renewable energy	Total			
Texas	1	0.482029	0.306461	0.13258386	0.92107357	0.00088867	0.01312368	0.01755549	0.03156784	0.03842164	0.00893695	0.0779
New Mexico	1	0.369109	0.368783	0.45689306	1.194785	0.00394661	0.02581013	0.02342291	0.05317964	0	−0.2479646	0.0711
California	1	0.438233	0.298716	0.00654587	0.74349518	0.03399997	0.02806347	0.02696325	0.08902668	0.04150256	0.12597557	0.0904
Arizona	1	0.358122	0.259005	0.28416152	0.90128922	0.04313436	0.02435019	0.00367843	0.07116298	0.22053221	−0.1929844	0.0736

Figure15:Environmental scores of each state

4.2.5 Analysis and Results

From the scores we can see that California have the "best" profile for use of cleaner, renewable energy in 2009,because it has the highest score. From the figure above we can find the reason. On the one hand, clean, renewable energy sources have higher weights and fossil fuels have lower weights due to their pollution and non-renewables. On the other hand, California uses fossil fuels less often than the other four states and California has the highest percentage of renewable energy. In addition,by the highly use of nuclear power, California also reduced its pollution.So California has the best profile for use of cleaner, renewable energy in 2009.

4.3 Predict the Energy Profile of each state in 2025 and 2050

4.3.1 Statement of Gray Prediction model

The grey system theory is fairly appropriate for prediction. The accumulated generating operation (abbreviated as AGO) [1,2] is the most important characteristic for the grey system theory and its purpose is to reduce the randomness of data. A non-negative smooth discrete function can be transformed into a sequence having the approximate exponential law which is the so-called grey exponential law. The 1-AGO data of the original series are used as the intermediate information for the grey prediction model building. Using the AGO technique efficiently reduces noise by converting ambiguous original time-series data to a monotonically increased series. The AGO technique is capable of identifying the systematic regularity quickly and easily. That is, the grey prediction just needs minimal data to construct a grey differential equation for prediction. The main feature of grey theory is its capability of using as few as four data items to forecast the future data.[4]

4.3.2 Establish Gray Prediction model

In Grey theory, the accumulated generating operation (AGO) technique is applied to reduce the randomization of the raw data. These processed data become monotonic increase sequence which complies with the solution of first order linear or- dinary differential equation. Therefore, the solution curve would fit to the raw data with high precision. In the following sec- tion, the derivation of GM(1,1) is briefly described:[5]

Step 1: Assume that the original series of data with m entries is

$$x^{(1)} = \{x^{(0)}(1), x^{(0)}(2), \cdots, x^{(0)}(k), \cdots, x^{(0)}(m)\} \tag{1}$$

where raw material $x^{(0)}$ stands for the non-negative original historical time series data.

Step 2: Construct $x^{(1)}$ by one time accumulated generating operation (1-AGO), which is

$$x^{(1)} = \{x^{(1)}(1), x^{(1)}(2), \cdots, x^{(1)}(k), \cdots, x^{(1)}(m)\} \tag{2}$$

where $x^{(1)}(k) = \sum\limits_{i=1}^{k} x^{(0)}(i)$ and $k = 1, 2, 3, \cdots, m.$

Step 3: The result of 1-AGO is monotonic increase sequence which is similar to the solution curve of first order linear dif- ferential equation. As the result, the solution curve of following differential equation represents the approximation of 1-AGO data.

$$\frac{d^{\Lambda}x^{(1)}}{dt} + ax^{(1)} = b, \tag{3}$$

whereΛrepresents Grey predicted value complemented the corresponding initial condition, ${}^{\Lambda}x^{(1)}(1) = x^{(0)}(1)$, with the model parameters a and b.

Step 4: The model parameters a and b can be solved by discretizationed of Eq. (3), and then we can deduce the equation.

$$\frac{d^{\Lambda}x^{(1)}}{dt} = \lim_{\Delta t \to 1} \frac{^{\Lambda}x^{(1)}(t+\Delta t) - {}^{\Lambda}x^{(1)}(t)}{\Delta t}, \tag{4}$$

If the sampling time interval is unity, then let $\Delta t \to 1$, and therefore the Eq. (4) reduces to

$$\frac{d^{\Lambda}x^{(1)}}{dt} \cong x^{(1)}(k+1) - x^{(1)}(k) = x^{(0)}(k+1), \tag{5}$$

where $k = 1, 2, 3...$

The predicted value $^{\Lambda}x^{(1)}$,background value, is defined as

$$^{\Lambda}x^{(1)} \cong Px^{(1)}(k) + (1-P)x^{(1)}(k+1) = z^{(1)}(k+1), \tag{6}$$

where $k = 1, 2, 3...$

Here P is traditionally set to be 0.5 in the original model. And the source model can be obtained

$$x^{(0)}(k) + az^{(1)}(k) = b, \tag{7}$$

where $k = 1, 2, 3...$

To do this, using the least square method and the Eq. (7), the model parameters a and b can be written as

$$\begin{bmatrix} a \\ b \end{bmatrix} = (B^T B)^{-1} B^T Y_N, \tag{8}$$

where B and Y_N are defined as follows

$$B = \begin{bmatrix} -z^{(1)}(2) & 1 \\ -z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -z^{(1)}(m) & 1 \end{bmatrix}, Y_N = \begin{bmatrix} x^{(0)}(2) \\ x^{(0)}(3) \\ \vdots \\ x^{(0)}(m) \end{bmatrix}, \tag{9}$$

Taking another hand, due to the expansion of Eq. (8), the model parameters a and b are also expressed by the following parametric forms

$$a = \frac{CD - (n-1)E}{(n-1)F - C^2}, b = \frac{DF - CE}{(n-1) - C^2}, \tag{10}$$

where C, D, E, and F are given by

$$C = \sum_{k=2}^{n} z^{(1)}(k), D = \sum_{k=2}^{n} x^{(0)}(k), \tag{11}$$

$$E = \sum_{k=2}^{n} z^{(1)}(k)x^{(0)}(k), F = \sum_{k=2}^{n} \left[z^{(1)}(k)\right]^2, \tag{12}$$

Step 5: To solve Eq. (3) together with initial condition, the particular solution is

$$^{\Lambda}x^{(1)}(k+1) = (x^{(0)}(1) - \frac{b}{a})e^{-ak} + \frac{b}{a}, \tag{13}$$

where $k = 2, 3, 4...$

Hence, the desired prediction output at k step can be estimated by inverse accumulated generating operation (1-IAGO) which is defined as

$$^{\Lambda}x^{(0)}(k+1) {=}^{\Lambda}x^{(1)}(k+1) {-}^{\Lambda}x^{(1)}(k) = (1-e^{a})(x^{(0)}(1) - \frac{b}{a})e^{-ak} + \frac{b}{a}, \tag{14}$$

where $k = 1, 2, 3...$

4.3.3 Error Analysis

To examine the precision of the proposed model, further tests are required to determine the error between the forecast value and actual value. This study adopts two error analysis definition, relative percentage error (RPE) analysis and the roll- ing grey model (RGM) error analysis, to assess the model precision.[6]

- **Relative percentage error analysis**

  Relative percentage error (RPE) compares the real and forecast values at specific time k. RPE is defined as

  $$RPE = \varepsilon(k) = \frac{x^{(0)}(k) {-}^{\Lambda}x^{(0)}(k)}{x^{(0)}(k)} \times 100\%, \tag{15}$$

  where $k = 2, 3, 4..., m$ and $x^{(0)}(k)$ is the actual value and $^{\Lambda}x^{(0)}(k)$ which is the forecast value.

  The total model precision can be defined by average relative percentage error (ARPE) as follows

  $$ARPE = \varepsilon(avg) = \frac{1}{m}\sum_{k=2}^{m} |\varepsilon(k)| \times 100\%, \tag{16}$$

  where $k = 2, 3, 4...$,and the ARPE should exclude the $\varepsilon(1)$ as it is zero.

- **The rolling grey model error analysis**

  The grey rolling model is based on the forward data of the choosing sequence. In general, the set of $\{x^{(0)}(1), x^{(0)}(2), x^{(0)}(3), x^{(0)}(4)\}$ is used to build the GM(1,1), and the next point $\{x^{(0)}(5)\}$ is predicted. Comparing the real and forecasted values, the residual error test is adopted hereafter. To calculate the residual percentage, the following equation is used

  $$\varepsilon(RGM, k+1) = \frac{x^{(0)}(k+1) {-}^{\Lambda}x^{(0)}(k+1)}{x^{(0)}(k+1)} \times 100\%, \tag{17}$$

where $k+1 \leq m$ and $x^{(0)}(k+1)$ is the actual value and ${}^{\Lambda}x^{(0)}(k+1)$ is the forecast value.

The RGM is a reasonable model for gaining the varying tendency because the RGM parameters are updated continuously as the model will be reconstructed when a new observation rolls in. Chen et al. [6−7] adopted rolling grey model error analysis to examine the feasibility of novel nonlinear grey forecasting model.

4.3.4 Optimize the model

Traditional gray prediction has some disadvantages, especially when dealing with unsmooth data.We improved this model by Logarithmic function - power function transformation, which can improve the smoothness of the original data.

Step 1: Use the Logarithmic function transformation to process original data

$$x^{(0)}(m) \to Inx^{(0)}(m), \tag{18}$$

where $m = 1, 2, 3, ..., m$

Step 2: Use the power function transformation to process original data $Inx^{(0)}(m)$

$$Inx^{(0)}(m) \to \{Inx^{(0)}(m)\}^{\frac{1}{T}}, (T \geq 1) \tag{19}$$

where $m = 1, 2, 3, ..., m$

Step 3: Put the processed data into the gray prediction model,and get the result ${}^{\Lambda}x^{(0)}(k+1)$.

Step 4: Restore the real results from ${}^{\Lambda}x^{(0)}(k+1)$.

$${}^{\Lambda}x^{(0)}(m+1) \to \exp\{\{[In^{\Lambda}x^{(0)}(m)]^{\frac{1}{T}}\}^{T}\}, (T \geq 1) \tag{20}$$

where $m = 1, 2, 3, ..., m$

4.3.5 Analysis and Results

Based on the Optimized model, we predict the energy consumption of each state in the next few decades. After some corrections, we calculate the energy distribution in 2025 and 2050.

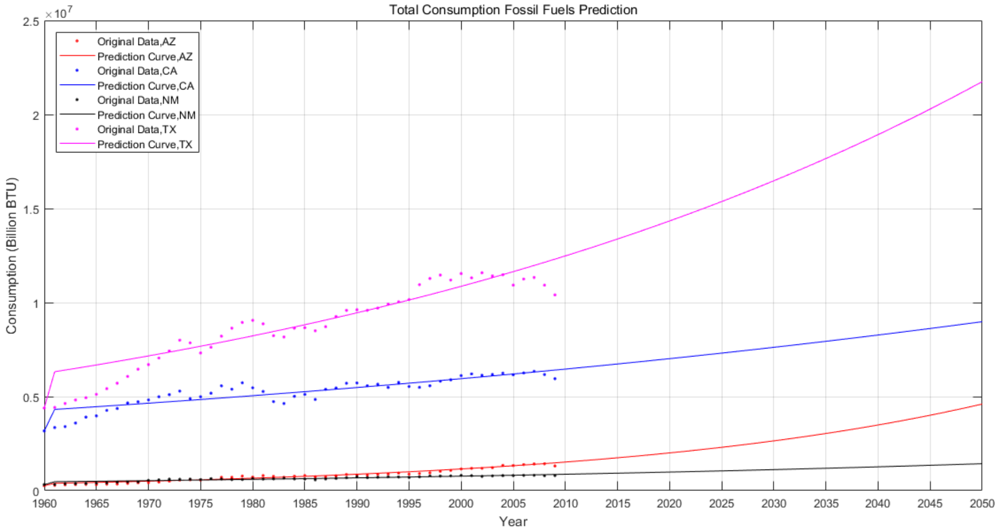


Figure16:Total Fossil Fuels Consumption Prediction

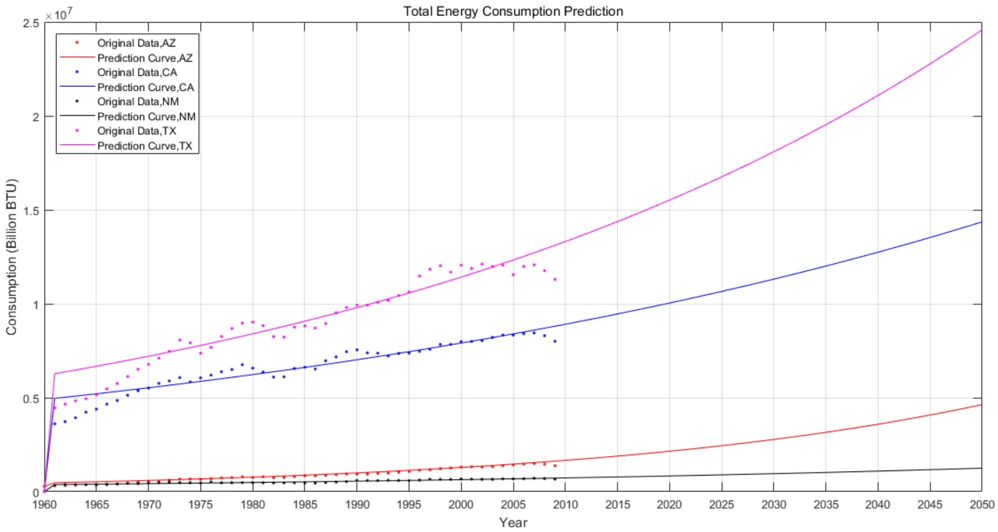


Figure17:Total Energy Consumption Prediction

Perform the same operation as above,we get the prediction of other energy consumption in 2025 and 2050.

States	Total energy	Source						
		Fossil fuels				Renewable energy	Nuclear electric power	Net interstate flow of electricity
		Petroleum	Natural gas	Coal	Total			
Texas	16574000	8561000	4364360	2452000	15377360	41970	528600	626070
New Mexico	886792	378000	196180	481900	1056080	44640	0	-213928
California	10185180	4510000	2861320	81480	7452800	99080	687900	1945400
Arizona	2464160	893200	649200	738000	2280400	146400	475300	-437940

Figure18:Energy Consumption in 2025

States	Total energy	Source						
		Fossil fuels				Renewable energy	Nuclear electric power	Net interstate flow of electricity
		Petroleum	Natural gas	Coal	Total			
Texas	24027778	14120000	3302500	4370000	21792500	104600	674500	1456178
New Mexico	1243396	464000	189400	767200	1420600	128000	0	-305204
California	14120370	5597000	3460880	93120	9151000	143100	1444000	3382270
Arizona	4622650	1636000	1879130	1083000	4598130	197600	827900	-1000980

Figure19:Energy Consumption in 2050

	Original Model	Optimized Model
TETCB-AZ	0.081458	0.031367
TETCB-CA	0.126457	0.055621
TETCB-NM	0.046825	0.032198
TETCB-TX	0.071857	0.054791
FFTCB-AZ	0.061232	0.050012
FFTCB-CA	0.094324	0.061232
FFTCB-NM	0.059735	0.048879
FFTCB-TX	0.168648	0.567312

Figure20:Practical error analysis

5 Actions to Take

5.1 Renewable Energy Usage Targets

The United States government did not clearly set renewable energy development goal. According to the International Energy Outlook 2016 (AEO2016) released by EIA and the energy profile of the states,we calculate and propose the goal that renewable energy will takes 15% of the total energy generated by the states in 2025,25% in 2050.[8]

5.2 Three Actions to take

Action1: Improve technology to optimize the energy structure

- Increasing the proportion of photovoltaic and wind power.Integrating renewable energy with buildings. As to the instability of wind and solar energy, the wind-photovoltaic hybrid generation system can be used.[9]

- Improving fossil fuel mining, washing and processing technology to improve efficiency and minimize waste and pollutants.

Action2: Encourage policies for renewable energy

Renewable energy has great potential. It is more clean and environmental friendly. In recent years, the renewable energy industry is under rapid development. To support these companies,the state government can issue the following policies:

- First,The government can subsidize emerging renewable energy companies. This will help to mature the renewable energy industry. The use of renewable energy will promote the development of state economy and optimize the state's industrial structure.
- Second,The government can implement price incentives. Encourage consumers to use renewable energy products, such as wind power, green cars and so on. This will not only make the living more environmental friendly,but also optimizes the structure of energy use.
- Finally, the government can enact laws and regulations to promote the development of renewable energy. Governors can formulate a series of preferential policies and supporting measures to create a good environment for the development of renewable energy. The government can also use the coordination of the market economy to encourage all sectors of invest renewable energy.[10]

Action3: Interstate cooperation and trade contracts

Combined with the previous analysis of the similarities in different states, there some suggestions for the interstate cooperation trade.

(1) States help each other in resource development

California has the most environmentally friendly and clean energy structure. It has been the leader in the renewable energy.But California has the greatest energy consumption. So,it need import large amounts of electricity each year.Texas is rich in energy resources,and it has a well-developed industry, but renewable energy only takes a small part. They have a less clean energy structure.Mexico highly relies on fossil fuel, and a large part of its energy production is used for electricity exports.It is worth mentioning that Mexico is the only one who don't have nuclear power.Arizona is similar to California. They are also good at developing renewable energy and nuclear power. They also export excess electricity.

In order to make the energy profile of each states more environmental, the cooperation among the states is essential.

First, California and Arizona have advanced technologies for renewable energy development.They can help Texas and Arizona develop renewable energy to optimize their fossil fuel-based energy profile.Second, Texas and New Mexico can export their vast energy resources to California and Arizona as a reward for sharing technology for renewable energy development.Then Arizona could help build a nuclear power plant in New Mexico. New Mexico can use nuclear power to replace part of the use of fossil fuels.

(2) Preferential policies for the state trade in resources

After signing the interstate energy compact, the states need to develop some policies to ensure the promotion and implementation of interstate commerce. Governors can encourage resource trade and grant some trade subsidies. New traffic routes can be designed to promote the transport of resources between states.

5.3 Tendency after the policies change

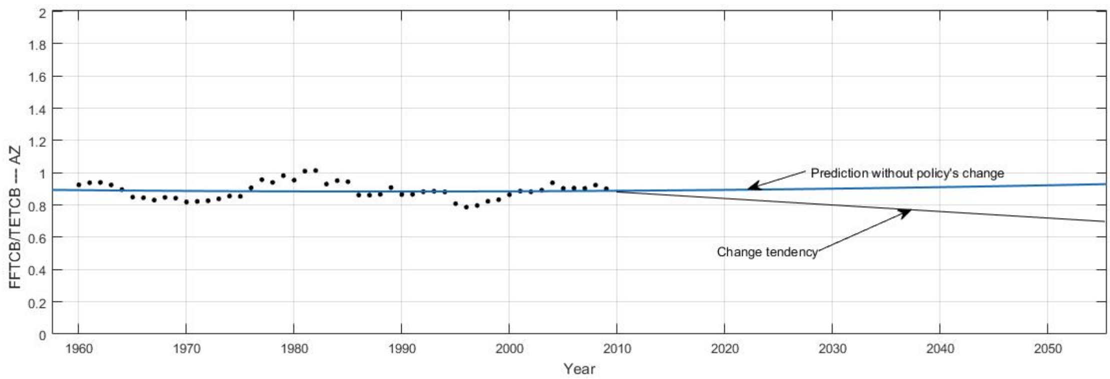


Figure21: Tendency after the policies change

Y-axis direction represents FFTCB/TETCB.The smaller the value are,the better energy structure a state has.From the figure above,we can see that after the policies change,Arizona has a better energy structure in renewable energy.

6 Memo

Dear Governors,

We are here to help you easily understand how the energy profile in Texas,New Mexico,California,Arizona evolved from 1960 - 2009.We also predict the future evolution of energy profile under the current policy. Based on our projections, we propose some suggestions to reach the goals of the new four-state energy compact.

By sorting the original data since 1960, we found that the our four states have roughly the same energy profile.For decades,fossil fuel consumption takes the largest part of energy consumption, especially petroleum products. In recent years, the use of nuclear power and renewable energy is increasing. In the four states, California has the cleanest energy structure in our model reviews.

In terms of energy production,the energy profile in the four states is somewhat different. Mexico and Texas is abundant in natural gas;,Arizona is abundant in coal and nuclear power,California is abundant in crude oil. Total fossil fuel production in all states has been declining in recent years due to energy crisis, but it still takes the largest in energy production. The production of renewable energy is less, and its change is not obvious.

After collecting 50 years of energy data,We predict the the evolution of energy resources in our model.The predictions shows that under the current policy,the energy consumption of each state will continue to grow, but the proportion of clean energy will not change much.However,under the global energy crisis,this prediction is obviously not suitable to the sustainable use of resources.So, we need to set some goals for the future.Wish we together can reach these goals,so that the energy structure of each states will be cleaner and more environmentally friendly.Drawing on the results of the model and other countries' experiences, we propose the development goals that 15% of the electricity will come from renewable sources in 2025 and 25% in 2050.

In order to reach goals we propose,we are there to give some practical suggestions. Our suggestions is divided into three parts :s cience and technology innovation, policy support, interstate cooperation.

The government can encourage enterprises to improve their technology for renewable energy use. On the one hand, the government can subsidize emerging renewable energy companies.On the other hand, the government can implement price incentives to encourage consumers to use renewable energy products.Four states can also sign up some interstate energy contract.Each state has its own advantages and disadvantages,we can help each other.For example, California and Arizona can provide Mexico and Texas with the advancd technology to develop renewable energy,and Texas and New Mexico can export their vast energy resources as reward.

We sincerely hope our analysis and advice can help yours.

Yours sincerely,
A group of modelers who are enthusiastic about mathematical modeling.

7 Model Analysis

7.1 Sensitivity Analysis

In this section, we tested the sensitivity of the AHP model by changing one of the parameters,and compare the difference between the original results and changed results.

We changed the cleanliness of coal from the original 1 to 3.The changed weights and original weights are shown in the following:

Original Weight=[0.067847,0.085939,0.067847,0.203003,0.203003,0.19584,0.066394,0.110130];

Changed Weight=[0.066710,0.082743,0.082743,0.201161,0.201161,0.193998,0.063198,0.108283];

	Texas	New Mexico	California	Arizona
original score	0.0779	0.0711	0.0904	0.0736
changed score	0.0781	0.0766	0.0885	0.0762
Δ(%)	0.256739409	7.735583685	-2.101769912	3.532608696

Figure22:AHP Sensitivity Analysis

As is shown in the table, changes in coal evaluation have a small effect on the scores.The model is less sensitive.

7.2 Strength and Weakness

7.2.1 Strength

AHP model:

1. AHP is a systematic method of analysis.
2. AHP is a simple and practical decision method.
3. AHP requires less quantitative data information.

Grey Prediction model:

1. Grey prediction model is mainly based on matrix in the calculation process. It is easy to combine with MATLAB to solve its problems in computation.

2. The grey prediction program compiled by MATLAB is simple, practical, easy to operate and has high prediction accuracy.

7.2.2 Weakness

AHP model:

1. AHP can not provide a new scheme for decision making

2. AHP has large data statistics when the index is too much, and the weight is hard to be determined.

Grey Prediction model:

1. Grey prediction model strongly relies on historical data.

2. The GM (1,1) model does not consider the relationship among all factors

8 References

References

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9 Appendices

B1	C1	C2	C3	C4	C5	C6	C7	C8	Weight
C1	1	1	1	1/5	1/5	1/5	1	1	0.05
C2	1	1	1	1/5	1/5	1/5	1	1	0.05
C3	1	1	1	1/5	1/5	1/5	1	1	0.05
C4	5	5	5	1	1	1	5	5	0.25
C5	5	5	5	1	1	1	5	5	0.25
C6	5	5	5	1	1	1	5	5	0.25
C7	1	1	1	1/5	1/5	1/5	1	1	0.05
C8	1	1	1	1/5	1/5	1/5	1	1	0.05

B2	C1	C2	C3	C4	C5	C6	C7	C8	Weight
C1	1	1/3	1	1/5	1/5	1/5	1/3	1/5	0.033962
C2	3	1	3	1/3	1/3	1/3	1	1/3	0.076176
C3	1	1/3	1	1/5	1/5	1/5	1/3	1/5	0.033962
C4	5	3	5	1	1	1	3	1	0.194931
C5	5	3	5	1	1	1	3	1	0.194931
C6	5	3	5	1	1	1	3	1	0.194931
C7	3	1	3	1/3	1/3	1/3	1	1/3	0.076176
C8	5	3	5	1	1	1	3	1	0.194931

B3	C1	C2	C3	C4	C5	C6	C7	C8	Weight
C1	1	1	1	3	3	5	3	5	0.223042
C2	1	1	1	3	3	5	3	5	0.223042
C3	1	1	1	3	3	5	3	5	0.223042
C4	1/3	1/3	1/3	1	1	3	1	3	0.086232
C5	1/3	1/3	1/3	1	1	3	1	3	0.086232
C6	1/5	1/5	1/5	1/3	1/3	1	1/3	1	0.036089
C7	1/3	1/3	1/3	1	1	3	1	3	0.086232
C8	1/5	1/5	1/5	1/3	1/3	1	1/3	1	0.036089

Consistency ratio: B1:0.0000, B2:0.0088, B3:0.0099

Here are programmes we used in our model as follow.

calculation of AHP matlab source:

```
clc,clear
fid=fopen('txt3.txt','r');
n1=3;n2=8;
a=[];
for i=1:n1
tmp=str2num(fgetl(fid));
a=[a;tmp];
end
for i=1:n1
str1=char(['b',int2str(i),'=[];']);
str2=char(['b',int2str(i),'=[b',int2str(i),';tmp];']);
eval(str1);
for j=1:n2
tmp=str2num(fgetl(fid));
eval(str2);
end
end
ri=[0,0,0.58,0.90,1.12,1.24,1.32,1.41,1.45];
[x,y]=eig(a);
lamda=max(diag(y));
num=find(diag(y)==lamda);
w0=x(:,num)/sum(x(:,num));
cr0=(lamda-n1)/(n1-1)/ri(n1)
for i=1:n1
[x,y]=eig(eval(char(['b',int2str(i)])));
lamda=max(diag(y));
num=find(diag(y)==lamda);
w1(:,i)=x(:,num)/sum(x(:,num));
cr1(i)=(lamda-n2)/(n2-1)/ri(n2);
end
cr1, ts=w1*w0, cr=cr1*w0
```

Grey Prediction model:

```
w=2.73109


%%%%%%%%%%%%%%%%%%%%TETCB
TETCB_filename = 'C:\Users\yyf\Desktop\MCM\total\TETCB-AZ.csv';
delimiter = {''};
formatSpec = '%f%[^\n\r]';
fileID = fopen(TETCB_filename,'r');
dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'TextType', 'string',
'ReturnOnError', false);
fclose(fileID);
TETCB = [dataArray{1:end-1}];

VarName1=power(TETCB,w)
syms a b;
c=[a b]';
A=VarName1';
B=cumsum(A);
n=length(A);
for i=1:(n-1)
    C(i)=(B(i)+B(i+1))/2;
end

D=A;D(1)=[];
D=D';
E=[-C;ones(1,n-1)];
c=inv(E*E')*E*D;
c=c';
a=c(1);b=c(2);

F=[];F(1)=A(1);
for i=2:(n+41)
    F(i)=(A(1)-b/a)/exp(a*(i-1))+b/a ;
end
G1=[];G1(1)=A(1);
for i=2:(n+41)
    G1(i)=F(i)-F(i-1);
end
predict1=power(G1,1/w)

A=TETCB'
B=cumsum(A);
n=length(A);
for i=1:(n-1)
    C(i)=(B(i)+B(i+1))/2;
end

D=A;D(1)=[];
D=D';
E=[-C;ones(1,n-1)];
c=inv(E*E')*E*D;
c=c';
a=c(1);b=c(2);

F=[];F(1)=A(1);
for i=2:(n+41)
    F(i)=(A(1)-b/a)/exp(a*(i-1))+b/a ;
end
G1=[];G1(1)=A(1);
for i=2:(n+41)
    G1(i)=F(i)-F(i-1);
```

```
end

%%%%%%%%%%%%%%%%%%%%CA
filename = 'C:\Users\yyf\Desktop\MCM\total\TETCB-CA.csv';
delimiter = {''};

formatSpec = '%s%[^\n\r]';
fileID = fopen(filename,'r','n','UTF-8');

fseek(fileID, 3, 'bof');

dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'TextType', 'string',
'ReturnOnError', false);

fclose(fileID);

raw = repmat({''},length(dataArray{1}),length(dataArray)-1);
for col=1:length(dataArray)-1
    raw(1:length(dataArray{col}),col) = mat2cell(dataArray{col}, ones(length(dataArray{col}), 1
end
numericData = NaN(size(dataArray{1},1),size(dataArray,2));

rawData = dataArray{1};
for row=1:size(rawData, 1)

    regexstr = '(?<prefix>.*?)(?<numbers>([-]*(\d+[\,]*)+[\.]{0,1}\d*[eEdD]{0,1}[-+]*\d*[i]{0,1
    try
        result = regexp(rawData(row), regexstr, 'names');
        numbers = result.numbers;

        invalidThousandsSeparator = false;
        if numbers.contains(',')
            thousandsRegExp = '^\d+?(\,\d{3})*\.{0,1}\d*$';
            if isempty(regexp(numbers, thousandsRegExp, 'once'))
                numbers = NaN;
                invalidThousandsSeparator = true;
            end
        end
        if ~invalidThousandsSeparator
            numbers = textscan(char(strrep(numbers, ',', '')), '%f');
            numericData(row, 1) = numbers{1};
            raw{row, 1} = numbers{1};
        end
    catch
        raw{row, 1} = rawData{row};
    end
end

TETCB_CA = cell2mat(raw);

VarName1=power(TETCB_CA,w)
syms a b;

A=VarName1';
B=cumsum(A);
n=length(A);
for i=1:(n-1)
    CC(i)=(B(i)+B(i+1))/2;
end

D=A;D(1)=[];
```

```
D=D';
E=[-CC;ones(1,n-1)];
c=inv(E*E')*E*D;
c=c';
a=c(1);b=c(2);
F=[];F(1)=A(1);
for i=2:(n+41)
    F(i)=(A(1)-b/a)/exp(a*(i-1))+b/a ;
end
G2=[];G2(1)=A(1);
for i=2:(n+41)
    G2(i)=F(i)-F(i-1);
end
predict2=power(G2,1/w)

%%%%%%%%%%%%%%%%%%%%NM
filename = 'C:\Users\yyf\Desktop\MCM\total\TETCB-NM.csv';
delimiter = {''};
formatSpec = '%s%[^\n\r]';
fileID = fopen(filename,'r','n','UTF-8');
fseek(fileID, 3, 'bof');
dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'TextType', 'string',
'ReturnOnError', false);
fclose(fileID);
raw = repmat({''},length(dataArray{1}),length(dataArray)-1);
for col=1:length(dataArray)-1
    raw(1:length(dataArray{col}),col) = mat2cell(dataArray{col}, ones(length(dataArray{col}), 1
end
numericData = NaN(size(dataArray{1},1),size(dataArray,2));
rawData = dataArray{1};
for row=1:size(rawData, 1)
    regexstr = '(?<prefix>.*?)(?<numbers>([-]*(\d+[\,]*)+[\.]{0,1}\d*[eEdD]{0,1}[-+]*\d*[i]{0,1
    try
        result = regexp(rawData(row), regexstr, 'names');
        numbers = result.numbers;
        invalidThousandsSeparator = false;
        if numbers.contains(',')
            thousandsRegExp = '^\d+?(\,\d{3})*\.{0,1}\d*$';
            if isempty(regexp(numbers, thousandsRegExp, 'once'))
                numbers = NaN;
                invalidThousandsSeparator = true;
            end
        end
        if ~invalidThousandsSeparator
            numbers = textscan(char(strrep(numbers, ',', '')), '%f');
            numericData(row, 1) = numbers{1};
            raw{row, 1} = numbers{1};
        end
    catch
        raw{row, 1} = rawData{row};
    end
end

TETCB_NM= cell2mat(raw);

VarName1=power(TETCB_NM,w)
syms a b;

A=VarName1';
B=cumsum(A);
n=length(A);
```

```
for i=1:(n-1)
    CC(i)=(B(i)+B(i+1))/2;
end
D=A;D(1)=[];
D=D';
E=[-CC;ones(1,n-1)];
c=inv(E*E')*E*D;
c=c';
a=c(1);b=c(2);
F=[];F(1)=A(1);
for i=2:(n+41)
    F(i)=(A(1)-b/a)/exp(a*(i-1))+b/a ;
end
G3=[];G3(1)=A(1);
for i=2:(n+41)
    G3(i)=F(i)-F(i-1);
end
predict3=power(G3,1/w)

%%%%%%%%%%%%%TX
filename = 'C:\Users\yyf\Desktop\MCM\total\TETCB-TX.csv';
delimiter = {''};

formatSpec = '%s%[^\n\r]';


fileID = fopen(filename,'r','n','UTF-8');

fseek(fileID, 3, 'bof');

dataArray = textscan(fileID, formatSpec, 'Delimiter', delimiter, 'TextType', 'string',
'ReturnOnError', false);
fclose(fileID);
raw = repmat({''},length(dataArray{1}),length(dataArray)-1);
for col=1:length(dataArray)-1
    raw(1:length(dataArray{col}),col) = mat2cell(dataArray{col}, ones(length(dataArray{col}), 1
end
numericData = NaN(size(dataArray{1},1),size(dataArray,2));
rawData = dataArray{1};
for row=1:size(rawData, 1)
       regexstr = '(?<prefix>.*?)(?<numbers>([-]*(\d+[\,]*)+[\.]{0,1}\d*[eEdD]{0,1}[-+]*\d*[i]{
    try
        result = regexp(rawData(row), regexstr, 'names');
        numbers = result.numbers;
        invalidThousandsSeparator = false;
        if numbers.contains(',')
            thousandsRegExp = '^\d+?(\,\d{3})*\.{0,1}\d*$';
            if isempty(regexp(numbers, thousandsRegExp, 'once'))
                numbers = NaN;
                invalidThousandsSeparator = true;
            end
        end
        if ~invalidThousandsSeparator
            numbers = textscan(char(strrep(numbers, ',', '')), '%f');
            numericData(row, 1) = numbers{1};
            raw{row, 1} = numbers{1};
        end
    catch
        raw{row, 1} = rawData{row};
    end
end
```

```
TETCB_TX= cell2mat(raw);

VarName1=power(TETCB_TX,w)
syms a b;
A=VarName1';
B=cumsum(A);
n=length(A);
for i=1:(n-1)
    CC(i)=(B(i)+B(i+1))/2;
end
D=A;D(1)=[];
D=D';
E=[-CC;ones(1,n-1)];
c=inv(E*E')*E*D;
c=c';
a=c(1);b=c(2);

F=[];F(1)=A(1);
for i=2:(n+41)
    F(i)=(A(1)-b/a)/exp(a*(i-1))+b/a ;
end
G4=[];G4(1)=A(1);
for i=2:(n+41)
    G4(i)=F(i)-F(i-1);
end
predict4=power(G4,1/w)
t1=1960:2050;
t2=1960:2009
plot(t2,TETCB,'.r',t1,predict1,'r')
hold on;
plot(t2,TETCB_CA,'.b',t1,predict2,'b')
hold on;
plot(t2,TETCB_NM,'.k',t1,predict3,'k')
hold on;
plot(t2,TETCB_TX,'.m',t1,predict4,'m')

legend('Original Data,AZ','Prediction Curve,AZ','Original Data,CA','Prediction Curve,CA','Origi

grid on;

xlabel('Year')
ylabel('Consumption (Billion BTU)')
title('Total Energy Consumption Prediction');
set(gca,'Xtick',1960:5:2050)
```