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2018
MCM/ICM
Summary Sheet
Renewable Tomorrow

With the global demand for energy growing, the need to adopt various energy sources is growing. Since the different states have various of climate, population, industries, the four states wish to form a compact to increase the usage of the renewable and cleaner resource. In this article, a series of methods are applied to help them to analyze the energy profile and set some goals for the interstate energy compact.

First, to measure the level of the usage of the renewable energy, we introduce a metric, that is, Renewable Energy Performance Index(IR). To calculate and use the index, we apply the **Analytic Hierarchy Process (AHP)**. Further, we select the four variables as the composition of the metric. They are P_R (Proportion of Renewable Energy Consumption), η (energy efficiency), P_C (Proportion of Cleaner Energy Consumption) and E_{PP} (Energy consumption per capita), respectively. Through the check of the establishment, we find the method is reasonable. In order to describe the change of the renewable energy production and consumption in an easily understood way, we draw the line chart of the total production and the proportion of various of energy.

Next, by the establishment of the index α, we combine the two kinds of data of the renewable energy, the production and the proportion, into one indicator. Then the indicator is more comprehensive and vivid. To find the possible influential factors of the similarities and the difference among the four states' energy profile, we set up a three-layers relationship figure. By comparing the difference of possible factors in the four states, the relationship between the four states' condition and their energy profile is established.

Then, select five main energy production as the criteria and apply the Technique for **Order Preference by Similarity to an Ideal Solution (TOPSIS)** to obtain the distance between one state's viable solution and the ideal solution. Through calculating the distance, the grades of the four states is sorted from the largest to the smallest. Therefore, the state who has the"best" profile is determined.

Also, we use the **Gray Model and Linear Regression Model** to predict the energy profile for 2025 and 2050 in the four states. The results show that the development of the renewable energy has some improvement but just a little. Furthermore, we use the **Time Series Predicted model** to verify our prediction.

After the first part' analysis, we have a good comprehension of the energy profiles of four states. To make renewable targets for 2025 and 2050: First, we raise an energy potential model to predict the renewable potential (The maximum energy that can be achieved in future) as the construction of development plan to figure out the most potential energy of each of the states, help them to know their advantages. Then, we use multi-objective programming to get the renewable energy distribution targets, the plan and the method we give can help four states get the maximum total renewable energy and other goals can be optimized. Furthermore, from discussion and investigation we get the third direction we can strive to solve the electricity transmission problem.

Finally, according to the targets we set, we present three actions they can take in the future to meet the goals: (1) Utilize the conditions (2) Multi-development (3) Big Net

Contents

1 Introduction

1.1 Background

For any state or country, the energy production and consumption is the essential part of the development of its economy. In 1865, William Stanley Jevons published The Coal Question [1] in which he saw that the reserves of coal were being depleted and that oil was an ineffective replacement. What's more, it is equally important to protect the environment and keep sustainable during the process of using energy. Under these circumstances, the requirement of developing the renewable and cleaner energy becomes more urgent. Energy policies affect the market in a variety of ways such as: price, production, consumption, supply and demand. In the US, the energy policy is determined by federal, state, and local entities in the United States, which address issues of energy production, distribution, and consumption, such as building codes and gas mileage standards.

In the states of the United States, energy reserves, climates, geography, industrial production, and population vary widely, so the states' energy production and use vary greatly. In order to devise better policies to address the issue of energy development, many states work together to develop policies to promote energy management and development. For example, in 1970, 12 western states in the U.S. formed the Western Interstate Energy Compact(WIEC), which foster the cooperation between these states for the development and management of the nuclear energy technologies.

1.2 Restatement of the Problems and Analysis

The four states California(CA), Arizona(AZ), New Mexico(NM) and Texas(TX) want to form a realistic new energy compact. The four states are adjacent to each other, which is helpful to them to perform the interstate compact. The focus of the energy compact is to realize the increase of the cleaner, renewable energy' usage.

For the first part, based on the data in the file, we are asked to characterize the energy profile for each of the four states in general. To develop a model to quantify the energy profile and apply the model to analyze the evolvement of the profile for each of the four states from 1960 to 2009. Show the results obtained from the model in a simple way which is easily understood. Find the similarities and difference of the energy profile of the four states and why they take place. Create some criteria and choose some data to evaluate the four states' energy profiles for use of cleaner, renewable energy in 2009 and select the state who have the "best" profile. Based on the model that we defined an d the historical evolution of the energy profiles and the differences between the state profiles, predict the energy profile in 2025 and 2050 without any policy changes.

For the second part, from the result and predictions we analyze in part one, we need to find the force point including how to distribute the layout of renewable to get the max imum amount of renewable energy to develop renewable energy and make the goals f or four states, and then we need to plan the concrete measures they can take to achiev e the goals we set.

For the final part, we need to submit a one-page memo to the governors. In the memo, every state profiles in 2009, the predictions of the energy usage without any policy changes and our recommended goals for the energy compact are included.

2 General Assumption and Symbol Explain

2.1 Assumption and Justification

To simplify the problem, we have some basic assumptions and give the justification of it.

1) The data source is actual and reliable. What's more, the statistics we collected from the website are reliable and accurate. The assumption is the basis of modeling and all the data come from the EIA or other government website.
2) We assume that the "0" in the data file means the value of the variable is 0, instead of not recording in the data file. First, in our modeling, the case of applying the data "0" to analyze the problem seldom happen. What's more, when we use the "0", the results
3) When we can't find the data of one kinds of energy' production, use the consumption instead of the production (For example, we apply NGTXB (the Natural gas total end-use consumption (including supplemental gaseous fuels)) to instead of its production). The reason for this is that the production is equal to the consumption in one state.

2.2 Symbol Explain

Explain	**Symbol**
Total Energy Production	E_T
Renewable Energy Production	E_{RT}
Unrenewable Energy Production	E_{UT}
Cleaner Energy Production	E_{CT}
Energy Efficiency	η
Proportion of Renewable Energy Consumption	P_R
Proportion of cleaner Energy Consumption	P_C
Total energy consumption per capital	E_{PP}

3 Models

3.1 Energy profile evaluation and Performance Indicators

To create an energy profile for each of the four states, there are two parts in the analysis:

1. The comprehensive measure based on AHP (Analytic Hierarchy Process) [2] is used to measure the degree of resources rational using the level of sustainable development.
2. In the second part, select some data from the file, which have a close relationship with the renewable and cleaner energy production and consumption. By transforming the data into the graph and the line chart form, we can get the vivid understanding of the profile.

With the two models, one state energy profile is conducted easily and we get acquainted with the renewable and cleaner energy production and usage situation. The energy structure of the renewable and cleaner energy is also obtained.

3.1.1 The metric based on AHP

Since the four states establish some policies to increase the usage of cleaner and renewable energy sources, one metric measuring the level of the usage is urgently needed. However, the “level” of the consumption is fuzzy and difficult to calculate. To quantify the metric, there are four variables chosen as the four indicator of the “level” because they have a close relationship with the metric and represent all the aspects of the “level”. The more important thing is that we can calculate them by formula. They are P_R (Proportion of Renewable Energy Consumption), η (energy efficiency), P_C (Proportion of Cleaner Energy Consumption) and E_{PP} (Energy consumption per capita per year), respectively.

For the metric, some of the variables are somehow more important than others. Therefore, in order to make our model more accurate and reliable, we introduce a weighted index of the “level”, that is:

$$I_R = \lambda_1 P_R + \lambda_2 \eta + \lambda_3 P_C - \lambda_4 E_{PP},$$

where $\lambda_i > 0 (i = 1, 2, 3, 4)$, and the positive signs before the $\lambda_1, \lambda_2, \lambda_3$ mean that the three variable P_R, η, P_C have the positive influence on the index I_R ,while the negative sign before λ_4 means that the variable E_{PP} have the negative influence on the index I_R.

We calculate the weights($\lambda_i (i = 1, 2, 3, 4)$) by the AHP(Analytic Hierarchy Process). By comparing the value between two variables, we obtain 4×4 matrix as following:

$$\begin{array}{c|cccc} & P_R & \eta & P_C & E_{PP} \\ \hline P_R & 1 & 3 & 2 & 5 \\ \eta & \frac{1}{3} & 1 & \frac{1}{2} & 4 \\ P_C & \frac{1}{2} & 2 & 1 & 2 \\ E_{PP} & \frac{1}{5} & \frac{1}{4} & \frac{1}{2} & 1 \end{array}$$

The meaning of the value of the element in the matrix is explained in the Table. All the values are determined by our own subjective decisions.

Table1.The multiplication table of R_{10}

Intensity of Value	Interpretation
1	Requirements i and j have equal value.
3	Requirements i has a slightly higher value than j.
5	Requirements i has a strongly higher value than j.
7	Requirements i has a very strongly higher value than j.
9	Requirements i has an absolutely higher value than j
2,4,6,8	Intermediate scales between two adjacent judgments.
Reciprocals	Requirements i has a lower value than j

To calculate the weights, we input the 4×4 matrix into Matlab. Further, by the program related to the AHP, all the weights are obtained and shown in the following table. In the process of the consistency check of the matrix,

$$CR=\frac{CI}{RI}=\frac{0.0606}{0.9}=0.0673<0.1.$$

Therefore, the coherence of the matrix is qualified and the weights are reliable.

Table2.AHP derived weights

Factor	λ_1	λ_2	λ_3	λ_4
Weight	0.4719	0.1944	0.24928	0.84128

Then, the formula of the weighted index has been obtained：

$$I_R=0.4719P_R+0.1944\eta+0.24928P_C-0.84128E_{PP}$$

In order to evaluate the level of renewable and cleaner energy consumption in the four state, parts of the data are chosen to calculate the four variable.

$$P_R=\frac{E_{RT}}{E_T}$$

$$\eta = \frac{E_{RT}}{E_T}$$

$$P_C = \frac{E_{CT}}{E_T}$$

The values of the variables E_T, E_{RT} symbolled by TEPRB (Total energy production) and RETCB(Renewable energy production) while another value E_{CT} is represented by the sum of the TEPRB, NUETB (Electricity produced from nuclear power) and NGTXB (Natural gas total end-use consumption). All of the data can be found in the data file "ProblemCData.xlsx". The last variable E_{PP} is represented by TETPB (Total energy consumption per capita) in the file. Since the former three variables range from 0 to 1 while the last variable is some large number, in order to make the index more proper. We apply the following formula to change E_{PP} into e_{PP}, which has the range from 0 to 1.

$$e_{PP} = \frac{E_{PP} - E_{PPmin}}{E_{PPmax} - E_{PPmin}}$$

Then, the formula of I_R can be changed into another form, which is more reasonable:

$$I_R = 0.4719 P_R + 0.1944 \eta + 0.24928 P_C - 0.84128 e_{PP}$$

Further, using the data of energy consumption and production in different states from 1960 to 2009 in the file and substituting the data into the formulae, the index can be calculated. In order to make the trend of the index clearer and get acquainted with the different of the four states, we transform the results into line chart form, shown in the following chart:

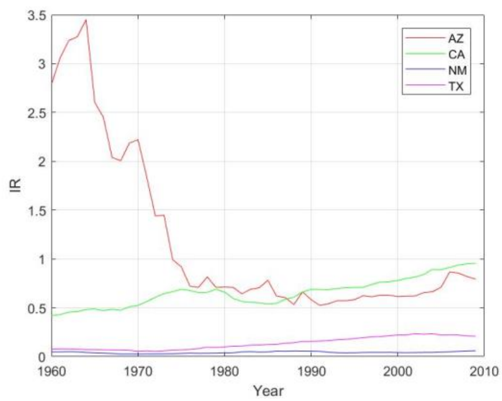


Figure1. The I_R changing from 1960 to 2009

From the graph, we draw the conclusion about the energy using and its trend. The three states (CA, NM, TX) have the low level of the renewable and cleaner energy consumption, but the level increases from 1960 to 2009. The degree of the three states' sustainable development is also low, but the degree has increase as the time goes.

Compared to another three states, the AZ state have the high index all the time, that means the state have an advantage in the aspect of the usage of the energy. However, the index of AZ decline with the time.

3.1.2 Measurement and analysis of the usage of renewable and clean energy

In order to analyze the data about the renewable and cleaner energy, the first work is selecting the useful information from the data file.

The "useful" means that:

(1) The data related to the renewable and cleaner energy profile.

(2) The data is representative enough to help us to analyze the profile comprehensively and accurately.

Based on this standard, the E_{RT} (Renewable Energy Production) of the four states is chosen. To analyze the trend of the energy production, the REPRB (Renewable energy production) in the data is used to represent the E_{RT}. Though importing the data from 1960 to 2009 into the MATLAB, the line chart of energy production is obtained.

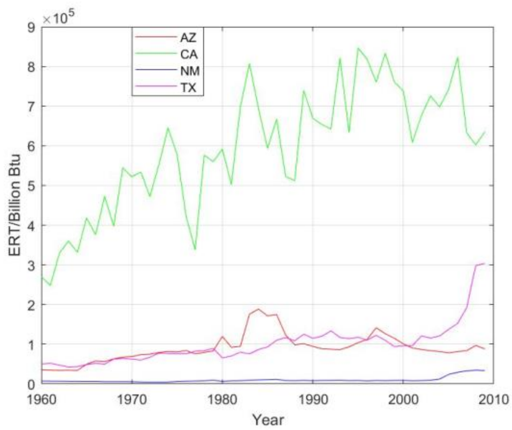


Figure2. The E_{RT} changing from 1960 to 2009

The graph shows that:

(1) The usage of the renewable and cleaner energy in CA is much more than other three states.

(2) CA experienced the largest increases across all the states included.

(3) The level of renewable energy production in the TX is at a low level all the time.

(4) The development of the renewable energy of two states AZ and NM is in a slow speed, but the development of TX have some positive change in the recent year.

Further, in another aspect, in order to characterize the rationality of the structure, that is, the proportion of various energy sources in total energy, some other statistics from the data file are applied. The selected data are WYEGB (Electricity produced from wind energy), SOTCB (Photovoltaic and solar thermal energy total consumption), HYTCB (Hydroelectricity total production), BMTCB (Biomass Total Consumption), GETCB (Geothermal Energy Total Consumption) respectively.

The method of the calculation of some kind of renewable energy is shown:

$$\text{Rate} = \frac{\text{WYEGB/SOTCB/HYTCB/BMTCB/GETCB}}{\text{Renewable energy production}}$$

Like the analysis of the total renewable energy production, import the rate of every kind of the energy into MATLAB, and then draw the line chart of the rate (Figure3).

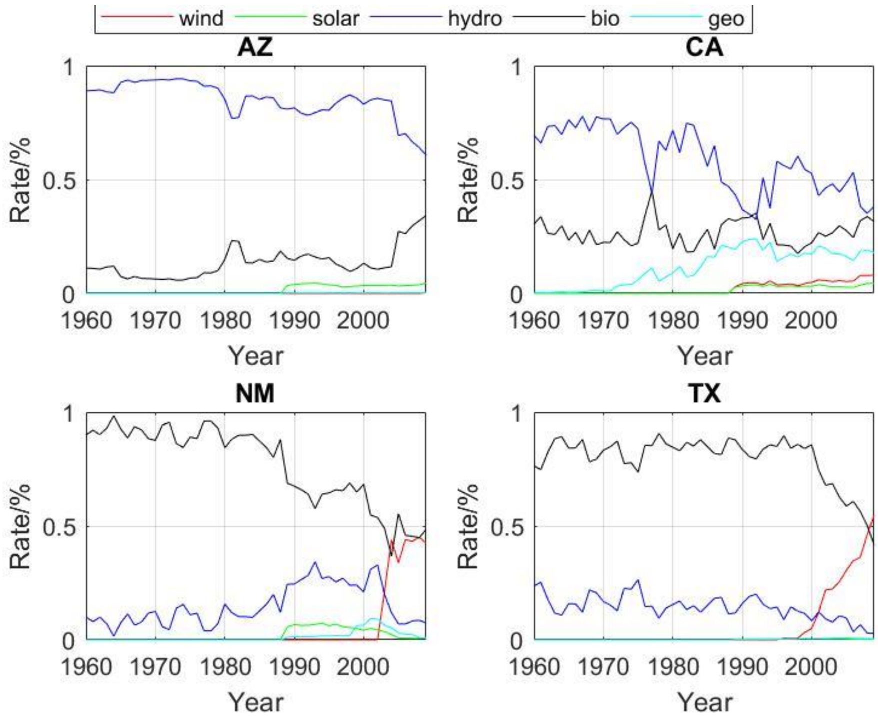


Figure3. The rate of renewable energy production in four states

Through analyzing the figure, we can conclude that:

Similarities:

(1) The solar energy development of the four state is in a low level.

(2) The two main kinds of energy in the four states are water energy and biomass energy.

Difference:

(1) The exploit of the water resource in AZ and CA takes the most proportion among the five kinds of energy, while the biomass energy is in the dominant position.

(2) In recent year, the wind energy production in NM and TX develops quickly, and even occupy a considerable proportion.

In the above analysis, we divide the proportion and the total production of the renewable and cleaner energy into two part. In order to synthesize the two evaluation, an index α is introduced:

$$\alpha = \rho^{\beta}$$

where ρ represents the module of the total production of the renewable and cleaner energy. For the obtain of the β, the process is elaborated as follow:

(1) Create a 5-dimensional direction vector $\vec{V_i} = (R_W, R_S, R_H, R_B, R_G)$, where R_W, R_S, R_H, R_B, R_G represents any one kind of the energy's proportion taking in the total renewable energy production.

(2) Since our goal of the management of the renewable energy development is to keep the balance among the different kinds of the energy. Therefore, the ideal direction vector is the unit direction vector $\vec{V} = (1,1,1,1,1)$. To measure the difference between $\vec{V_i}$ and $\vec{V}$, we calculate the angle' cosine between the two vector:

$$\beta = \cos(\theta) = \frac{\vec{V} \bullet \vec{V_i}}{|\vec{V}| \bullet |\vec{V_i}|}$$

Therefore, the α has been obtain. The value of α can account for the situation of the renewable development. The larger value of α means that the renewable and cleaner energy development is more balanced and the has a higher level.

3.1.3 The similarities and difference and the influential factor

Considering the possible influential factors of the similarities and difference of the four states' the usage of the cleaner, renewable energy, the three layers' relationship model is established in the figure:

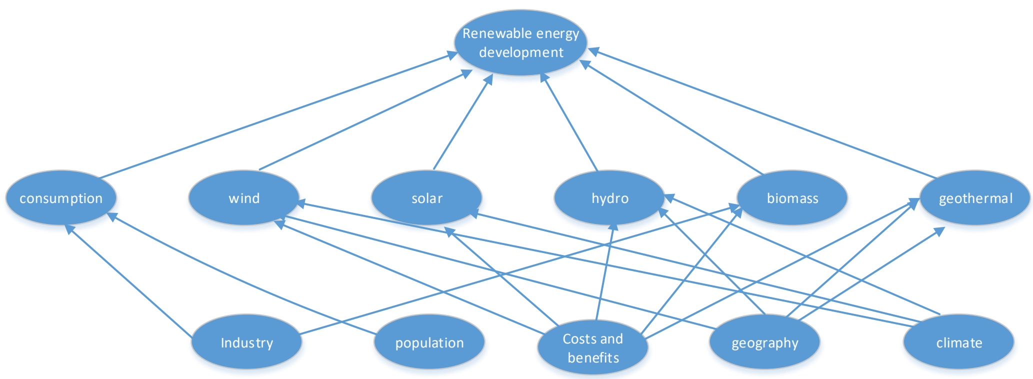


Figure4. The 'Neural Network' relationship model

Based on the fact that the renewable energy production consists of five kinds of energy and the renewable consumption has an important influence on the renewable energy development, the relationship between the first layer and the second layer is determined. According to the common sense, the climate is the crucial factor of the wind power, solar energy and hydro-energy. The main consumption renewable energy comes from the industry and human. Since the flow of the wind could be impeded by the mountain or other special landforms and the exploit of hydro-energy depend on the river, the relation between the geography and wind or hydro-energy is established. What's more, the geothermal energy relies on the geography more. The industry waste is the important source of the biomass raw materials. Then we obtain the relationship between the second layer and the third layer.

To get the possible influential further, the different energy resource from the United State is found as the figure below:

Power Plant Type	Cost $/kW-hr
Coal	$0.11-0.12
Natural Gas	$0.053-0.11
Nuclear	$0.096
Wind	$0.044-0.20
Solar PV	$0.058
Solar Thermal	$0.184
Geothermal	$0.05
Biomass	$0.098
Hydro	$0.064

Adapted from US DOE[2]

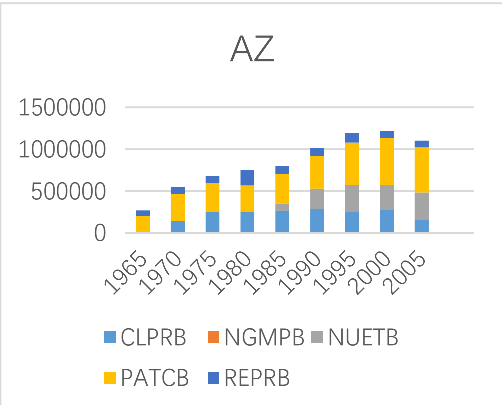
Figure5. Average levelized electricity cost

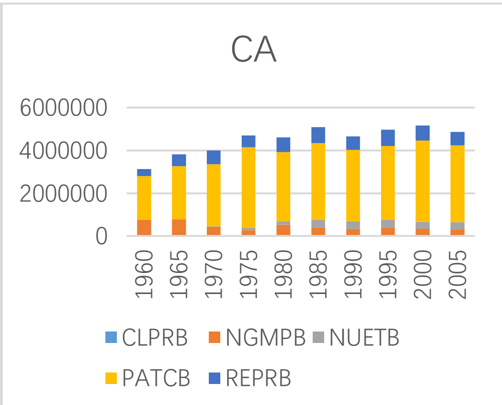
From the figure (1) in appendix, we find that the four states' resources are very adequate, but the similarity (1) is the opposite of the fact. The reason is that the solar energy exploit needs some high interest and the high level of the technology. The second similarity is shown in the figure (1) and (5) in appendix, that the four states have the sufficient water and biomass energy, especially the CA and the TX, because the exploit of the water and biomass resources is cheap compared to other two resource.

We find that the wind resource is abundant enough in NM and TX from the figure (5) in appendix. However, since the cost of the usage of wind energy, the states NM and TX develops the kind of energy in recent years.

3.1.4 The comparison between the renewable and unrenewable energy

In order to measure the development difference between the renewable and cleaner energy and get acquainted with the situation of the renewable energy, we select the CLPRB (Coal production), NGMPB (Natural gas marketed production), NUETB (Electricity produced from nuclear power), PATCB (All petroleum products total consumption), REPRB (Renewable energy production) to compare. We draw the histogram of the four states' five energy production. To simplify the process of analyzing, the span of horizontal axis is five years. (For example, the 1960 represents the five years begin at 1960 and end at 1970). We can get the conclusion that in the four states the development of the renewable energy is in a low level from 1960 to 1970.





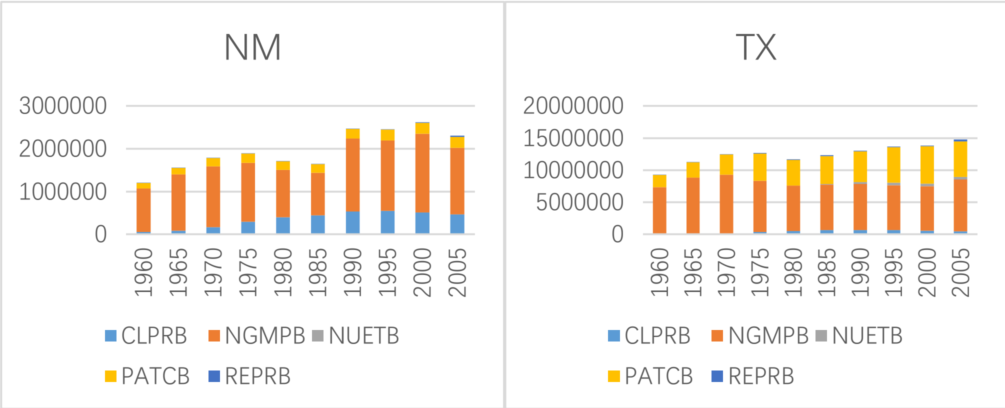


Figure6. The renewable energy development situation in four states

3.1.5 The criteria of the "best" profile in 2009.

By analyzing the composition of the renewable and cleaner resources structure, there are five main kinds of the renewable and cleaner energy. They are water energy, nuclear energy, wind energy, geothermal energy and biomass energy, respectively, because they occupy the largest proportion. In further, to create the criteria, the TOPSIS（Technique for Order Preference by Similarity to an Ideal Solution）method [6] is used.

Since there are five main kinds of the renewable and cleaner energy, then we set five goals $f_j (j = 1, 2, \cdots, 5)$ in this decision issue. The renewable energy situation in the four states is four viable solutions $Z_i = (Z_{i1}, Z_{i2}, \cdots, Z_{i5}) (i = 1, 2, 3, 4)$. Assume that an ideal solution to the problem of normalization weighted goal is Z^+,where

$$Z^+ = (Z_1^+, Z_2^+, \cdots, Z_5^+),$$

Then apply the Euclidean norm to measure the distance between the arbitrary viable solution and the ideal solution Z^+, that is:

$$S_i^+ = \sqrt{\sum_{j=1}^{5} (Z_{ij} - Z_j^+)^2} \, (i = 1, 2, 3, 4) \quad (1)$$

where Z_{ij} is the normalized weighted value of the j_{th} objective to i_{th} solution.

In the similar way, assume that an negative ideal solution to the problem of normalization weighted goal is $Z^- = (Z_1^-, Z_2^-, \cdots, Z_5^-)$, then the distance between the arbitrary viable solution and the negative ideal solution Z^-:

$$S_i^- = \sqrt{\sum_{j=1}^{5} (Z_{ij} - Z_j^-)^2} \, (i = 1, 2, 3, 4) \quad (2)$$

Then, the proximity of any viable solution relative to the ideal solution is defined as:

$$C_i = \frac{S_i^-}{S_i^- + S_i^+} (0 \le C_i \le 1, i = 1, 2, 3, 4) \quad (3)$$

Under this circumstance, if Z_i is the ideal solution, the corresponding $C_i = 1$; f Z_i is the negative ideal solution, the corresponding $C_i = 0$. The closer the distance between the viable solution and the ideal solution Z^+ is, the closer C_i is to 1.On the contrary, the closer the distance between the viable solution and the ideal solution Z^- is, the closer C_i

is to 0.Therefore, by compare the two states' C_i, the state can be selected which has the "best" profile for use of cleaner, renewable energy in 2009.

The establishment of the ranking of the four states' profile for the use of cleaner, renewable energy in 2009 consists of four steps:

Step 1:

From the data file, we obtain the four states' production of the five kinds of cleaner and renewable energy in 2009 in the same unit. The five kinds of energy production are respectively EMFDB (Biomass inputs (feedstock) for the production of fuel ethanol), GEEGB (Electricity produced from geothermal energy by the electric power sector), HYTCB (Hydroelectricity total production), SOEGB (Electricity produced from photovoltaic and solar thermal energy by the electric power sector), WYTCB (Electricity produced from wind energy). The data is shown in the table below.

Table2. Production of the five kinds of renewable energy

	EMFDB	GEEGB	HYTCB	SOEGB	WYTCB
AZ	7623.613	0	62730.89	138.0552	288.3592
CA	6861.251	125443.2	272187.2	6318.522	56996.58
NM	3811.806	0	2644.599	0	15095.97
TX	23217.37	0	10039.7	0	195454.8

By the TOPSIS, there is a decision matrix A:

$$A=\begin{bmatrix} f_{11} & f_{12} & \cdots & f_{15} \\ f_{21} & f_{22} & \cdots & f_{25} \\ \vdots & \vdots & \cdots & \vdots \\ f_{41} & f_{42} & \cdots & f_{45} \end{bmatrix}=\begin{bmatrix} 7623.613 & 0 & 62730.89 & 138.0552 & 288.3592 \\ 6861.251 & 125443.2 & 272187.2 & 6318.522 & 56996.58 \\ 3811.806 & 0 & 2644.599 & 0 & 15095.97 \\ 23217.37 & 0 & 10039.7 & 0 & 195454.8 \end{bmatrix}$$

To obtain the standardized decision matrix Z',whose element is Z'_{ij} , input f_{ij} into the formula:

$$Z'_{ij}=\frac{f_{ij}}{\sqrt{\sum_{i=1}^{4} f_{ij}^2}}\left(i=1,2,3,4\right),$$

then we get the matrix:

$$Z'=\begin{bmatrix} 0.0242 & 0 & 0.1988 & 0.0004 & 0.0009 \\ 0.0217 & 0.3975 & 0.8625 & 0.0200 & 0.1806 \\ 0.0121 & 0 & 0.0084 & 0 & 0.0478 \\ 0.0736 & 0 & 0.0318 & 0 & 0.6193 \end{bmatrix}$$

Step 2:

Considering that the renewable and cleaner energy production varies widely from kind to kind. The difference is one to two orders of magnitude. Hence, in an effort to make the result more accurately and reliable, the normalized weighted decision matrix Z is introduced to instead of the former decision matrix Z'. The element of the matrix Z :

$$Z_{ij}=W_j Z'_{ij}(i=1,2,3,4;\ j=1,2,\cdots,5)$$

The weight matrix $W=\begin{bmatrix} W_1 & W_2 & W_3 & W_4 & W_5 \end{bmatrix}$ is determined by the relation among the five kinds of the energy. The meaning of the W_j is shown below:

$$W_1 = \frac{\text{EMFDB}_{max}}{\text{Total Energy Max Production}},$$

$$W_2 = \frac{\text{GEEGB}_{max}}{\text{Total Energy Max Production}},$$

$$W_3 = \frac{\text{HYTCB}_{max}}{\text{Total Energy Max Production}},$$

$$W_4 = \frac{\text{SOEGB}_{max}}{\text{Total Energy Max Production}},$$

$$W_5 = \frac{\text{WYTCB}_{max}}{\text{Total Energy Max Production}},$$

$$\sum_{j=1}^{5} W_j = 1$$

The Total Energy Max Production is the sum of the $(\text{EMFDB})_{\text{max}}$, $(\text{GEEGB})_{\text{max}}$, $(\text{HYTCB})_{\text{max}}$, $(\text{SOEGB})_{\text{max}}$, $(\text{WYTCB})_{\text{max}}$. The reason for doing this is that the proportion of one energy can account for the energy relative production.

Therefore, the normalized weighted decision matrix is attained:

$$Z = \begin{bmatrix} 0.0010 & 0 & 0.0875 & 0.0000 & 0.0003 \\ 0.0009 & 0.0795 & 0.3795 & 0.0002 & 0.0560 \\ 0.0005 & 0 & 0.0037 & 0 & 0.0148 \\ 0.0029 & 0 & 0.0140 & 0 & 0.1920 \end{bmatrix}$$

Step3:

Determine the ideal and negative ideal solutions. The larger the Z_{ij} of Z is, the better the solution is. Then we get the ideal solution:

$$Z^+ = (Z_1^+, Z_2^+, \cdots, Z_m^+) = \{\max_i Z_{ij} \mid j = 1, 2, \cdots, 5\} = \{0.0050, 0.0795, 0.3795, 0.0002, 0.1920\}$$

and the negative ideal viable solution:

$$Z^- = (Z_1^-, Z_2^-, \cdots, Z_m^-) = \{\min_i Z_{ij} \mid j = 1, 2, \cdots, 5\} = \{0.0009, 0, 0.0014, 0, 0.0003\},$$

Step 4:

By the MATLAB and the two formulae (1) and (2), we can calculate the distance between the ideal solution and the four states' viable solution. Through inputting the four distances into (3) the, we get the

$$C = \begin{bmatrix} C_{AZ} & C_{CA} & C_{NM} & C_{TX} \end{bmatrix} = \begin{bmatrix} 0.1895 & 0.7405 & 0.0332 & 0.3392 \end{bmatrix}$$

By comparing the four entity, the order is

$$C_{CA} > C_{TX} > C_{AZ} > C_{NM}$$

The result tells us that the California(CA) appeared to have the "best" profile for use of cleaner, renewable energy in 2009.

4 Prediction of the energy profile of each state

In order to predict the energy profile of each state, using the statistical data from the data file and combining the index and model created before, we establish a gray model that is useful to predict the changing of discrete numbers.

4.1 An Introduction to Grey Prediction Model

Grey model is a model of differential equation formed by the operation of generation, transfer change discrete random numbers into some regular generation numbers, whose randomness are significantly weakened, so as to facilitate the study and description of the changing process.

The first-order linear model of grey prediction, or GM (1,1) is used in the analyzing process. The establishment of the GM (1,1) model consists of five steps as follow:

Step 1:

Inputting one kind of index of the renewable energy production from 1960 to 2009 into an original sequence $X^{(0)}$ with 50 elements.

$$X^{(0)} = \left(X^{(0)}(1), X^{(0)}(2), \cdots, X^{(0)}(50) \right)$$

Step 2:

Using the original sequence $X^{(0)}$ to generate the first-order accumulated generating operation sequence $X^{(1)}$:

$$X^{(1)} = \left(X^{(1)}(1), X^{(1)}(2), \cdots, X^{(1)}(50) \right)$$

where $X^{(1)}(k) = \sum_{t=1}^{k} X^{(0)}(t)(1)$.

Step 3:

Let $Z^{(1)}(t)$ is the mean sequence of the sequence $X^{(1)}$, that is:

$$Z^{(1)}(t) = 0.5X^{(1)}(t) + 0.5X^{(1)}(t-1)(2),$$

Then the GM (1,1) model is established:

$$X^{(0)}(t) + aZ^{(1)}(t) = b, t = 2, 3, \cdots, 50 (3)$$

where, a and b are parameters to be estimated, the solution to the model is

$$X^{(1)}(t+1) = (X^{(0)}(1) - \frac{b}{a})e^{-at} + \frac{b}{a} (4)$$

Step 4:

Use the GM (1,1) model to create a matrix and calculate the values of a and b.

where

$$Y=\begin{bmatrix} X^{(0)}(2) \\ X^{(0)}(3) \\ \vdots \\ X^{(0)}(n) \end{bmatrix}, \theta=\begin{bmatrix} a \\ b \end{bmatrix}, B=\begin{bmatrix} -Z^{(1)}(2) & 1 \\ -Z^{(1)}(3) & 1 \\ \vdots & \vdots \\ -Z^{(1)}(50) & 1 \end{bmatrix}$$

where Y is data vector, θ is the parameters matrix, B is the data matrix. For the θ, if there exists $\left(B^T \bullet B\right)^{-1}$, then using the ordinary least-square method, the estimation of parameters $\hat{a}, \hat{b}$ can be obtained by

$$\theta=\begin{pmatrix} a \\ \hat{b} \end{pmatrix}=\left(B^T \bullet B\right)^{-1} B^T \gamma$$

Step 5:

Make predictions through inverse accumulated- generation operation. Substitute the parameter values of $\hat{a}, \hat{b}$ obtained from step 4 into equation (4) in order to obtain $\hat{X}^{(1)}(t+1)$. Series $X^{(1)}$ is the original series $X^{(0)}$ produced through the one-time accumulated generation. Therefore, before the prediction begins, $X^{(1)}(t+1)$, obtained through prediction, must undergo an inverse accumulated-generation restoration to become $\hat{X}^{(0)}(t+1)$.

The inverse generated series is:

$$X^{(0)}(t+1)=X^{(1)}(t+1)-X^{(1)}(t).$$

Based on the GM (1,1) model that we create, enter the different states' $P_R, \eta, P_C, E_{PP}, E_{RT}$ from 1960 to 2009 to the GM (1,1) respectively, then we obtain the value of every variable in 2025 and 2050. Further, we can calculate the number of the I_R .All the results is shown in the tables below.

Table3. $P_R, \eta, P_C, E_{PP}, E_{RT}$ **prediction of 2025**

2025	AZ	CA	NM	TX
P_R	0.202	0.345	0.038	0.041
η	5.751	3.765	0.296	1.407
P_C	0.908	0.988	0.097	0.345
E_{PP}	241.7	223.5	325.9	365.7
e_{PP}	0.059863624	0.020057919	0.244019685	0.331067324
I_R	1.434687	1.139423	0.079137	0.35103
E_{RT}	1.344*10^5	8.269*10^5	0.632*10^5	4.812*10^5

Table4. $P_R, \eta, P_C, E_{PP}, E_{RT}$ **prediction of 2050**

2050	AZ	CA	NM	TX
P_R	0.107	0.598	0.856	0.119
η	9.487	5.429	0.336	1.848
P_C	0.959	0.993	0.138	0.463

E_{PP}	230.7	209.3	300.4	328.4
e_{PP}	0.035805231	0.010999278	0.188247956	0.249487502
I_R	2.130844428	1.586227607	0.488076756	0.059869565
E_{RT}	1.682*10^5	10.36*10^5	1.177*10^5	8.934*10^5

From the two tables, we can conclude that all the total renewable energy production of the four states increase compared to the year before. However, the index of the four states have increased except the TX, that means the level of sustainable development and the renewable energy development will decline.

5 Renewable energy target

5.1Energy potential

After the former modelling, "profile" trends and "best" profile analysis, and the predictions of energy profile about the four states, we now have a series of the energy basic facts mainly about the renewable energy, to make or plan the renewable usage targets for 2025 and 2050, we mainly concern about three parts to make suggestions or goals for states.[7]

First, to develop the renewable source more specifically, we must find the main "force point" to put into resources and get the max reward back.

Consider the economy and growth trends in energy development, we use GDP and growth rate in the past years to represent this two factors and define

$$P = F \bullet \left(\frac{e^{G}}{e^{(-F_{GDP})} + 1} \right)$$

as the energy potential (can be explain as max production in the future), F represent the predicted energy production we estimate. Here G represent the growth rate we calculate in the latest five years, and we think the more GDP a state has, then it have more potential to develop the energy. So we put the GDP' forecast into consideration. P_w, P_s, P_h, P_b, P_g represent the energy potential for the wind, solar, hydro, biomass, geothermal respectively.

And we get the energy potential estimate for the five kinds of renewable of the four states, as follow：

Table5. Energy potential (Unit: billion btu)

Year	2025					2050				
	P_s	P_w	P_g	P_b	P_h	P_s	P_w	P_g	P_b	P_h
CA	6000	500	560	45000	18000	7500	700	700	62000	25000
AZ	4000	70000	160000	250000	50000	5300	90000	180000	270000	62000
NM	500	20000	700	25000	570	750	30000	1300	40000	830
TX	1200	400000	4000	220000	1700	1800	500000	5500	350000	2400

To see the potential more visually, we make the bar chart to analyze these data as follow:

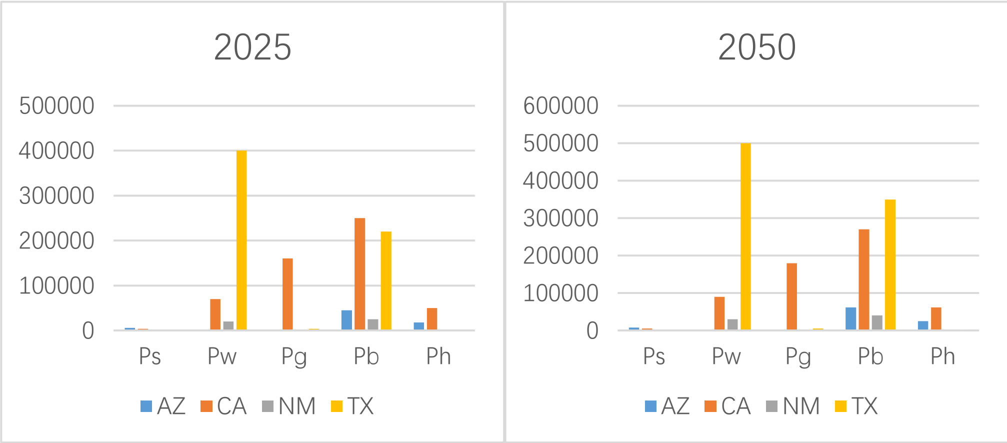


Figure8.Bar chart of energy potential prediction

From the data we calculate and estimate, we can find that in 2025, the biomass and geothermal of CA, the wind and biomass of AZ, the biomass of NM, and the wind of TX can be most potential energy, as the same as 2050, so in the future the first target of the four states, is to strive to develop the most potential renewable sources to make more energy as possible as they can.

5.2 Energy distribution

In the process we analyze, we have known that the renewable energy will be an important strategic position in the future, so in the second part, we want to find how to make energy distribution can get the max renewable energy amount so that improve the energy profile or structure[8].

After consulting many materials in some energy website and literature, we raise three goal for evert state in this part:

First goal we define is to make the total energy of renewable resource be the largest as we can,

$$E_{RTmax} = E_w + E_s + E_h + E_b + E_g$$

E_{RTmax} represents the total amount of the renewable energy, E_w, E_s, E_h, E_b, E_g represent the ideal energy amount of five kinds of renewable sources.

Considering the equipment area of five kinds of renewable energy, we want to minimize the land area the energy production equipment occupies, to save the land source to be distributed for other usages like commercial and so on.

$$\min S_T = u_w E_w + u_s E_s + u_h E_h + u_b E_b + u_g E_g$$

S_T represents the total energy used to construct the equipment, the u_w, u_s, u_h, u_b, u_g represent the land area to produce per billion btu energy.

As we all know, developing the renewable energy need the certain investment, although there will have feedback, and will have more energy could to use, we want to reduce the government investment to produce more energy. So we want to minimize the fees to construct the new energy as follow

$$\min M_T = c_w E_w + c_s E_s + c_h E_h + c_b E_b + c_g E_g$$

M_T represents the expenditure to construct and maintain the new energy,

c_w, c_s, c_h, c_b, c_g represent the fees to produce per billion btu energy of each, the data came from a renewable source website.

We assume that every kind of energy has its minimum and maximum production, for the minimum production we can use the lowest production in the past fifty years during 1960-2009, and use the potential we estimate to restrict the maximum production. And we get the following inequations as the restrictions

$$\begin{cases} L_w \le E_w \le P_w \\ L_s \le E_s \le P_s \\ L_h \le E_h \le P_h \\ L_b \le E_b \le P_b \\ L_g \le E_g \le P_g \end{cases}$$

L_w , L_s , L_h , L_b , L_g represent the lowest production in the past fifty years during 1960-2009.

Based the second part analysis, we hope to make a renewable energy distribution targets including every kind of energy production they will achieve for the four states, to get the maximum energy productions, minimum occupation of the land, and minimum cost to construct the equipment. But after we tried multi objective programming approach with the help of MATLAB, we don't get the reasonable energy distribution. This part need to be improved in the future.

5.3 Energy transportation

From the predictions we make, we can forecast that in 2025 and 2050, some states' energy usage η has surpass 1, so if one state satisfy

$$\eta > 1$$

We can judge that state needs energy import. So there will be the energy transmission between the energy supply state and energy receive state. But as we investigate, some renewable sources aren't connected to the electricity nets,

in some extent, it means the energy produced by the renewable sources couldn't be used and transferred to other states effectively, unless the energy produced by renewable sources could be inputted to the main electricity net, then we can transfer this part of energy through the wire roads which has been build and connected between the different state, so we set a general goal:

(1) by 2025, four-state needs to merge most of the dominant sources of themselves,

including the water source of AZ and the wind source of TX and NM into the main electricity net to share cleaner and safe energy with each other.
(2) by 2050, four-state needs to add some of other kinds of energy into the main net to get the quantities of energy as possible as we can to improve the renewable source amount and make the energy produced more flexibly and variously

5.4 Strength and weakness

5.4.1 Strength:

We divide the targets into three parts, first we define the energy potential, to calculate and estimate the potential of each kind of energy to instruct each state to develop the renewable source, then we give a energy distribution plan for each state to achieve some goals, and at last, we discuss and find the possible measure we can do with renewable resource to help to solve the electricity flow between the four states.

5.4.2 Weakness:

In the first part, we estimate the renewable energy potential, but we only take three factors in count, in fact there are more factors should be taken into consideration.
We don't quantify the electricity resources dispatching, so we can't get the specific energy distribution schedule plan.
For the compact of the four states, we only consider the renewable source strategy.
In the second part, we don't plan the program considerately, which will make the energy distribution a little unreasonable

6 Take actions

6.1 Utilize the conditions

Four states should utilize the advantages substantially they have including geographical advantages, climate advantages and so on to develop the most potent renewable energy like Arizona and California should utilize its sufficient light intensity to develop its solar energy; Texas and New Mexico should get more energy from the wind

6.2 Multi-development

According to our plan for the optimized energy distribution, there will be a "best" renewable source investment direction or development force, and for the past years, every state has its weakness, so to achieve the second goal, they need to communicate the experience, the technology and other things to help each other to develop other renewable sources, the state don't "good at", to gain more renewable sources from the nature and ameliorate the energy profile, and reduce the carbon emission.

6.3 Big Net

To meet the third goal we set, we'd better set goal step by the year to make the final electricity net[9], connecting the all the renewable resources and other kinds of energy, so in the next decades of years, we'd better construct this big-net from the advantage

sources to other sources, from the large-scale renewable production node.
But before that we need to make a whole four-state net layout to make an overall plan to be the guidance in the future engineering

7 Optimization

7.1 Optimization one of the energy profile

In the first part we define the energy profile to estimate or analysis the four state, when we check the data we calculate, we found that the energy efficient η of some states is larger than 100%, and that means this state need import energy from the other place, to some extent, it reflect energy usage of this state is not qualified but the overall score will larger than other states, so when we evaluate the profile, we will divide this part into two situations, and make a supplement of the previous index.

If the energy efficient η>1, then we will make the index as follow

$$I_R = \lambda_1 P_R - \lambda_2 \eta + \lambda_3 P_C - \lambda_4 E_{PP}$$

So after the optimization of energy profile, and take this factor into account, we get the variation of I_R as follow:

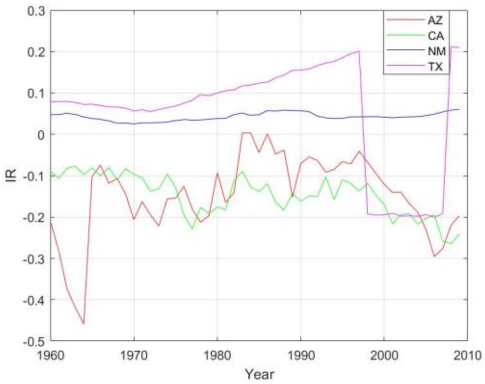


Figure9.Improved profile

We can find that after the optimization, the I_R of TX has a drop around 1995, we can make a statement that profile of TX become “bad” during the 1995—2006.
So after the optimization, we can judge and see the profile more fairly.

7.2 Optimization two of the prediction in forecasting the profile

In this part, we want to use time series predictive model to confirm the predictions models we use in part one. Because of the complexity of the ARIMA model, so we don’t explain the details of it, and predict the model with the help of SPSS.
Here we give a simple we predict use the time series predictive model to make comparison with the former prediction of the UCA, and after the profiling, we use ARIMA(3,2,2) to make forecast[10].

Table6.Model Description

	Model Type
Model ID energyUCA Model_1	ARIMA(3,2,2)

The situation is as follow:

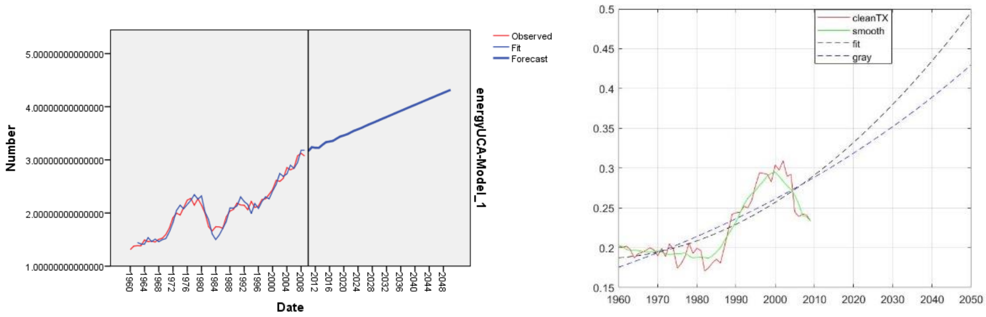


Figure10.Comparison of different kinds of prediction

From the comparison, we found that the gray model is consistent with ARIMA in some content. And verify the model we established before.

8 Sensitivity analysis of the energy profile index

When we create the energy profile, we make an overall evaluation to be a part of the profile based on AHP. Before we get the weight of each part of the component we need to fill a matrix based on the importance of each component, so we try to change the matrix , see the effect of defining the matrix on the four state rank of the energy profile I_R[11].

After we change the matrix from fixed to tested as follow

$$\begin{array}{c|cccc} & P_R & \eta & P_C & E_{PP} \\ \hline P_R & 1 & 3 & 2 & 5 \\ \eta & \frac{1}{3} & 1 & \frac{1}{2} & 4 \\ P_C & \frac{1}{2} & 2 & 1 & 2 \\ E_{PP} & \frac{1}{5} & \frac{1}{4} & \frac{1}{2} & 1 \end{array} \Rightarrow \begin{array}{c|cccc} & P_R & \eta & P_C & E_{PP} \\ \hline P_R & 1 & 5 & 1.5 & 7 \\ \eta & 0.2 & 1 & \frac{1}{3} & 3 \\ P_C & \frac{2}{3} & 3 & 1 & 4 \\ E_{PP} & \frac{1}{7} & \frac{1}{3} & \frac{1}{4} & 1 \end{array}$$

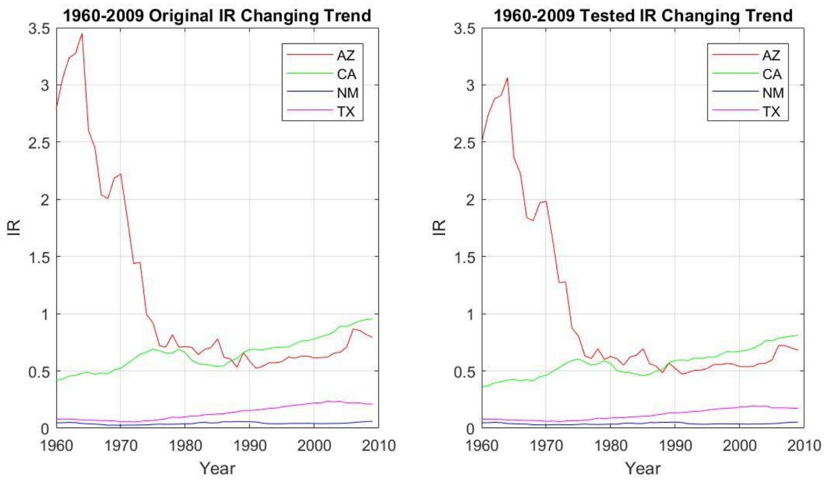


Figure11.Comparison of different weight matrix

When the matrix change, the rank of each state almost don't change, so our ranking system has enough robustness and can reduce the influence made by man-made errors.

Reference

[1]Jevons, W.S., 1865. The Coal Question: An Inquiry Concerning The Progress of Nation, and the Probable Exhaustion of Our Coal-Mines. London: Macmillan and Co. [online] Available at: http://www.econlib.org/library/YPDBooks/Jevons/jvnCQCover.html.

[2]Saaty, Thomas L.; Ernest H. Forman (1992). The Hierarchon: A Dictionary of Hierarchies. Pittsburgh, Pennsylvania: RWS Publications. ISBN 0-9620317-5-5.

[3]https://www.nrel.gov/gis/assets/docs/resource-maps.pptx

[4]https://maps.nrel.gov/reatlas/?aL=pTw6AJ%255Bv%255D%3Dt%260BO3Oa%255Bv%255D%3Dt%260BO3Oa%255Bd%255D%3D1&bL=clight&cE=0&lR=0&mC=37.82280243352756%2C-95.185546875&zL=4

[5] http://www.renewable-energysources.com/

[6]Qiaofeng Fu, Study on TOPSIS method. [J]. The journal of Xi′an University of Science and Technology,2008(01):190-193.

[7] Shi Dan. Analysis of Development Goals and Implementation Effects of Renewable Energy in China [J]. JOURNAL OF NANJING UNIVERSITY (PHILOSOPHY, HUMANITIES AND SOCIAL SCIENCES),2009,46(03):29-36.

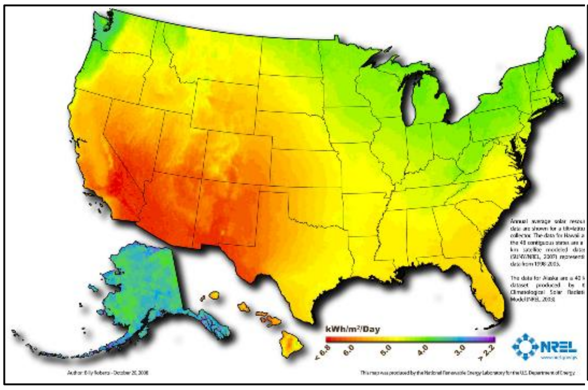
[8]M. Ricardo Saavedra M., Cristiano Hora de O. Fontes, Gaudencio Francisco Gaud 锚ncio. Sustainable and Renewable Energy Supply Chain: A System Dynamics Overview[J]. Renewable and Sustainable Energy Reviews,2017.

[9] Dezem, V. (2015). "Mexico Sets National Target of 5% Renewable Energy by 2018." Bloomberg L.P.

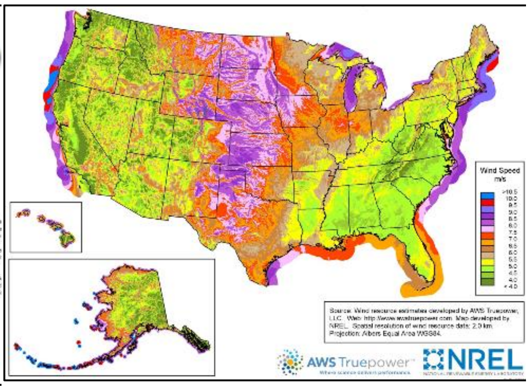
[10] Zhao Ying. China's GDP time series model of the establishment and empirical analysis [J] Journal of Xi'an University of Finance and Economics, 2006.4

[11] Yu Liping, Pan Yuntao, Wu Yishan. Sensitivity Analysis of Science and Technology Evaluation - A Single Index and Combination Index [J]. Soft Science, 2009,23 (08): 1-4 + 10.

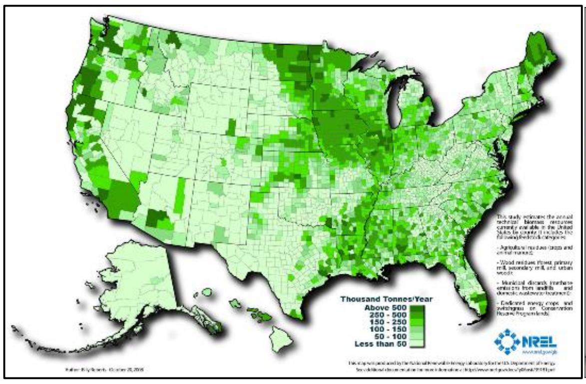
Appendix



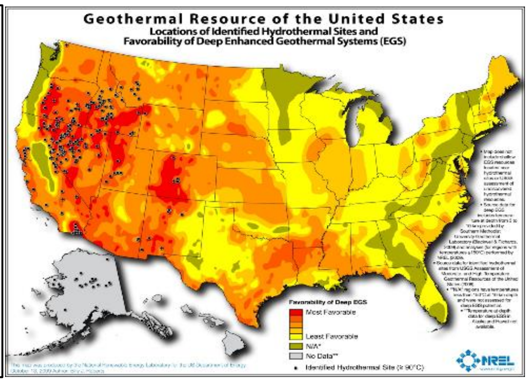
Figure(1).U.S. Photovoltaic Solar Resource[3]



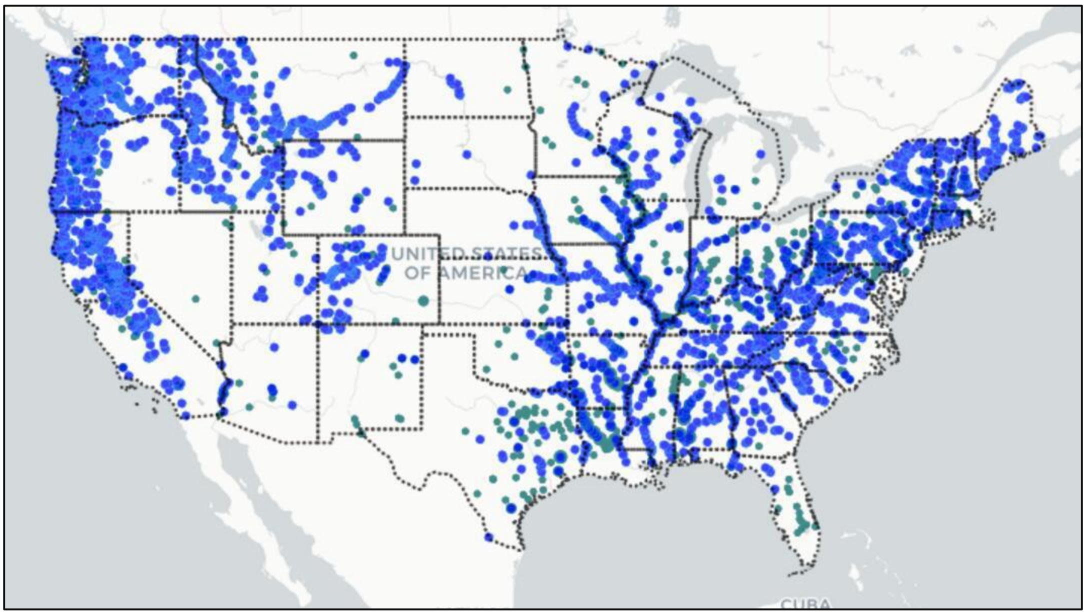
Figure(2).U.S. Wind Resource(80m) [3]



Figure(3).U.S. Biomass Resource[3]



Figure(4).U.S. Geothermal Resource[3]



Figure(5).U.S. Hydraulic Resources[4]

MEMO

TO: Mr. Governor
FROM: Team#77812
DATE: February 12, 2018
SUBJECT: Applicants for Sales Post

As required, our team has summarized the state profiles as of 2009 and predict the energy profile of each state without the policy changing and determine the goals of the energy compact. The details are as follow:

- **The state profiles in 2009**

  In 2009, the three states AZ, NM, TX produce no geothermal energy. What's more, the solar energy production of the two states NM and TX is zero. In our evaluation system, the order of the four states get are CA， TX， AZ, NM(from the largest to the smallest). That means that CA has the best energy profile. The different states have different proportion of the energy production and we can know that the geothermal and solar energy need to be developed.

- **The energy profile in 2025 and 2050 without the policy changing**

  All the total renewable energy production of the four states increase compared to the years before. However, the index of the four states have increased except the TX, that means the level of sustainable development and the renewable energy development of the TX will decline. The another issue needed attention is that the energy efficiency is over 1 the three states AZ, CA, TX in 2009, which means the energy consumption is over the production. Hence, taking some measures to deal with the situation is necessary.

- **The goals of the energy compact**

  (1) Utilize the conditions

  Four states should utilize the advantages substantially they have to develop the most potent renewable energy like Arizona and California should utilize its sufficient light intensity to develop its solar energy; Texas and New Mexico should get more energy from the wind.

  (2) Multi-development

  To achieve optimized energy distribution, every state need develop its weakness, so to achieve the second goal, they need to communicate the experience, the technology and to help each other to develop other renewable sources, the state don't "good at", to gain more renewable sources from the nature and ameliorate the energy profile, and reduce the carbon emission.

  (3) Big Net

  To meet the third goal that we set, we'd better set goals step by the year to make the final electricity net, connecting the all the renewable resources and other kinds of energy and before that we need to make a whole four-state net layout to make an overall plan to be the guidance in the future engineering