For office use only	Team Control Number	For office use only
T1 ________________	**75380**	F1 ________________
T2 ________________		F2 ________________
T3 ________________	Problem Chosen	F3 ________________
T4 ________________	C	F4 ________________

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MCM/ICM

Summary Sheet

With the large amounts of energy consumption, energy problem is getting more and more attention. Increasing usage of cleaner, renewable energy has become an irreversible trend. Aimed to look for the better energy system, we select 8 kinds of energy to carry out the below work. They are most-used and the represent of energy.

According to the comprehensive analysis of the energy's impact on varied factors, we treat energy system, ecology system and economy system as subsystems of wider system. In order to get each kind of energy's evaluation value of each subsystem, we develop the **"3E" (Energy, Ecology, Economy) model** to calculate. And the principle of "3E" is also the criteria of energy's influence degree on a subsystem.

Then apply **the Entropy Method** to acquire the energy's weight of total energy. Combining the calculated value of evaluation value and weight, we can get the energy's comprehensive evaluation value under the criteria of "3E".

When determine the "best" profile for use of cleaner, renewable energy in 2009, taking reality into account, we use **Analytic Hierarchy Process (AHP)** and **Gray Comprehensive** to build and standard about the economic, environmental and social effects of 7 energy sources. Then we use this standard to calculate a comprehensive score of each state and get the result of which state has the best profile in 2009. Finally, our model demonstrates **California** is the best user of cleaner, renewable energy. We use **Long Short Term Memory networks(LSTM)** to predict the Energy Profile for 2025 and 2050.

In conclusion, the total energy consumption is getting more and more. The rate of clean, renewable energy's use will increase in the following few years. We also do the future discussion from **Sustainable Energy Development and Energy Security.** Last, the article puts forward a few suggestions to meet four states' energy compact goals.

Contents

1 Overview

1.1 Background

Energy production and usage play an important role in the development of economy. With the consumption of all kinds of energy, increasing usage of cleaner, renewable energy has become an irreversible trend. Moreover, The United States is the greatest importer and consumer of energy in the world. They have been working on solving the energy problem, which is important and urgent.

There exists a policy called interstate compact in the United States. It 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.

Along the U.S. border with Mexico, there are four states – California (CA), Arizona (AZ), New Mexico (NM), and Texas (TX). They need to form such an interstate compact about the new energy to increase usage of cleaner, renewable energy sources, which is critically important for the development of them even the whole country. Therefore, working out an appropriate energy strategy is urgent.

1.2 Restatement of the Problem

We are required by the four governors of these states to perform data analysis and modeling to inform their development of a set of goals for their interstate energy compact with the data provided.

In order to complete the interstate energy compact, we need to finish these three parts below, the first part is the following:

- Using the data provided, create an energy profile for each of the four states.
- Develop a model to characterize how the energy profile of each of the four states has evolved from 1960 – 2009. Analyze and interpret the results of our model to address the four states' usage of cleaner, renewable energy sources.
- Determine which of the four states appeared to have the "best" profile for use of cleaner, renewable energy in 2009.
- Based on the questions above, predict the energy profile of each state for 2025 and 2050

After finishing the first part, we still need to conduct a deep discussion. The second part is the following:

- Determine renewable energy usage targets for 2025 and 2050 and state them as goals for this new four-state energy compact.
- Identify and discuss at least three actions the four states might take to meet their energy compact goals.

Finally, we need to summarize the result. The third part is:

- Prepare a one-page memo to the group of Governors summarizing the state profiles as of 2009. Give the predictions recommended goals with regard to energy usage absent any policy changes.

1.3 Literature Review

Energy problem has received a considerable attention in recent years. Researching the energy structure in different situations is an essential prerequisite of the development. Generally speaking, the task contains two steps. First, analyze and research the historical usage of the energy. Then, based on the conclusion of the first step, forecast and adjust the energy structure. Several relevant theories have been put forward to solve the problem over the years.

Multiple Energy Network (MEN) puts forward useful principles for optimized allocation of energy, including the principle of balance between supply and demand, reasonably mining, environment protection, regional consideration, reasonable collocation and substitution of energy. [1]

As for the prediction, the models based on time series are widely used. There is a paper published in 2003 dealing with time series of categorical or ordinal variables, which are combined with time varying covariates. In this paper, the conditional expectations are modeled as a regression model in a GLM-type manner. Its parameters are estimated using a likelihood-approach. Special attention is given to the multivariate and the cumulative logistic regression model, with a regression term defined by a recursive scheme. In this process, the main concern is directed at forecasts for such time series. Using an approximation formula for conditional expectations l-step predictors are developed. Bias and mean square errors are estimated by using expansion formulas and employing Box-Jenkins as well as nonparametric methods. [2]

Refer to the related researches, we would develop a specific model for the specific energy problem under given conditions. And the reality would be taken into account.

2 Assumptions and Justifications

A variety of variable factors are involved in the process of solving the energy problem. Considering those factors, also making the method more feasible, we make the following basic assumptions to simplify the problem.

- **Ignore the influence of unimportant energy.** We consider 8 kinds of influential energy are quite enough to do a comprehensive evaluation.

- **Energy policy won't change in the four states.** When predicting the energy profile, there is no change in energy policy.
- **External influence factors will not change sharply.** In the phase of prediction, the possible influential factors (e.g. explosive growth of new technology, geography, population, climate) would not have a sharp change comparing with historical situation.

3 Notation

Abbreviation	Description
X	original data matrix
a_j	weight coefficient
V_i	comprehensive coefficient
$\Delta(min)$	Minimum difference of two stage
$\Delta(max)$	Maximum difference of two stage
ε_0	gray correlation coefficient
σ_g	sigmoid function
σ_c	hyperbolic tangent function
σ_h	hyperbolic tangent function
f_t	forget gate's activation vector
i_t	input gate's activation vector
o_t	output gate's activation vector
c_t	cell state vector
h_t	output vector of the LSTM unit
W_i	weight matrices
b_i	bias vector
e_j	entropy of index j

4 Energy profile

Creating an energy profile requires data to provide a powerful support. Since the problem gives us a large amount of numerical information, we need to do the data analysis first.

We select the data of total energy consumption to depict the overall condition of the four states. And we express in a graphic way to make the result be more intuitive and vivid.

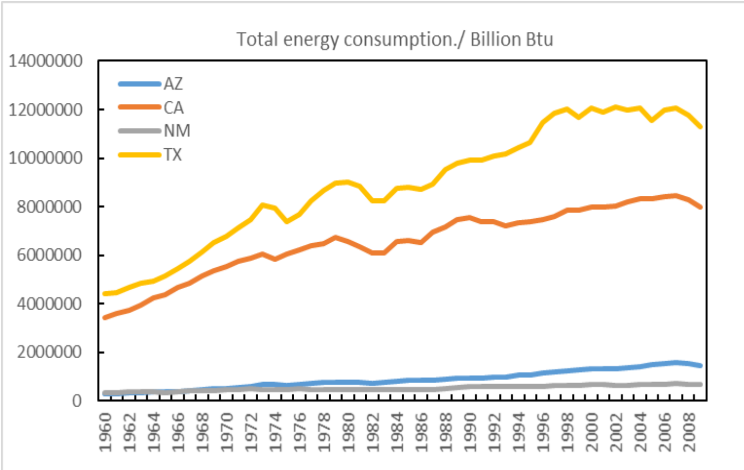

Figure 1: Total Energy Consumption from 1960 to 2009

In terms of the trend of quantity change, from Figure 1, we can see that each state's total energy consumption of the four states has been on the rise from 1960 to 2009. And among the four states, Texas(TX) ranked first in the amount energy consumption, the next is California(CA). By comparison, we can find out a similarity between CA and TX obviously. Their trends of total energy usage remain the same basically. — before 1998, they showed a marked increase. And after that, the consumption remained stable generally. Moreover, their energy consumptions are far more than Arizona(AZ) and New Mexico(NM) all the time. Then, let's pay attention to the energy, renewable energy.

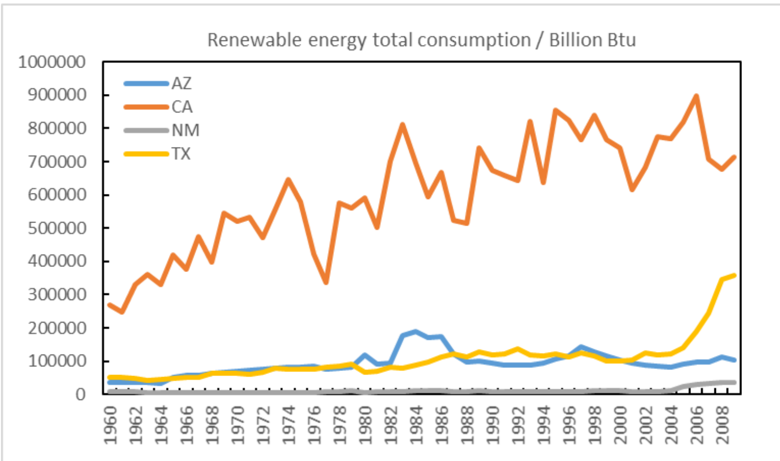

Figure 2: The Rate of Clean, Renewable Energy Use

From Figure 2, we can see California's rate of clean, renewable energy is much higher than other states. And it displays a general ascending trend. However, we also notice that the rate of clean, renewable energy of TX is increasing rapidly in recent years.

In addition to the analysis of total energy consumption and the rate of clean, renewable energy' use, we find out some influential and representative energy. Those are petroleum, natural gas, geothermal, solar thermal energy, nuclear fuel, wind energy, hydroelectricity and coal. Petroleum and natural gas's usage is maximal of all kinds of energy. And the others represent clean, renewable energy. We take TX as an example to analyze. The following figure shows above 8 kinds of energy's consumption from 1960 to 2009.

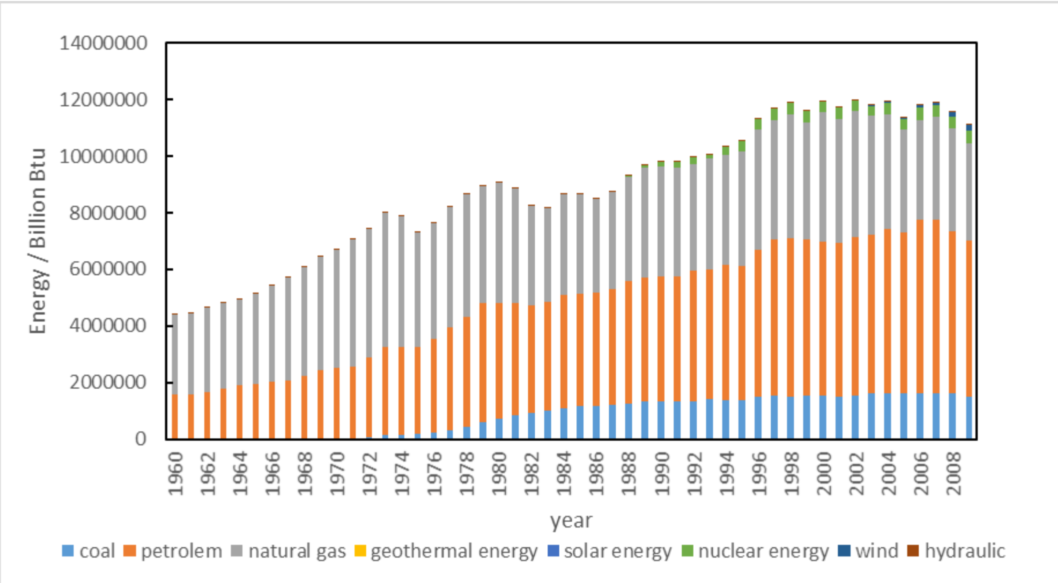

Figure 3: 8 Kinds of Energy's Consumption of TX from 1960 to 2009.

From figure 3, we can see each kind of energy's consumption present an upward trend in general. And the rate of clean, renewable energy's use is also increasing on the whole.

5 Evolvement of Energy Profile

According to the overview of the energy consumption, we already know the overall situation. To know energy situation in detail, we set up models to do more accurate analysis.

5.1 Model

In order to characterize how the energy profile of each of the four states has evolved from 1960 – 2009, we decide to the use 8 kinds of energy (as mentioned above) to describe.

First, we introduce a multiple criteria optimization model: "3E" (Energy, Ecology, Economy)[3].We believe to judge an energy profile comprehensively, none of these three criteria is dispensable.

5.1.1 Model Theory and Establishment

- **The model of "3E"**

First, three criteria are defined as E, K, C (energy consumption, expenses, CO2 emission). Then, our multiple criteria optimization model can be written as:

$$\min(E \cdot s_e + K \cdot s_k + C \cdot s_c), \tag{1}$$

s_e,s_k,s_c——weight coefficients of energy, economical and ecological factors.

The value of weight coefficients (s_e,s_k,s_c) can be chosen by regarding the purpose of any analysis. A larger coefficient is given to the factor, which is of major importance for the analysis.

Moreover, for each criterion E, K, C, many factors should be taken into consideration. For better understanding, we only discuss energy consumption E below, since those three criteria have no difference mathematically. In our case, we select 8 kinds of energy. Thus, energy factor E is determined as follows:

$$E = \sum_{n=1}^{8} E_n \cdot w_n, \tag{2}$$

Where E_n is the evaluation value of each energy. w_n is given weight coefficients, the same as (s_e,s_k,s_c), a larger coefficient can be given to the factor, which is of major importance for the analysis. From Equation (2), we conclude that how to obtain the evaluation value of each energy is crucial.

- **The Entropy Method**

To achieve the optimization, we use the Entropy method to acquire the evaluation value of each energy.

Define the source data of each energy consumption from 1960-2009 as $X_{mn}(m = 1,2,\dots,50; n = 1,2,\dots,8)$:

- ✓ First, we calculate the weight of *n*-th energy in *m*-th year. We define the weight as P_{mn}.

$$P_{mn} = \frac{X_{mn}}{\sum_{m=1}^{50} X_{mn}}, \tag{3}$$

- ✓ Second, we deal with the entropy of each energy:

$$e_n = -k \sum_{m=1}^{50} P_{mn} \, lnP_{mn} \ (k > 0) \tag{4}$$

- ✓ Third, we calculate the otherness coefficient g_n of each energy:

$$g_n = 1 - e_n \tag{5}$$

- ✓ Forth, calculate the evaluation value E_n:

$$E_n = \frac{g_n}{\sum_{n=1}^{8} g_n}, \tag{6}$$

5.1.2 Model Implementation and Result

Follow the steps above, we get comprehensive evaluation value of the 8 kinds of energy. To make the result clearer, we use following table to show.

Table1: comprehensive evaluation value of the 8 kinds of energy

State	coal	petroleum	natural gas	geothermal energy	solar energy	nuclear energy	wind	hydraulic
AZ	0.06109	0.25844	0.30543	0.02413	0.02419	0.0159	0.0054	0.30543
CA	0.18158	0.24211	0.43233	0.0135	0.00552	0.01155	0.00533	0.10808
TX	0.01652	0.0956	0.77114	0.00571	0.00699	0.000686	0.00315	0.09404
NM	0.04038	0.25768	0.64934	0.00677	0	0.00799	0.00352	0.03432

So far, we get the comprehensive evasluation value of the 8 energy in each state. Now, we make an analysis of the result.

5.2 Analysis and Interpretation

To make the analysis more intuitive and show more clearly the rate of each kind of energy' comprehensive evaluation (CE), we turn numerical result to pie chart.

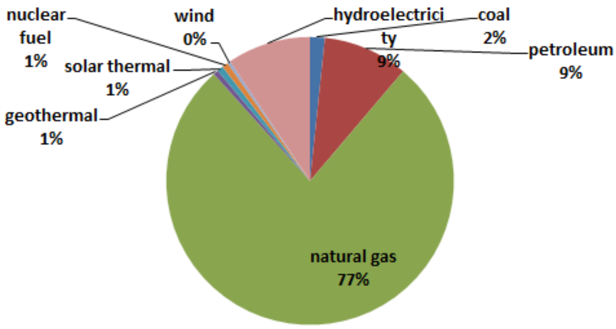

Figure 4: TX's rate of energy' comprehensive evaluation

From figure 4, we can obviously discovery that there are some similarities and differences among the four states. In terms of cleaner, renewable energy sources, we come to the result following result.

Table 2: cleaner, renewable energy' rate of comprehensive evaluation

	AZ	CA	TX	NM
Rate	68.05%	57.63%	88.79	70.19%

According to this chart, we can see that the clean, renewable energy's comprehensive evaluation has great proportion in each state. And Texas (TX) ranks first. California (CA) is the last. To make the result more detailed, we make use the following bar charts to express.

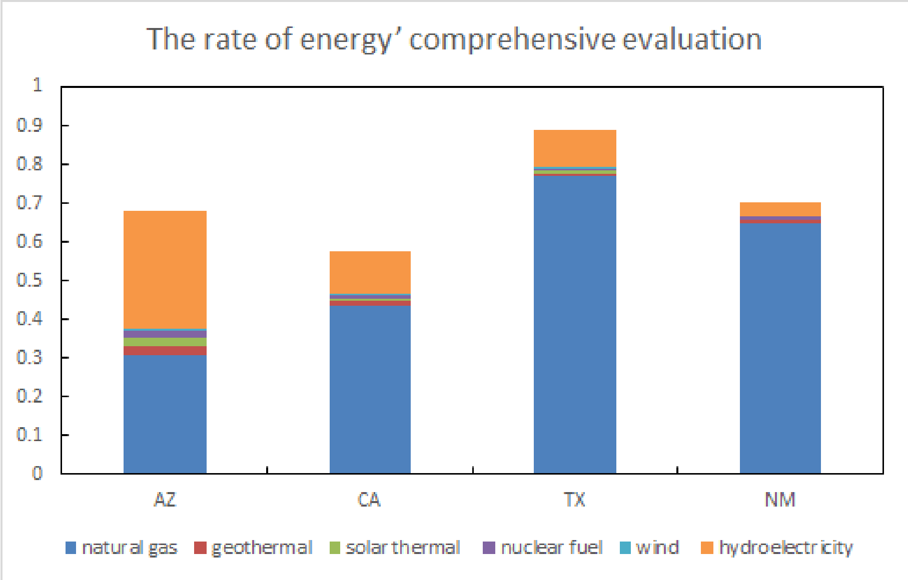

Figure 5: The rate of energy' comprehensive evaluation

This picture shows natural gas is the main usage of clean, renewable energy, then is the hydroelectricity.

On the basis of the result, we discuss the reasons of this situation from following influential factors. [4] [5]

- **Energy**

  California's crude oil and natural gas deposits are located in the Central Valley and along the coast, including the large Midway-Sunset Oil Field. Provided adequate resources are available, its development will decrease a lot of limits.

- **Population**

  The population of Arizona was 6587.653 Thousand in 2009, California was 36887.62 Thousand, New Mexico was 2007.315 thousand, Texas is 24770.65 thousand. The population of California and Texas is larger than that of Arizona and New Mexico. It also reasonably explains the situation of total energy consumption. There is a positive relationship between them.

- **Cities and towns**

  California has 482 incorporated cities and towns, of which 460 are cities and 22 are towns. Texas has three cities with populations exceeding one million. The more prosperous the city is, the more energy consumed.

- **Rivers**

  In terms of the development of hydroelectric generation, the conditions of water are essential. Hydro-electric power plants is a clean source of energy. The vast majority of rivers in California are dammed as part of two massive water projects: the Central Valley Project and the California State Water Project.

- **Nuclear power plants**

  California is also home to two major nuclear power plants: Diablo Canyon and San Onofre, the latter having been shut down in 2013. New Mexico have no nuclear power plants. The production of nuclear power in the four states basically fixed because of practical constraints.

- **Ecology**

  California's real gross domestic product is 1736901 million dollars in 2009. Texas is 1066437 million dollars. They both have an advanced economy. However, they adopted different tactics in energy.
  California pays attention to economic efficiency because of their abundant energy. Texas, by contrast, was concerned about the clean, renewable energy's comprehensive evaluation. That's their difference.

6 "Best" Profile Of Four States

In this part, we use Analytic Hierarchy Process (AHP) and gray comprehensive to build and standard about the economic, environmental and social effects of 7 energy sources. Then we use this standard to calculate a comprehensive score of each state and get the result of which state has the best profile in 2009.

First, we construct three judgment matrix respectively about energy model considering economic, environmental and social effects. Each element of matrix use nine number from one to nine to represents the relative importance between horizontal indicator and vertical indicator, and the reciprocal of number represent opposite meaning.

Table2: Judgment Matrix Considering Economic Effects

C_1	$b1_1$	$b1_2$
$b1_1$	1	3
$b1_2$	1/3	1

Table3 : Judgment Matrix Considering Environmental Effects

C_2	$b2_1$	$b2_2$	$b2_3$	$b2_4$
$b2_1$	1	1	1	1
$b2_2$	1	1	1	1
$b2_3$	1	1	1	1
$b2_4$	1	1	1	1

Table4 :Judgment Matrix Considering Social Effects

C_3	$b3_1$	$b3_2$	$b3_3$
$b3_1$	1	3	5
$b3_2$	1/3	1	3
$b3_3$	1/5	1/3	1

The variables in matrix are as following:

Table5: variables

$b1_1$	the rate of energy income
$b1_2$	unit cost
$b2_1$	impact on water environment
$b2_2$	impact on atmosphere environment
$b2_3$	impact on soil environment
$b2_4$	impact on social environment
$b3_1$	Renewability of energy
$b3_2$	Employment opportunities provided
$b3_3$	Degree of approval of the masses

Second, we calculate the product of each element of a row of matrix:

$$M_i = \prod_{j-1}^{n} b_{ij} (i = 1,2,3, \dots n)$$

Then we calculate the n square root of each row :

$$W_i = \sqrt[n]{M_i}$$

Normalize the vector to get the weight coefficient of each index:

$$W_i = W_i / \sum_{j-1}^{n} W_j$$

Third, we use gray comprehensive to compute the degree of correlation between each index and the optimal value.

Step1: Determine the comparison series(evaluation object) and reference series(evaluation criteria). It is assumed that the evaluation object is m. The evaluation index is n, and the comparison number and comparison series as follows:

$$X_i = \{X_i(R) \mid R = 1,2, \dots . n\}, (i = 1,2, \dots m)$$

Reference series:

$$X_0 = \{X_0(R) \mid R = 1,2, \dots . n\}, (i = 1,2, \dots m)$$

Step2: Determine the weights corresponding to the values of each index (using AHP)

Step3: Calculate the gray correlation coefficient:

$$\varepsilon_{0i} = \frac{\Delta(min) + \rho\Delta(max)}{\Delta_{0i}(k) + \rho\Delta(max)}$$

(ρ is resolution coefficient and range 0 to 1.)

Step4: Calculate the degree of grey weighted correlation:

$$r_i = \frac{1}{N}\sum_{k=1}^{N} \varepsilon_i\,(k)$$

According to the size of grey weighted correlation degree, the bigger correlation have the better result of the evaluation.

Finally, we get the correlation degree of each energy in field of economic, environment and society. The table below show the result:

Table5: The Correlation degree of each renewable and cleaner energy

Index	Natural gas	wind	hydroelectricity	Nuclear fuel	Solar thermal
Economic	0.78	0.68	0.63	0.63	0.66
Environment	0.57	0.87	0.75	0.75	0.96
Society	0.59	0.86	0.52	0.52	0.94
comprehensive	0.63	0.80	0.69	0.66	0.89

Then we multiply the usage of each energy in 2009 with corresponding comprehensive correlation for each state (Table6 show the usage of each cleaner and renewable energy in 2009). We compare the final score can find which stare have the best profile for use of cleaner, renewable energy in 2009.

$$S = \sum_{i=1}^{5} x_i * r_i$$

Table 6: The usage of each cleaner and renewable energy in 2009

State	Natural gas	Solar thermal	Nuclear fuel	wind	Hydroelectricity
AZ	376674	4732	320723	288	62730
CA	2391377	31397	332249	56996	272187
NM	247119	282	0	15095	2644
TX	3462210	819	434065	195454	10039

The final score show in Table7,and it is clearly that California have the best profile for use of cleaner, renewable energy in 2009.

Table 7: Final Score of Each State

AZ	CA	NM	TX
245762.3636	443732.8183	12254.61136	415087.3363

7 Prediction the Energy Profile for 2025 and 2050

7.1 Model

Because there are many complex factor to influence the change of energy profile in the time series of each state and linear regression with little variable can not get the satisfied result. Therefore, we propose to use Long Short Term Memory networks(LSTM)[6] to predict he energy profile of each state. LSTM are a special kind of RNN and are well-suited to predict time series given time lags[disambiguation needed] of unknown size and duration between important events.

7.1.1 Model Theory

Long short-term memory (LSTM)[7] units (or blocks) are a building unit for layers of a recurrent neural network (RNN). A RNN composed of LSTM units is often called an LSTM network. A common LSTM unit is composed of a cell, an input gate, an output gate and a forget gate. The cell is responsible for "remembering" values over arbitrary time intervals; hence the word "memory" in LSTM. Each of the three gates can be thought of as a "conventional" artificial neuron, as in a multi-layer (or feedforward) neural network: that is, they compute an activation (using an activation function) of a weighted sum. Intuitively, they can be thought as regulators of the flow of values that goes through the connections of the LSTM; hence the denotation "gate". There are connections between these gates and the cell.

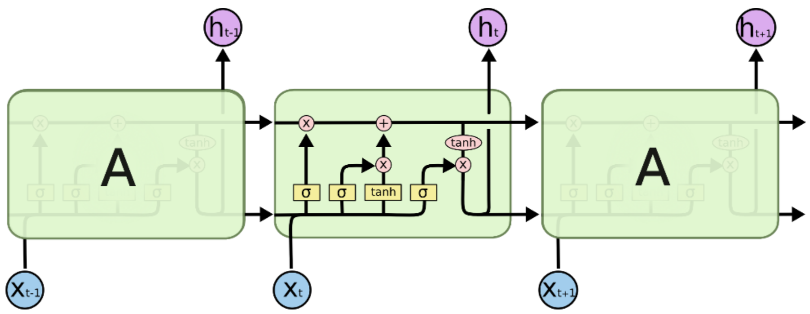

Figure 6. The Repeating Module in a Standard RNN Contains a Single Layer.

7.1.2 Establishment of the Model

We choose a common architecture of LSTM units is composed of a memory cell, an input gate, an output gate and a forget gate. In the equations below, each variable in lowercase italics represents a vector. Matrices W_q and U_q collect respectively the weights of the input and recurrent connections, where q can either be the input gate i, output gate o, the forget gate f or the memory cell c, depending on the activation being calculated.

- **LSTM with a forget gate**

Compact form of the equations for the forward pass of a LSTM unit with a forget gate

$$f_t=\sigma_g(W_f \ + \ U_f h_{t-1} \ + \ b_f \ )$$

$$i_t = \sigma_g(W_i x_t + U_i h_{t-1} + b_i)$$

$$o_t = \sigma_g(W_o x_t \ + \ U_o h_{t-1} + b_o)$$

$$c_t = f_t \ \text{o} \ c_{t-1} + i_t o \sigma_c(W_c x_t + \ U_c h_{t-1} + b_c)$$

$$h_t = o_t \ o \ \sigma_h(c_t)$$

To minimize LSTM's total error on a set of training sequences, iterative gradient descent such as back propagation through time can be used to change each weight in proportion to its derivative with respect to the error. A problem with using gradient descent for standard RNNs is that error gradients vanish exponentially quickly with the size of the time lag between important events. This is due to $lim_{n\to\infty} W^n = 0$ if the spectral radius of W is smaller than 1.[22][23] With LSTM units, however, when error values are back-propagated from the output, the error remains in the unit's memory. This "error carousel" continuous feeds error back to each of the gates until they learn to cut off the value. Thus, regular back propagation is effective at training an LSTM unit to remember values for long durations.

7.1.3 Model Implementation

We use TensorFlow Time Series, a collection of ready-to-use classic models (state space, autoregressive), and flexible infrastructure for building high-performance time series models with custom architectures, to train a LSTM model to predict energy profile, as we have defined it. Then, we take the related data from 1960 to 2009 as an input and set learning rate was 0.001,steps was 20000, batch size was 10.

7.2 Conclusion of the prediction

Follow the steps above, we get the result of 8 kinds of energy of each state in 2025 and 2050. we show the parts of result in the form of line chart.

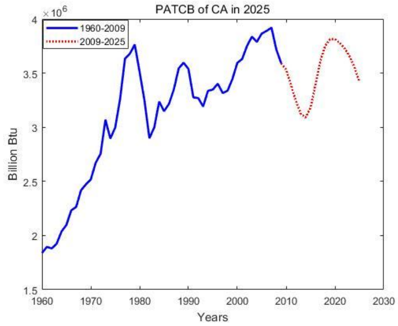

Figure 7:PATCB of CA in 2025

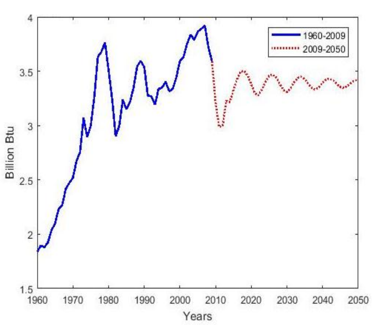

Figure 8: PATCB of CA in 2050

According to the line chart, the use of petroleum in CA will decrease firstly and then keep stable in the period of time. Besides, the rate of renewable and cleaner energy increase. For example, the rate of solar thermal will increase by 17% in 2025 and 33% in 2050 as well as the rate of wind-generated electricity will increase by 27% in 2025 and 37% in 2050. Table below show all the result of each state in 2025 and 2050

Table8: The 8 Kinds of Energy Profile in 2025

State	coal	petroleum	Natural gas	geothermal	Solar thermal	Nuclear fuel	wind	hydroelectricity
CA	3420500	96185	2380500	180990	38229	381410	78352	326650
NM	273640	293150	308820	766	2930	0	15236	2453
TX	5458100	165510	3932000	2770	1032	403460	365450	10125
AZ	556320	438730	398360	317	3611	297940	288	78806

Table9: The 8 Kinds of Energy Profile in 2025

State	coal	petroleum	Natural gas	geothermal	Solar thermal	Nuclear fuel	wind	hydroelectricity
CA	3419800	61970	2480900	86430	46959	444930	91920	393770
NM	275280	262630	268510	790	1955	0	13844	2481
TX	5164300	147150	3993100	2730	1045	399460	370790	25430
AZ	553040	385940	474330	327	5073	233470	288	71489

From the two table, it is clearly that the use of petroleum of each state reduce and the use of coal and natural gas of each state keep stable. The usage of wind energy of Texas is more than other state. Additionally the rate of using renewable energy of each state all has different degrees of increase.

8 Targets of Renewable Energy Use for 2025 and 2050

In order to determine renewable energy usage targets for 2025 and 2050 , We need to do energy planning for 2025 and 2050. In this section, we use **random boundary interval linear programming(RBILP)** to make an energy plan.

RBILP can be expressed as a planning method containing a series of interval parameters, function interval parameters and random distribution parameters. It can be solved according to the linear programming method provided by Hung[8,9]. In this method, transforming the initial RBILP model into two random programming submodels, one of is f^- ,and the other is f^+ .According to Huang's interactive algorithm, first, determine the f^- submodel and solve it, and then determine the f^+ submodel and solve it. The interval range of the decision variables and the floating of the target function is obtained.

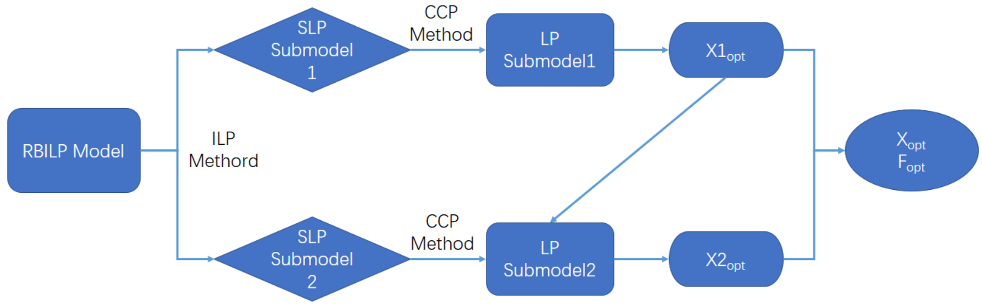

Figure9 : RBILP Model

To solve the two bottleneck energy investment planning problems (transmission and fluctuation) of renewable energy development, we propose a long-term investment planning model that can help analysts, investors and policy makers find out how to take full use of current and emerging technologies to support the development of renewable energy so that our energy infrastructure can be reformed to be cleaner in a long-term period. we use **random boundary interval linear programming(RBILP)** to solve this problem. objective function is a linear function which Calculated in part 1,and it is constrained by the conditions of the energy, environment and economy.

$$\text{Max}\, S = R \cdot X$$

S.t.

$$\begin{cases} PS_{iy}^{fp} + PS_{iy}^{wp} + PS_{iy}^{wh} + PB_{ijy} = PD_{iy}\eta \\ PS_{iy}^{fp} \le EC_{iy}^{fp} + CE_{iy}^{fp} \\ PS_{iy}^{wp} \le (EC_{iy}^{wp} + CE_{iy}^{wp}) \times TF_{iy} \\ PS_{iy}^{wh} \le \eta^{h} \times (EC_{iy}^{wh} + CE_{iy}^{wh}) \end{cases}$$

- **The planning results**

The results of capacity expansion for the fossil and renewable energy of each state are summarized in Table III and Table IV. The terms of these tables include AIFPC: Accumulated Installed Fossil Power Capacity; AIRPC: Accumulated Installed Renewable energy Power Capacity.

Table 10 : Energy Usage Targets for 2025

	AZ	CA	TX	NM
AIFPC(WM)	5929	14305	7551	2962
AIRPC(WM)	3091	4685	633	1088

Table 11: Energy Usage Targets for 2050

	AZ	CA	TX	NM
AIFPC(WM)	6649	16305	7551	3041
AIRPC(WM)	4125	7965	2633	1728

9 Actions for Energy Compact Goals

In order to meet the four states energy compact goals, each of the four states should increase their investment in renewable energy, increase wind turbines and solar generating sets. Here we have some suggestions for practical actions.

Establishing energy storage system

Four states jointly establish an energy storage system to store surplus clean power, and the stored energy is allowed to be traded among neighbouring states.

Corporate Tax Incentives

Corporate tax incentives include tax credits, deductions, and exemptions. These incentives are available in some states to corporations that purchase and install eligible renewable energy or energy efficiency equipment, or construct green buildings. In a few cases, the incentive is based on the amount of energy produced by an eligible facility.

Upgrading new energy generation equipment

Upgrading new energy generation equipment through equipment certification policies which require renewable energy equipment to meet certain standards, protect consumers from buying inferior equipment. These requirements not only benefit consumers; they also protect the renewable energy industry by making it more difficult for substandard systems to reach the market

Government loan programs

Government loan programs help customers overcome the financial barriers associated with renewable energy installations and energy efficiency improvements by providing low-cost financing, which helps spread capital costs over a longer period of time. State government loans are available to the residential, commercial, industrial, transportation, public and/or nonprofit sectors. Loan rates and terms vary by program; in some cases, they are determined on an individual project basis. Loan terms are generally 10 years or less. In recent years, the federal government has also offered loans for renewables and energy efficiency projects.

- **The planning results**

The results of capacity expansion for the fossil and renewable energy of each state are summarized in Table III and Table IV. The terms of these tables include AI-FPC: Accumulated Installed Fossil Power Capacity; AI-RPC: Accumulated Installed Renewable energy Power Capacity.

Table 12: Energy Usage Targets for 2025

	AZ	CA	TX	NM
AI-FPC(WM)	5929	14305	7551	2962
AI-RPC(WM)	3091	4685	633	1088

Table 13: Energy Usage Targets for 2050

	AZ	CA	TX	NM
AI-FPC(WM)	6649	16305	7551	3041
AI-RPC(WM)	4125	7965	2633	1728

10 Sensitivity Analysis

In order to evaluate our time series prediction model, we use the data from 1960 to 1999 to predict the data from 1999 to 2009 and compute the error between predictive value and real value. We define y is predictive value, y is real value and E is error rate.

$$E = \frac{\sum_{i=1}^{10} \frac{(y_i - y_i)}{y_i}}{n}$$

We choose the petroleum of CA as an example to evaluate our model. The table below show the predictive value and real value from 2000 to 2009.

Table14: Predictive Value and Real Value from 2000 to 2009

Value	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
predictive value	514894	539861	546258	552401	555497	556082	556670	556985	557018	557072
real value	512887	518202	529472	537085	562810	591290	602235	596215	578045	540273

In order to better express the result, the line char below compare the real line and predictive line from 2000 to 2009. Red line is predictive line and green line is real line.

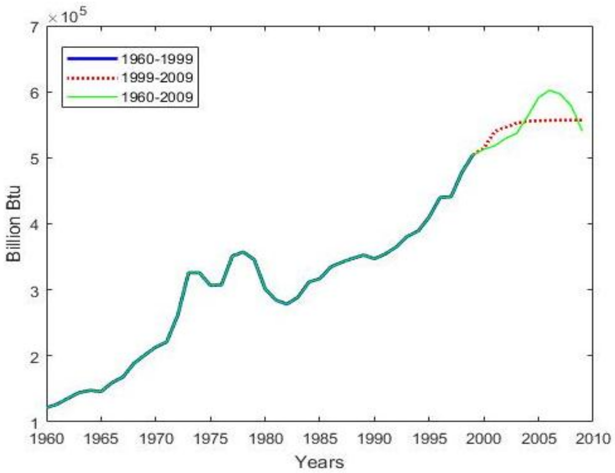

Figure 10: Compare the Real Line and Predictive Line from 2000 to 2009

According the result of predictive value, we calculate the error rate is 3.87%.

11 Further Discussion

Aiming at the further discussion about the energy problem of the four states, we work on two main aspects: sustainable energy development and energy security.

11.1 Sustainable Energy Development

- **Lower Environmental Costs**

  The arithmetic of environmental costs is composed of two parts: one is the decline of environmental quality and loss in other fields. The other is fees of pollutant drainage. We define them as " C_{loss} " and " C_{fee} ". lowering environmental costs should be realized as far as possible for the sustainable development of energy.

$$\min\ (C_{loss} + C_{fee})$$

- **Exploit Energy Reasonably**

  We should meet the current need without undermining future need. It means maintenance, rational use and improvement of natural resources. Therefore, the energy allocation and exploitation should be coordinated with the local ecological environment. Explore in accordance with the planned requirements.

$$n_{real}(\mathrm{k}, \mathrm{t}, \mathrm{a}) = n_{plan}(\mathrm{k}, \mathrm{t}, \mathrm{a})$$

  n_{real} is actual amount of energy use, n_{plan} is planned amount of energy. k means kind, t means time, a means area.

11.2 Energy Security

- **Balance Between Energy Supply and Demand**

  The balance of energy supply and demand consists of two parts: power balance and energy balance. Power refers to the power of the energy supply system here.

$$\sum_{i=1}^{n} P_n - P_b \approx P_c$$

$$E_1 + E_2 + E_3 - E_b \approx E_c$$

  $\sum_{i=1}^{n} P_n$ is total power of actual production, P_b is power loss in the process of production, P_c is power demand.

- **Collocate Energy Rationally**

Collocating Energy Rationally need the relationship among energy used is mutual standby. Also, we should consider energy replacement timely. Renewable energy is less polluted and cleaner than conventional energy. Using clean energy can not only help to reduce the pollution of energy consumption, but also alleviate the shortage of fossil energy. Besides, the utilization technology of renewable energy is no fully mature yet. The dependence on traditional energy is still stay in a high level, thus substitution of energy production’s form is also necessary. For example, replace oil and gas with coal oil and coal gas, replace natural gas with coalbed gas.

12 Strengths and Weaknesses

12.1 Strengths

- Our model of “3E” contains the factors of economy, environment and energy. There is lots of literature supporting it. And it also fits the reality.
- LSTM is good at solving the prediction of time series, and have better performance than other time series prediction model such as linear model and random Forest. In addition, LSTM can avoid the problem of gradient vanishing.

12.2 Weaknesses

- Our models are built on the basis of neglecting unimportant energy. Although the influence is small, there is still a deviation from the reality.
- Although LSTM perform well in time series prediction, but LSTM requires a large amount of data, 50 years data obviously too little. We have no adequate data to validate our model and our prediction result is not very ideal

13 Memo to the Group of Governors

To: Governors of California, Arizona, New Mexico, and Texas
From: Team # 75380
Date: February 12, 2018
Subject: Report on Four States' Energy Situation as of 2009

With the comprehensive analysis of our model, as described in the solution, we summarize that the total energy consumption and the rate of clean, renewable energy's use are both increasing annually. As for the development of each state in clean, renewable energy, we reach the following conclusions:

a) California's solar thermal energy and geothermal energy have the best development.

b) Texas' production of wind energy is maximal.

c) The percentage of renewable energy generation, New Mexico grows fastest. This is a good sign of renewable energy's development.

d) Arizona achieved a sustained and steady development of clean, renewable energy.

By predicting the future situation of the clean, renewable energy, coming to the following conclusions:

a) In the next few years, total energy consumption will increase constantly. But the rate of increase will slow down.

b) Clean and renewable energy has a greater role in production. The proportion of clean, renewable energy' production and consumption in all kinds of energy will increase. The increment will be fierce in the next few years, then, it will fluctuate for a period of time. Last, it will be stable.

c) Each of the four states can give priority to increase wind turbines and solar generating sets. Because solar energy and wind power can get the best comprehensive performance than other energy.

Four states' production of energy should be planned together. Our recommended goals for energy compact are:

a) Keep balance between the supply and demand.

b) Realize energy complementation among the four states.

c) Ensure the pluralistic development of each state's energy.

To promote the joint development of four states, some interstate energy source exchange projects sponsored by financial rewards can be conducted.

14 References

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