TITLE

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Abstract

The article analyzed and predicted the condition of energy usage in AZ, CA, NM, TX and put some suggestions on rational utilization of resources and environment protection. Part I. It used linear regression model to get the information about total amount and variation tendency of traditional energy and new energy. Secondly, considering CO_2, SO_2, NO_x, $PM_{2.5}$ and renewable as the indexes of the "best", using TOPSIS method ,it concluded that CA is the "best". Next, it used linear regression prediction and polynomial curve fitting to predict the probability values and the prediction intervals from 2025 to 2050. Part II.It take the lower prediction interval limit and the upper prediction interval limit as the goals for each state.Then,on the aspect of population, geography and industry; reduction pollution; and price of energy, it put forward 3 proposals to achieve the goals. Part III. It offered an memo which summarized all the results of analysis and predictions to governors.

Keywords: Polynomial Curve Fitting Regression Analysis Prediction TOPSIS Method Linear Regression

Contents

1 Introduction

Interstate compacts represent an opportunity for multi-state cooperation, reinforcing state sovereignty and avoiding federal intervention. Compacts enable the states in their sovereign capacity to act jointly and collectively, generally outside the confines of the federal legislative or regulatory process while respecting the view of Congress on the appropriateness of joint action. [1] Thus, states sometimes have interstate compacts for their own development. The Southern States Energy Board (SSEB), a multi-state regional organization, was committed to promote economic development and quality of life in the southern United States through innovations in energy and the environment. The California (CA) , Arizona (AZ), New Mexico (NM) and Texas (TX) four states were once members of this organization. [2]

2 Assumptions

1. Divide all types of energy into primary energy and secondary energy. We don't take secondary energy into consideration and regard all the amount of primary energy as total consumption (including the primary energy which convert to heat or secondary energy)

2. Define nuclear energy, hydrogen, wood and waste, biomass, geothermal energy, wind energy, photovoltaic and solar thermal energy are cleaner or renewable energy;natural gas, coal and petroleum aren't cleaner and renewable.

3.All the primary energy which is cleaner and renewable energy is consumed in the local state. In other words, the production of primary energy is equal to the total consumption of it.

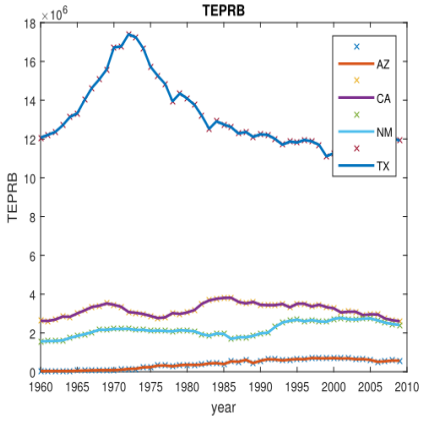
3 Notations

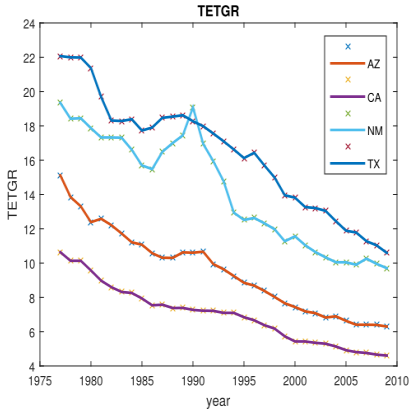
notation	description
x_A	traditional energy consumption in AZ
y_A	new energy consumption in AZ
x_C	traditional energy consumption in CA
y_C	new energy consumption in CA
x_N	traditional energy consumption in NM
y_N	new energy consumption in NM
x_T	traditional energy consumption in TX
y_T	new energy consumption in TX
t	years(from 1960 to 2050)

4 Part I

4.1 Part I A

In order to get the energy profiles of each state, we analyze TEPRB(The total energy production), TETGR(The total energy consumed per dollar of real GDP) and three kinds of energy consumption in four states.





From these graphes, we can see: 1.TX had the largest figures of TEPRB, and AZ had the smallest figures of TETRG. 2.The four lines of TETGR did not change a lot except for that of TX. 3.The TEPRB of TX peaked in 1990. 4.TX had the largest figures of TETGR, and CA had the smallest figures of TETGR. 5.The four lines of TETGR generally declined from 1977 to 2009.

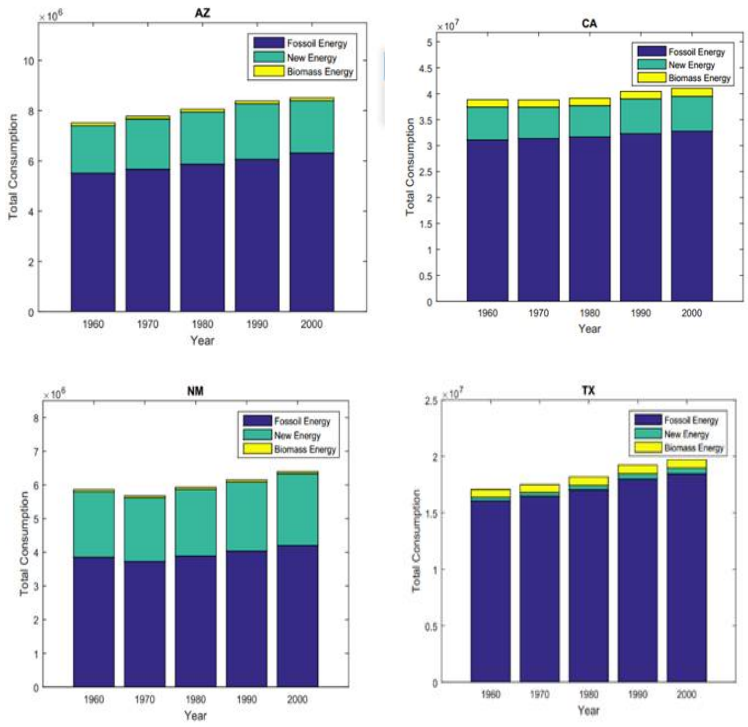
To conclude,

1.The total energy production of TX was the largest, and that of AZ was the smallest.CA and NM was moderate.

2.The total energy production did not change a lot in four states except TX,whose total energy production varied shapely around 1990.

3.The energy efficiency of CA was the highest, and that of TX was the lowest.AZ and NM was moderate.

4.The energy efficiency of each state rose up.



The four bar graphs above show the total consumption and the proportion of it of three kinds of energy in four states in nearly 50years.

From the four bar charts we can see: 1.The proportion of total energy consumption(for each state): fossil energy consumption >new energy and biomass energy consumption. 2.The proportion of new energy consumption of total consumption: NA> AZ>CA>TX. 3.The proportion of biomass energy consumption of total consumption: CA, TX> AZ >NM. 4.The proportion of fossil energy consumption of total consumption: TX>CA>AZ>NM.

4.2 Part I B

we use the linear regression to get the straight line of regression.

$$x_A = 22753.846t - 44372492.94$$

$$y_A = 9669.525t - 18972804$$

$$x_C = 50939.856t - 95852654.47$$

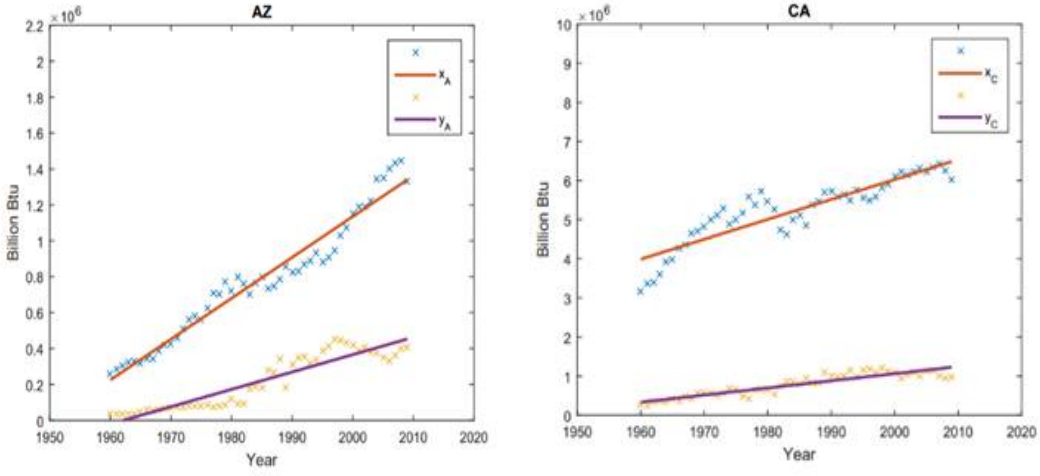
$$y_C = 18225.574t - 35388698$$

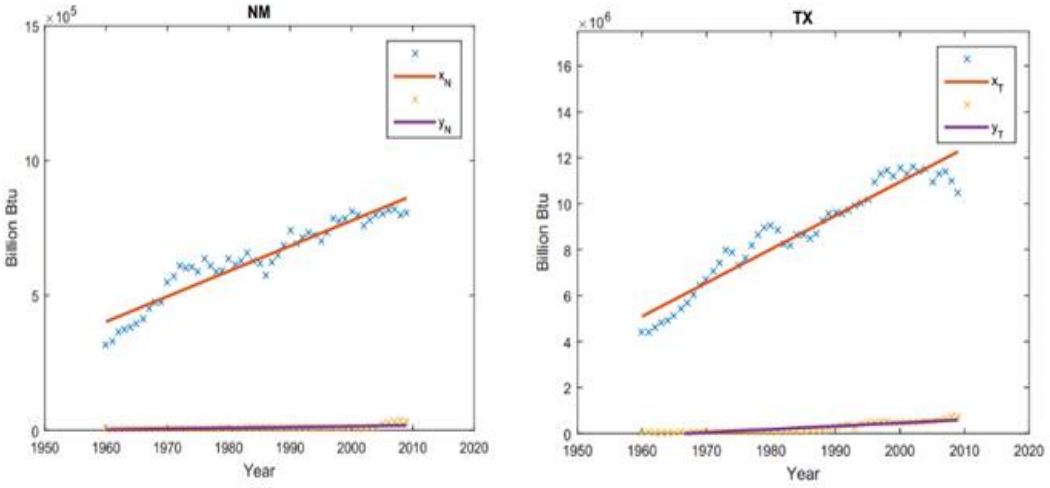
$$x_N = 9350.545t - 17924105.22$$

$$y_N = 327.076t - 638877.005$$

$$x_T = 146324.518t - 2.817 \cdot 10^8$$

$$y_T = 13796.265t - 27134846.62$$





We analyzed the four graphs, concluding the similarities and differences as follows:

Similarities:

1.The coefficient of t is positive in each graph, suggesting that both new energy and traditional energy consumption of each state increased from 1960 to 2009.

2.The coefficient of traditional energy is larger than that of new energy in each graph, representing the traditional consumption changing rate was higher than the new energy from 1960 to 2009.

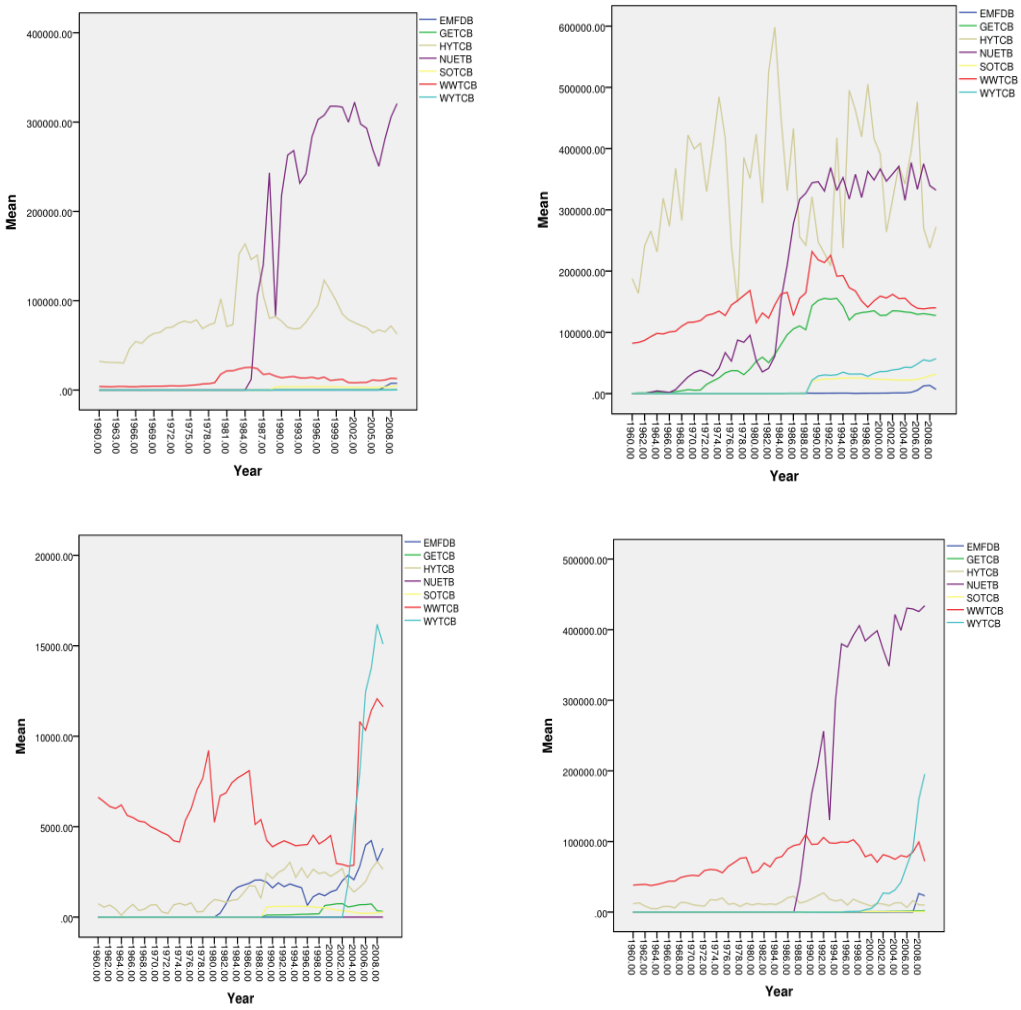
Differences:

1.The variable x of TX and CA is larger than that of NM and AZ . This indicates that TX and CA consumed more traditional energy than the other.

2.The slope of new energy in AZ and CA is higher than that of NM and TX. This indicates that the AZ and CA explore new energy more quickly than the other.

To take a better look at the consumption of each kind of new energy, we gathered the data of EMFDB, GETCB, HYTCB, NUTCB, SOTCB, WYTCB, WWTCB.

these 4 graphs below correspond AZ, CA, NM, TX(from left to right, from top to bottom)



After analyzing the four graphs, we found the similarities and differences as follows:

Similarities:

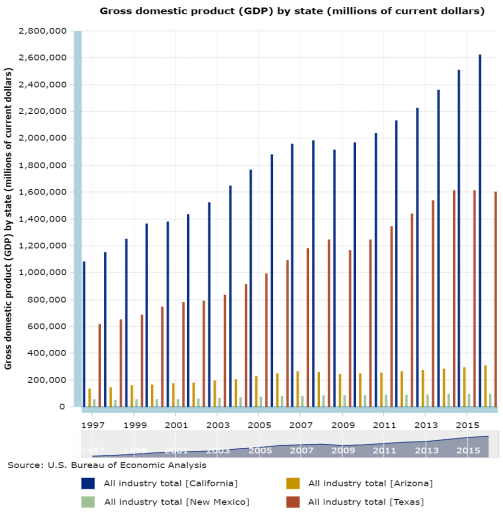
1.The nuclear energy was one of the main energy in AZ, TX and CA. The nuclear energy consumption rose up rapidly from 1985 to 2009.

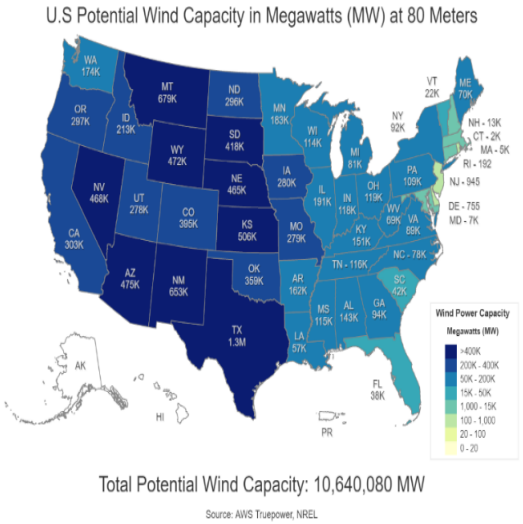
2.The hydroelectricity energy was one of main energy in AZ and CA from 1960 to 2009.

3.The wood waste energy was one of main energy in TX and NM. from 1960 to 2009.

Differences:

We ranked the population and the GDP of total industry in four states. And we use the GDP of total industry to define its degree of industry development.





In four states, between 1960 and 2009

1.Water resources: We found that AZ, TX and CA use more nuclear energy, but NM didn't choose nuclear as their primary energy. The reason why the major new energy consumption of AZ, TX and CA was nuclear energy is they were near water and had enough cooling resources.

2.Population: We can see from the pictures that CM has a larger population than others states. So, it was convincible that CM has the largest energy consumption.

3.Wind potential: We can know from the pictures that the TX and NM are abundant in wind potential. So, we thought this is the reason why their wind energy consumptions are large.

4.3 Part I C

4.3.1 Problem analysis

To find some indicators to value the extent of cleaner and renewable, we considered whether the energy is renewable and chose carbon dioxide emissions and the amount of pollutants they produced when they burned as the indexes, and evaluated the standard of cleaner renewable regard to energy consumption in the four states.

The principle is: Calculate the emissions of carbon dioxide, sulfur dioxide, nitrogen oxides, and PM2.5 in each state. The more carbon dioxide, sulfur dioxide,

nitrogen oxides, and PM2.5 emissions, the higher degree of not cleaner . The longer renew period, the higher degree of renewable. Then, use TOPSIS method to work out the sum of the five aspects as the total score. Finally, comparing these scores to find out which is the best.

4.3.2 Model hypothesis

1. Defining the emissions of CO_2, SO_2, NO_x, $PM_{2.5}$ as the indexes of measuring the standard of cleaner.

2. To avoid double-counting, we only considered the environment impact from the consumption of primary energy.

3. The environment of every states will be influenced merely by the energy they consumed in the states, and won t be impacted by their neighbors.

4. Geothermal, hydroelectricity, nuclear, solar and wind energy are all clean, which means no sulfur dioxide, nitrogen oxides and PM2.5 emissions when using and ignoring the carbon dioxide emissions from geothermal energy.

5. Because it's easy to remove the sulfur impurities from the natural gas in the process of development and the gas can be sufficient burning, we believed that the natural gas is free of sulfur dioxide and PM2.5.

6. Because the molecular composition of Wood and Waste is close to the biomass, we believed that their combustion has the same effect on the environment.

7. Because the renew period of oil, natural gas and nuclear energy is much longer than that of biomass, solar energy and wind energy. Therefore, we only use 0 and 1 to represent the level of renewable.

8. Suppose that the five aspects mentioned above share the same weight in the evaluation process.

4.3.3 TOPSIS method

Notations and description:

We evaluate these 5 indexes, C, S, N, P, R.Considering different economy in different state, we use C', S', N', P', R' to offset the effect because of different GDP.

Then, after normalization, (such as $c_A = C'_A/\sqrt{C'^2_A + C'^2_C + C'^2_N + C'^2_T}$),

Thus, we get the 5 values after normalization for each state.

$(c_A, s_A, n_A, p_A, r_A)$,$(c_C, s_C, n_C, p_C, r_C)$,$(c_N, s_N, n_N, p_N, r_N)$ and $(c_T, s_T, n_T, p_T, r_T)$.

Notation	Description	Notation	Description
C	total emission of CO_2	S	total emission of SO_2
N	total emission of NO_x	P	total emission of $PM_{2.5}$
R	total renewable index	C'	C/GDP
S'	S/GDP	N'	N/GDP
P'	P/GDP	R'	R/GDP
c	C'after normalization	s	S'after normalization
n	N'after normalization	p	P'after normalization
r	R'after normalization	D^+	distance from the Best Alternative
D^-	distance from the Worst Alternative	e	final index to evaluate

According to our assumptions, the higher these 5 values, the worse in the renewable and cleaner energy use.

So, the Best Alternative is (0,0,0,0,0),and the Worst Alternative is (1,1,1,1,1). and

$$D^+ = \sqrt{c^2 + s^2 + n^2 + p^2 + r^2}$$

$$D^- = \sqrt{(c-1)^2 + (s-1)^2 + (n-1)^2 + (p-1)^2 + (r-1)^2}$$

For one solution, the nearer to the Best Alternative and the farther from the Worst Alternative, the better it is.

so we use

$$e = \frac{D^-}{D^+ + D^-}$$

to evaluate whether one solution is best.

4.3.4 Model solving

We searched the data about emissions of each kind of energy, and use the renewable index we assumed.

	CO_2	SO_2	NO_x	$PM_{2.5}$	renewable
coal	888	10	4.8	2.2	1
petroleum	733	6	17.2	2	1
biomass	45	1.8	3	12.8	1
geothermal	0	0	0	0	0
hydroelectricity	26	0	0	0	0
nuclear	29	0	0	0	1
solar	85	0	0	0	0
wind	26	0	0	0	0
wood and waste	45	1.8	3	12.8	0
natural gas	499	0	3.2	0	1

Then, use Excel calculate every variable.

item	C	S	N	P	R
state					
AZ	963219683	7411123	12543181.3	2252002.2	1650931
CA	3898779870	22328670	70093007	9177148.9	6366030
NM	580679114	4598132	6631676.86	1374156.7	804733.6
TX	7120626101	48224605	113368247	15540275	10906542

item	C'	S'	N'	P'	R'
state					
AZ	3790.72599	29.16628	49.3633635	8.8626959	6.497196
CA	2068.9197	11.84889	37.1954324	4.8699298	3.378186
NM	7806.08585	61.81281	89.1498206	18.472828	10.81806
TX	6239.11961	42.25458	99.3336884	13.616448	9.556354

item	c'	s'	n'	p'	r'
state					
AZ	0.34821055	0.359084	0.33560247	0.3534023	0.401413
CA	0.19004794	0.145879	0.2528774	0.1941897	0.208713
NM	0.71705563	0.761016	0.60609525	0.7366087	0.668367
TX	0.57311641	0.520223	0.67533144	0.5429593	0.590416

item	D+	D-	e
state			
AZ	0.64884715	2.053421	0.75988793
CA	0.20261669	3.219202	0.94078685
NM	2.44997354	0.471687	0.16144478
TX	1.69856263	0.894471	0.34495148

As a conclusion, the ”best” usage of cleaner and renewable energy is CA.

4.4 Part I D

4.4.1 Problem analysis

The requirements of the subject is to predict the data from 2025 to 2050 on condition that the current policy won t be changed. Then, considering that from 1960 to 2009, there might be some changes and adjustments in policy, we must narrow the time range to make sure the policy is relatively stable. Therefore, we chose a period of time between 1990 to 2009 as a sample, and used them to predict the data we need.

We calculated the x and y energy of all States respectively, then, we used linear regression to analyze

First of all, we should do significance test.

Sig	AZ	CA	NM	TX
x	0.000	0.000	0.000	0.001
y	0.262	0.478	0.000	0.000

The results show that the y energy of AZ and x energy of AC cannot be predicted with the linear model under the F-test, so it s necessary to find some non-linear models. But others can be predicted by linear models. The results of SPSS are as

follows:

$$x_A = 36111.255t - 7109258761$$

$$x_C = 46254.607t - 86544016.79$$

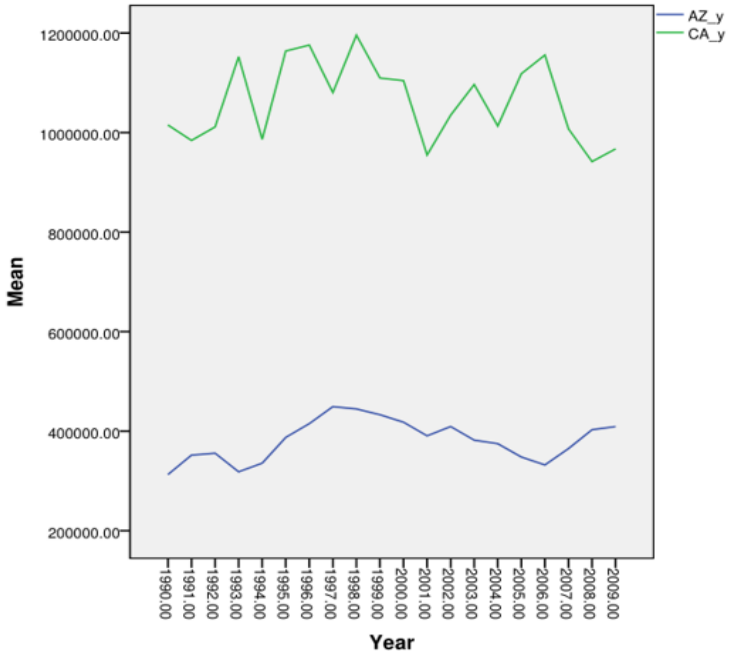
$$x_N = 5829.083t - 10886871.22$$

$$y_N = 1316.295t - 2617330.899$$

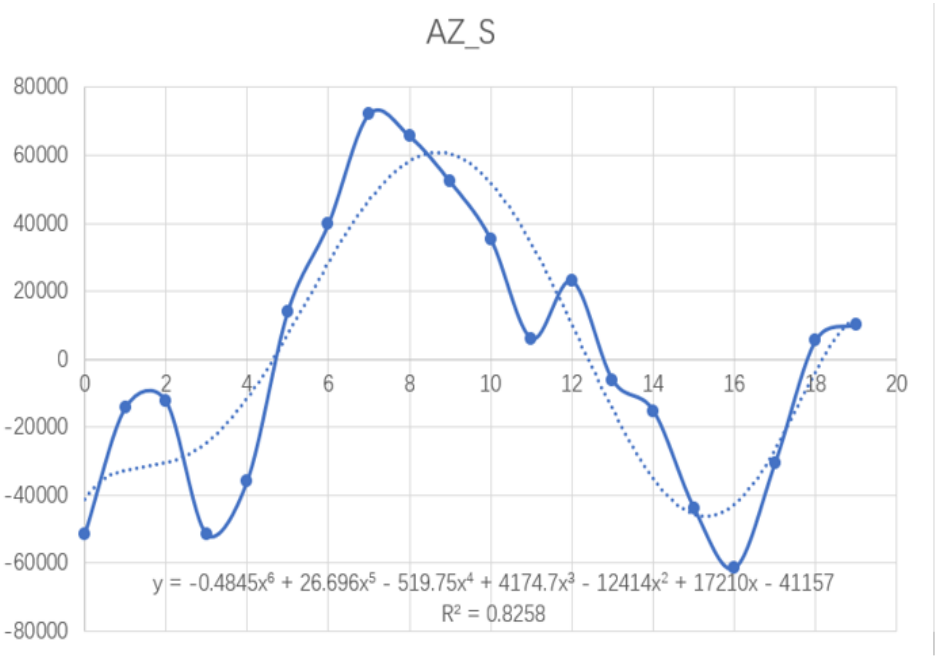
$$x_T = 82157.476t - 153500000$$

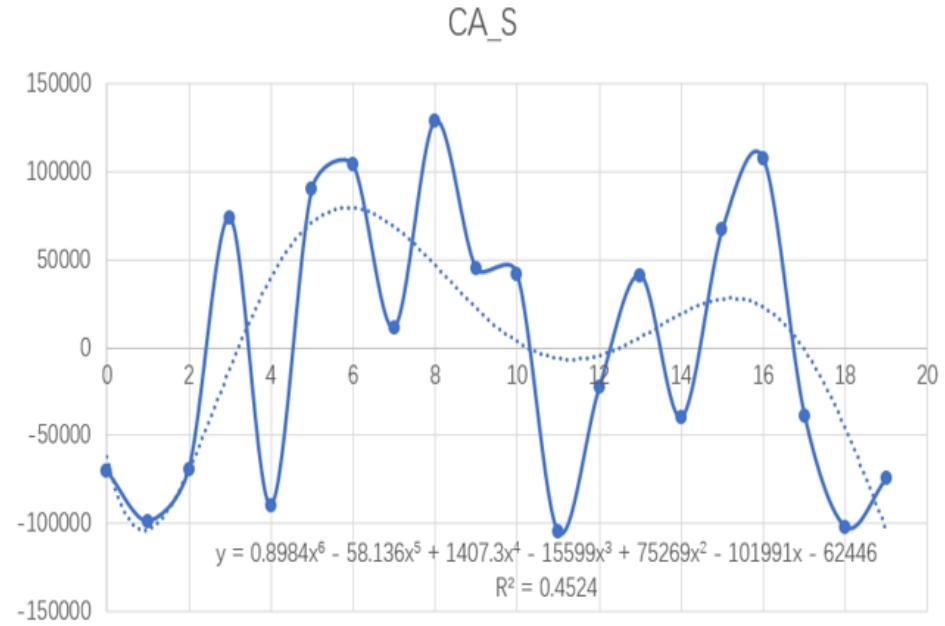
$$y_T = 18523.000t - 36544604.29$$

As for the y energy of AZ and y energy of CA, we made up the images according to the data.



The analysis of the image shows that the two images fluctuate drastically but with period regularity. In order to fit the data, we use the polynomial curve fitting.

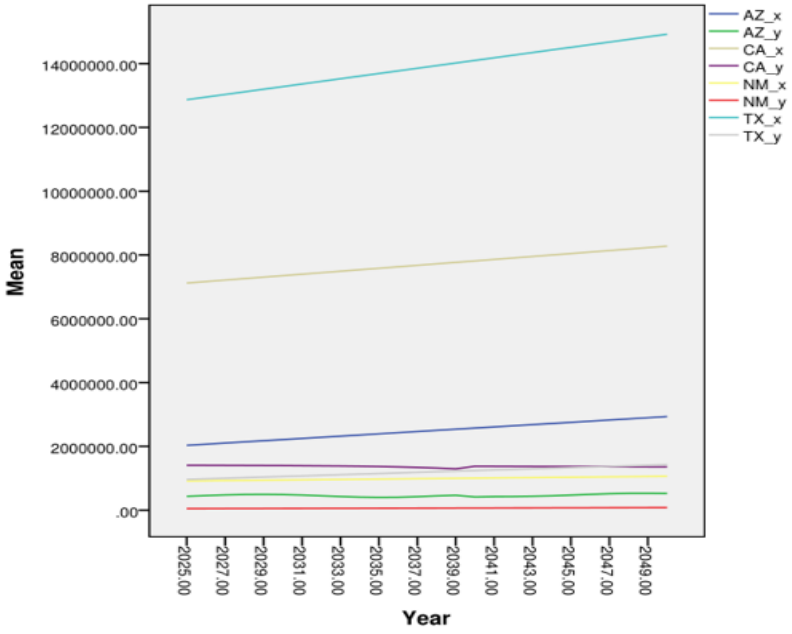




Regard the function above as a periodic function, and the period of it is 20, then, calculate the predicted value from 2025 to 2050.

	y_A	y_C		y_A	y_C
2025	435809.9	1409925.996	2038	449210.5	1321402.538
2026	458566.4	1407776.73	2039	466507.1	1295824.272
2027	478780	1405536.464	2040	414660.7	1378286.006
2028	492241.6	1403153.198	2041	424964.2	1376142.74
2029	496089.2	1400543.932	2042	428982.8	1374074.474
2030	489394.8	1397580.666	2043	436795.4	1372029.208
2031	473399.4	1394083.4	2044	451660	1369971.942
2032	451407	1389801.134	2045	472341.6	1367880.676
2033	428323.5	1384402.868	2046	495098.2	1365731.41
2034	409847.1	1377458.602	2047	515311.8	1363491.144
2035	401313.7	1368427.336	2048	528773.4	1361107.878
2036	406189.3	1356642.07	2049	532620.9	1358498.612
2037	424216.9	1341291.804	2050	525926.5	1355535.346

According to the linear regression and polynomial model, we got the predictions from 2025 to 2050.



5 Part II

5.1 Part II A

According to the analysis above, we can make the target of energy consumption. Considering that the four states should be more environmentally friendly, they'd better reduce fossil fuel combustion and increase the consumption of cleaner renewable as far as possible. Therefore, in the prediction internals we get already, when x and y approaching the x_2 and y_1 respectively, we can get the most satisfying condition. Thus, we choose the values of x_2 as the targets for renewable energy consumption and y_1 as the targets for fossil fuel consumption.

5.2 Part II B

On the aspect of population, geography and industry; emissions of pollutants and the price of energies, we put forward three suggestions.

5.2.1 Action 1

First, we assume that energy consumption is equal to the energy production.

According to the conclusion of task B of part I, we have suggestions as follows:

1. Since it was a traditional way for TX, CA and AZ of consuming nuclear energy and in these states nuclear infrastructure facilities were well-built, it could make it easy for these three states to continue following its traditional pattern (using nuclear power the most).

2. Another widely used new energy in CA and AZ was hydroelectricity. CA and AZ were rich in hydroelectricity. As a result of it, we suggest the two states also develop hydroelectricity.

3. The major used new energy in NM was wood waste and wind energy. NM was abundant in wind potential. In view of it, we suggested NM develop wind energy.

5.2.2 Action 2

Based on the normalized data obtained from problem C in Part 1, we can find that the largest emissions of NM and AZ was SO_2 and the largest emissions of CA and TX was NO_x.

1.From the maps that described the major sources of emissions, we found that SO_2 emissions primarily from burling coal and the nitrogen oxides emissions mainly from burling oil. So, we recommended AZ and NM to reduce the coal consumption and CA and TX to reduce the oil consumption.

2.According to the data in task C and the following tables, we can find more precise conclusions.

	CO_2	SO_2	NO_x	$PM_{2.5}$	renewable
coal	888	10	4.8	2.2	1
petroleum	733	6	17.2	2	1
biomass	45	1.8	3	12.8	1
geothermal	0	0	0	0	0
hydroelectricity	26	0	0	0	0
nuclear	29	0	0	0	1
solar	85	0	0	0	0
wind	26	0	0	0	0
wood and waste	45	1.8	3	12.8	0
natural gas	499	0	3.2	0	1

We use the data in tables above and the data provided in excel to calculate the source of SO_2 emissions from AZ and NM. Take AZ as an example: We multiplied one kind of energy consumed by AZ with SO_2 emissions produced by burning this energy per unit. Then we obtained the total SO_2 emissions from this type of energy. Finally, we worked out the main causes of emissions. Similarly, we calculated the data related to SO_2 in NM, as well as the data related to NO_x in CA and TX.

Then, we deleted the zero terms, and create two tables:

1. (the emission of SO2 from different energy)

Item	CLTCB	PATCB	EMFDB	WWTCB
AZ	4132600	3241600	13700	23200
NM	3061600	1508700	6900	20900

From this chart, we can see that AZ and NM should decline the use of CLTCB and PATCB.

2.(the emission of NO_x from different energy)

	CLTCB	PATCB	EMFDB	WWTCB	NGTCB
CA	252000	61748000	21000	420000	7652000
TX	7190000	94813000	70000	216000	11079000

From the chart, we can see that CA and TX should decline the use of PATCB and NGTCB.

5.2.3 Action 3

In order to make the state which has the worst environment and less GDP to achieve the goals we made above, it is critical to consider the energy changing among four states. Firstly, we make some hypothesis:

1. With the help of cables and pipelines, the transportation cost regard to electricity and gas among these states can be ignored.

2. The price of electricity in different states are the same and there is no difference on the export prices of electricity between any two states.

3. The electricity they purchased from other states influenced their environment little.

We take coal, petroleum, natural gas and wood and waste into consideration, and suppose the price of electricity is the same as 2009.

	CLTCD	NGTCD	PATCD	WWTCD	ESTCD
AZ	1.82553	6.38089	17.18042	7.83257	28.00765
CA	2.66232	6.37809	17.71125	3.9352	38.90736
NM	1.9015	5.95016	17.64435	9.83465	23.96256
TX	1.89361	4.65043	15.07646	3.62018	29.20894

CLTCD NGTCD PATCD WWTCD ESTCD AZ 1.82553 6.38089 17.18042 7.83257 28.00765 CA 2.66232 6.37809 17.71125 3.9352 38.90736 NM 1.9015 5.95016 17.64435 9.83465 23.96256 TX 1.89361 4.65043 15.07646 3.62018 29.20894

According to the data, we have some suggestions:

1. AZ, NM and CA can purchase natural gas from TX to get cheaper resources.

2. CA and TX can sell wood and waste to other states if the sum of transportation cost and the export price of CA and TX is lower than the price in other states.

3. NM should better reduce the consume of wood and waste and natural gas which is relatively cheap can be a substitution.

4. It s a greater choice for CA to buy cheaper electricity from other states and decrease the consumption generated in the state.

6 Part III

MEMO

To: The group of Governors
From: Our team
Date: 13 February
Subject: Analysis and prediction of energy usage in CA, AZ, NM and TX

Mr./ Mrs. Governor, we are writing to report you our key findings in these four days of analysis and prediction of energy usage in four states. We divided the findings into two parts.

In the first part, we concluded state profiles as of 2009: first of all, the total energy consumed per dollar of GDP generally declined in each state, indicating that the increase of energy efficiency of four states. Next, the total energy consumed per dollar of GDP of CA, NM and AZ has no significant changes. Besides, the traditional energy and new energy consumption of each state rose up. TX was the state consumed the largest of traditional energy, oppositely was NM. Then, CA, TX and NM mainly consumed nuclear energy; while NM mainly consumed waste wood energy. Finally, CA appeared to have the best profile for use of cleaner, renewable energy in 2009.

In the second part, we predicted the best profile and set goals in the absence of any policy changes by each governor s office from 2025 to 2050. We also predicted new energy and traditional energy consumption of each state with the 95% possibility in a range from 2025 to 2050.

7 Strengths and weaknesses

7.1 Merits

1.To analyze the data of 4 states from 1960 to 2009, we use the linear regression to find the quantity and the tendency with the time. All the linear model has passed significance test(significance level $\alpha = 0.01$), which means our model is accurate and reasonable.

2.We searched 5 indexes and their data, and next used the TOPSIS method to evaluate which is the best in cleaner and renewable energy usage. It could make our result objective and rational.

3.In the prediction, we predicted both the most likely quantity and the prediction intervals(significance level $\alpha = 0.05$). Consequently, the governs may attain more

data they want.

7.2 Defects

1.In the TOPSIS method, we failed to confirm the weight of 5 indexes because of the lack of data.

2.In the prediction model, we used the polynomial to fit the data which cannot be fit by linear model. We did not test other curves to achieve the best results.

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6.The information about Southern States Energy Board (SSEB)

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