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**2018**  
**MCM/ICM**  
**Summary Sheet**

## Evaluation and Forecast for Renewable Energy towards a Sustainable Future

### Summary

Due to the explosive development of the technology, the society and industry are facing more and more energy pressure for the conflict of energy dilemma and increasing global energy demand. Besides, unrestrained exploitation and incontinent use of fossil fuels results in serious global environmental issues.

Therefore, it is of great importance to explore the evolution of energy evolution and make forecasts, which reveal current energy situation and help governors to take plausible and effective measures.

In this paper, we mainly focus on four particular states: California (CA), Arizona (AZ), New Mexico (NM) and Texas (TX). Firstly, we have a deep sight into the given data, figuring out the inner relationship among 605 variates. Then based on the energy profile of each state, we provide a fancy visualization to show the evolution of energy utilization from different perspectives.

Secondly, we propose a novel Multiple Self-Adaptive Regression model (MSAR) to characterize the evolution of four states' energy profile between 1960-2009. Using MSAR, we capture eight major patterns in energy evolution process, which clearly explains how each kind of energy has evolved, as well as showing the differences and similarities of four states.

Thirdly, from different standpoints, we design six reasonable indicators to assess the usage of cleaner & renewable energy in four states. Then, we employ AHP to integrate these indicators and develop a more comprehensive metric Green Index (GI), finding that California ranks first in green energy utilization.

Furthermore, based on ARIMA, we design a revised ARIMA model with Development Index (DI-ARIMA) for predicting energy consumption. The key of DI-ARIMA lays on the special Development Index which characterizes the population, industry, geography and climate of each state.

Finally, challenging but practical green energy targets are determined according to our analysis and predictions. We also provide some detailed suggestions for each state and plausible cooperation compact for Western Interstate Energy Compact.

In the end, we make sensitivity analysis and discuss strengths and weaknesses.

**Keywords:** energy consumption; self-adaptive; evolution pattern; regression

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# 1 Introduction

## 1.1 Background

In the past fifty years, traditional energy sources such as coal and petroleum have played an essential role in industrial manufacture and residents' daily life, but released harmful gases and polluted environment. Recently, great efforts are made to replace them by alternative sources or renewable sources, such as wind, solar and geothermal energy, which is an effective way of sustainable development.

As we know, the United States is a highly industrialized country whose industrial sector accounted for about one-third of the total U.S. energy consumption in 2016 [1]. To better promote efficient use of resources and cleaner energy, energy policy are decentralized to the state level in many aspects. In particular, the Western Interstate Energy Compact (WIEC) is an interstate compact among 12 states. It was created to aid in the development and management of new energy technologies for the sake of all member states, which could then benefit the rest of the country in terms of economic growth and energy sustainability [2].

There are plentiful possible influential factors which contribute to the energy consumption such as geography, industry, population and climate. In consequence, it is necessary to analyze how the energy profile of each state has evolved in the past, and develop a model which could fit the historical data well and give reasonable and reliable predictions, which is extremely helpful for future policy making.

## 1.2 Restatement of the Problem

To help determine appropriate compact goals, we are not only required to analyze the evolution of four states' energy consumption but also interpret possible influential factors in a readily comprehensible way. Moreover, the prediction model and metrics are required for predicting energy profile for each of four states and evaluating the four states' usage of cleaner and renewable energy sources. In the end, we are asked to decide plausible compact goals and find solutions or measures should be taken by four states to meet the goals.

More specifically, the problem can be summarized into four parts as follows:

- Create an energy profile for each of the four states utilizing 50 years of energy data provided and design a model to depict the changes of energy profile.
- Analyze and interpret the influential factors of energy consumption. Compare the similarities and differences of four states and illustrate the variation tendency.
- Predict the energy profile based on the historical evolution of energy use and influential factors considered above.
- Develop metrics which measure the degree of renewable energy usage for states and evaluate the results in 2025 and 2050.
- Determine proper renewable energy usage targets for 2025 and 2050, and propose several actions the states might take to meet the compact goals.

### 1.3 Overview of Our Work

To address the problems above, we firstly figure out the meanings of given energy variables and the relationships between them before preprocessing the data in Section 3. Then we define and justify energy consumption profile that contains three parts according to the given data and concerned problems. After that, a fancy visualization is given in exhibiting our energy profile of 50 years.

Besides, generated energy profile indicates existing complex relationships between energy consumption by fuels and sectors, which makes it difficult to regress manually. However, we find that there are several patterns in energy consumption evolution in Section 4. In consequence, we propose a novel Multiple Self-Adaptive Regression model (MSAR), which is designed to model evolution process and self-adaptively switch the regression models.

Furthermore, a Development Index ARIMA model (DI-ARIMA) is proposed based on ARIMA [3] for the prediction of energy consumption. Development Index considers influential factors which measures the influence of population, industry, geography and climate on energy profile evolution. It is evaluated by 2010-2015 energy statistics.

In this paper, the usage of cleaner & renewable energy is an important focus. We pay attention to the prediction results and analysis of green energy usage. After that, Green Index (GI) is developed with six sub-metrics weighted by AHP which measures different aspects of green energy consumption.

Finally, challenging but practical green energy targets are determined based on our model and predictions. We put forward some specific suggestions for each state and plausible cooperation compact for WIEC. The framework of our work is illustrated in Figure 1.

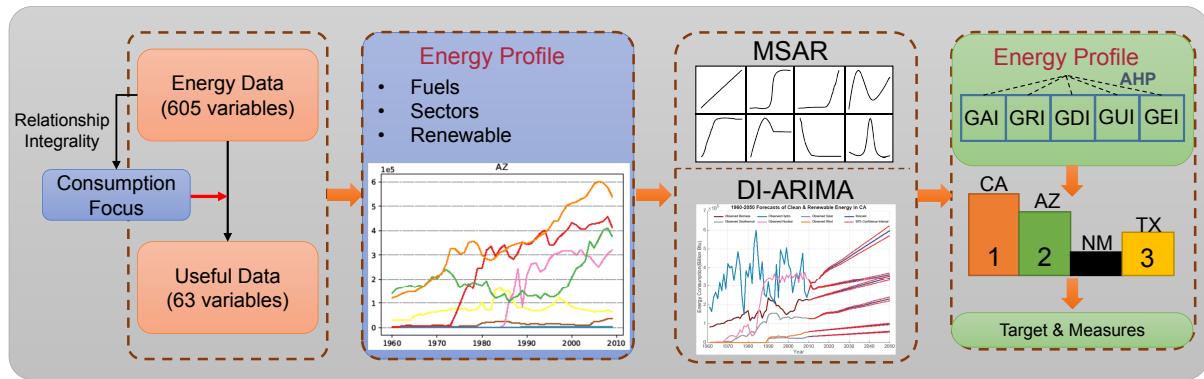


Figure 1: Overview of our work

## 2 Assumptions and Notations

### 2.1 General Assumptions

- The energy profile only involves three parts: energy consumption by sectors, fuels and cleaner energy consumption. Other variables provided are not considered for less significance, which is explained in Section 3.1.

- The policy is time invariant during the prediction. In other words, unexpected policy changes are not taken into consideration.
- Energy consumption data are time relevant and dependent. This is because models can not be easily formulated if the data are not reliable on time sequence.

## 2.2 Nomenclature

In this paper we use the MSN nomenclature following energy department. The relationships used in this paper are extracted according to official report [4] and displayed in Table 1. Other notations in our models are described later accompanying the equations.

Table 1: MSN codes and relationships used in this paper

|             | Commercial | Industrial | Residential | Transportation | Total |
|-------------|------------|------------|-------------|----------------|-------|
| Biomass     | BMCCB      | BMICB      | WDRCB       | EMACB          | BMTCB |
| Geothermal  | GECCB      | GEICB      | GERCB       | None           | GETCB |
| Hydro       | HYCCB      | HYICB      | None        | None           | HYTCB |
| Nuclear     | None       | None       | None        | None           | NUETB |
| Solar       | SOCCB      | SOICB      | SORCB       | None           | SOTCB |
| Wind        | WYCCB      | WYICB      | None        | None           | WYTCB |
| Coal        | CLCCB      | CLICB      | CLRCB       | CLACB          | CLTCB |
| Natural gas | NGCCB      | NGICB      | NGRCB       | NGACB          | NGTCB |
| Petroleum   | PACCB      | PAICB      | PARCB       | PAACB          | PATCB |
| Total       | TECCB      | TEICB      | TERCB       | TEACB          | TETCB |

Note 1: BMCCB = EMCCB + WWCCB, BMICB = EMICB + EMLCB + WWICB

## 3 Energy Consumption Profile

In this section, we analyze historical data of four states and generate comprehensive energy profile based on provided data. Firstly, we classify and weight 605 variables, giving the concrete definition of energy profile in this paper in Section 3.2. Based on defined energy profile, the statistics of 50 years' data involving energy consumption by sector, fuel and cleaner, renewable energy consumption trends are displayed and analyzed in Section 3.3 and 3.4 respectively.

### 3.1 Analysis of Provided Data

It is crucial to figure out the meanings of given energy variables and the relationships between them. To gain a comprehensive view of energy data, we refer to [4] and analyze the potential relationships. The relationships considered in this paper is shown clearly in energy flow chart (Figure 2, modified according to [1] provided by Lawrence Livermore National Laboratory).

- **Energy Consumption by Sector:** There are five sectors consuming energy in total, including Transportation, Commercial, Electric, Industrial and Residential

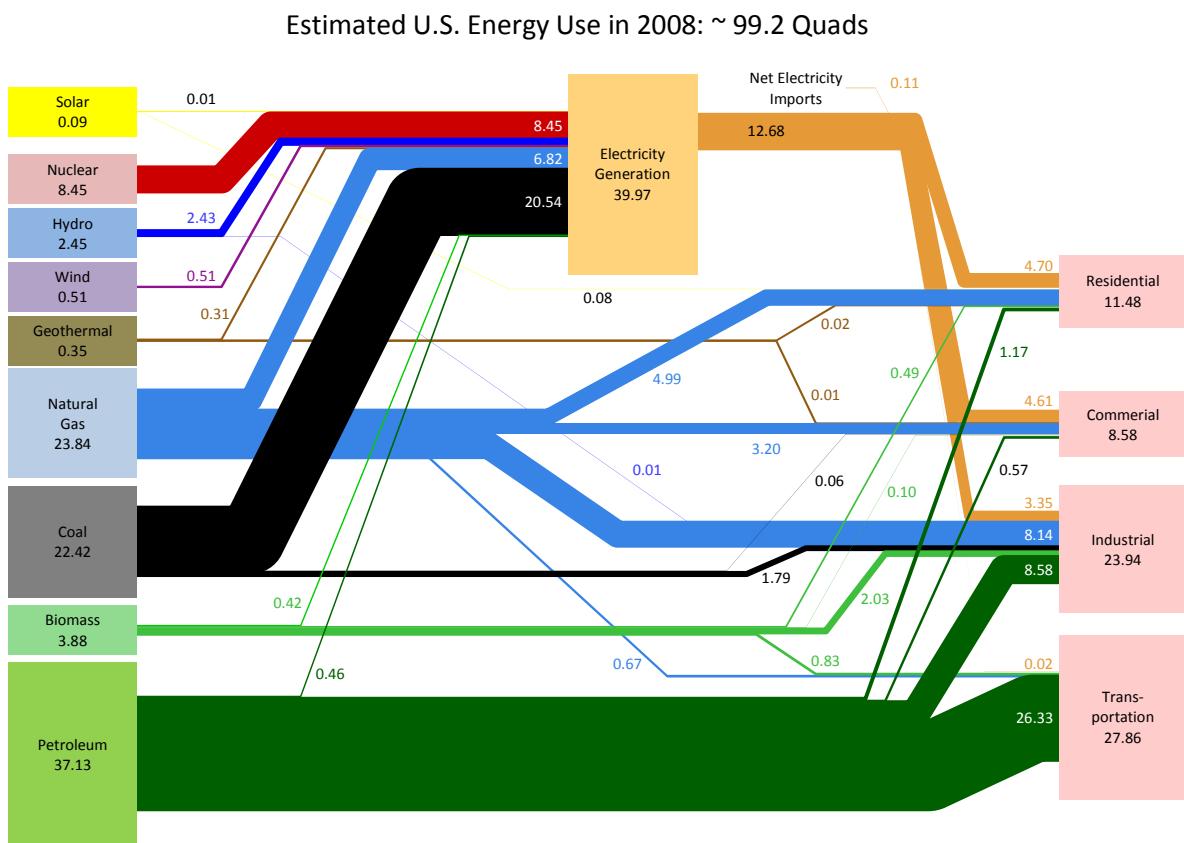


Figure 2: Energy flow chart of the United States [1]

(MSN Alphabet Order). Electric is different from others sectors for the generated electricity is consumed by other sectors, which is important and should be considered specially [5].

- **Energy Consumption by Fuel:** There are nine fuels consuming energy in total, including Biomass, Geothermal, Hydro, Nuclear, Solar, Wind, Coal, Natural gas and Petroleum (MSN Alphabet Order).
- **Traditional and Cleaner & Renewable Energy:** These fuels are categorized into traditional energy (Coal, Natural gas and Petroleum) and cleaner & renewable energy (Biomass, Geothermal, Hydro, Nuclear, Solar, Wind). Cleaner energy and renewable energy energy are slightly different. Nuclear power is cleaner but not renewable energy, other five kinds of energy are both cleaner and renewable energy.
- **Unconsidered Variables:** There are 605 variables provided in total and it is impossible to deal with them in an equation, which results in both complexity and ineffectiveness. So we select and aggregate important factors in the context of the problem and at a level useful to the decision makers. The influential factors are displayed as follows:
  1. **Production:** In this paper, we mainly concentrate on the energy consumption problem rather than production. Although there is a relationship between production and consumption to some extent, production data are deficient and not considered.

2. **Export, import and loss:** Even if export, import and loss are factors reflecting economy and energy usage, the deficiency of provided data and results in non-consideration.
3. **Conversion factor:** Standard Btu is adopted in our work, for its universality and effectiveness in many studies relevant to energy. As a result, conversion factor and other non-uniform units are not taken into account.
4. **Detailed categories of nine fuels :** We adopt the categories used by Department of Energy in U.S [6], which don't concern more detailed categories in product level. such as different kinds of products of petroleum or different origin of biomass.

### 3.2 Energy Profile

As a result, to simplify the question, we firstly consider these two essential parts and leave others behind. Besides, traditional and renewable sources are taken into account to discuss the development of cleaner and renewable energy in four states.

In this paper, energy profile are defined as:

- Energy consumption by **five sectors** (**Transportation, Commercial, Electric, Industrial and Residential**).
- Energy consumption by **nine fuels** (**Biomass, Geothermal, Hydro, Nuclear, Solar, Wind, Coal, Natural gas and Petroleum**).
- Traditional, cleaner & renewable and total energy consumption.

### 3.3 Energy Consumption by Sector

Common sense tells us that energy consumption varies from sector to sector, and that different measures should be taken.

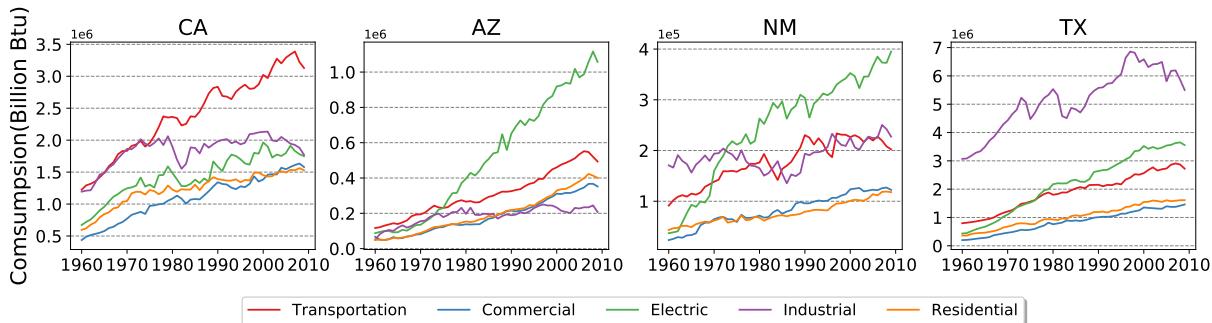


Figure 3: The historical trends of energy consumption by different sectors

The historical trends of energy consumption by different sectors in four states are illustrated in Figure 3, from which we can reach following conclusions:

- The energy consumption are increasing dramatically in all of the four states.

- The energy consumption of different states are varied greatly in both the amount of energy consumption and the distribution of different sectors due to the different structure of industry, economy and populations.
- As for Arizona and New Mexico, electric consumption has been boosting in the past thirty years, and overpassed other consumption greatly in 2009. Transportation and industrial consumption are the main consumption in California and Texas respectively.

### 3.4 Energy Consumption by Fuel

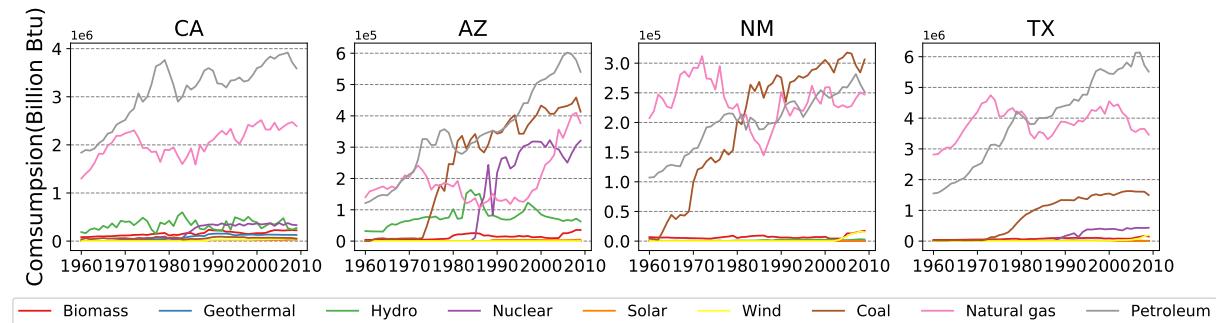


Figure 4: The historical trends of energy consumption by different fuels

Similar to sector, fuel is also an essential cue for energy consumption. The historical trends of energy consumption by different fuels during fifty years in four states are shown in Figure 4. By observing the sub-figures, we can conclude:

- Overall, clean sources still account for a small proportion (less than 5%) in the total energy sources, even though that there has been a persistent promotion in recent years.
- Fossil fuels are still playing an essential role in all of the four states. However, the consumption of petroleum is decreasing gradually.
- The variation of distribution and trends in four states exists. Petroleum and natural gas are main energy sources in California. Coal and natural gas are main sources and increasing dramatically in Arizona. As for New Mexico and Texas, traditional energy consumption are evenly distributed.

## 4 Energy Consumption Pattern

In this Section, we fully discuss our Multiple Self-Adaptive Regression model (MSAR) for solving Problem 1.2, which is designed for complex relationship in energy consumption.

Firstly, we formulate a simple but fundamental relationship between consumption by sector and fuel in Section 4.1 that is the basis of following MSAR model. Secondly, MSAR model are discussed in Section 4.2. Then the model is applied in the establishment of evolution patterns in 4.3. Finally, we analyze the results and successfully leveraging model to find discontinuity in evolution due to policies.

## 4.1 Fundamental Relationship between Sector and Fuel

As illustrated in Figure 2, there is a fundamental relationship between sector and fuel in terms of energy consumption shown in Equation (1).

$$\mathbf{S}(t) = \mathbf{W}_{\text{egb}}(t) \cdot \mathbf{F}(t) \cdot \mathbf{W}_{\text{ecb}}(t) + \mathbf{W}_{\text{oob}}(t) \cdot \mathbf{F}(t) \quad (1)$$

Where  $\mathbf{S}$  denotes different kinds of sectors in consuming energy such as residential and industrial sectors,  $\mathbf{F}$  denotes different kinds of fuels,  $\mathbf{W}$  denotes transition matrix from fuels to sectors and  $t$  denotes that the sectors, fuels and transition matrix are time variant.

In particular,  $\mathbf{W}_{\text{egb}}$  represents the matrix for electricity generation by fuels,  $\mathbf{W}_{\text{ecb}}$  represents the matrix for electricity consumption by the other four sectors, and  $\mathbf{W}_{\text{oob}}$  represents the matrix from fuel energy consumed by four sectors (without electric).

It is worthy to notice that transition matrix  $\mathbf{W}$  has practical meaning, which reflects the components of energy consumed by different sectors. For instance, in 2009, natural gas occupies 3.6% of the total energy consumption by transportation sector.

## 4.2 Multiple Self-Adaptive Regression

### 4.2.1 Multiple Regression

From Section 3, we know that the evolutions of different variables are different and follow their own rules. Moreover, the transition weights show the development and dependence. In consequence, to depict the complex relationship and model the energy consumption profile evolution, we propose a novel Multiple Adaptive Regression model (MSAR), which adopts different regression according to the patterns.

MSAR is a generic and effective solution for multiple variables fitting, especially for those cases that variables are weakly correlative. For instance, in energy consumption, the only relationship is that total amount is equal to the summation of each part (e.g. Total consumption by electric is equal to the summation of nine fuels energy consumed by electric for electricity generation). However, different parts seem independent<sup>1</sup> from each other. In addition, different variables seemingly obey different variation trends.

In consequence, to characterize the complex and variable-sensitive relationships over time, we manually explore the patterns at first. Then different regression models are chosen for different patterns.

### 4.2.2 Self Adaptivity

Multiple regression has a fatal weakness, that is, it is difficult to implement for the heavy calculation burden to analysts. To address this problem, we propose a self-adaptive solution, which finishes auto-regression and automatically selects patterns by computer softwares.

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<sup>1</sup>In this place, independence means weak correlation by calculating correlation matrix in 50 years

The idea behind MSAR is intuitive: Once we survey and summarize the patterns energy consumption obeys, it is possible to let computers choose regression types automatically by setting metrics.

As a result, with patterns equipped, MSAR obtains final regression type and fitted equations utilizing **mean squared error (MSE)**.

### 4.3 Pattern Establishment

Following the idea in Section 4.2, we try to determine the evolution patterns of transition matrix  $\mathbf{W}$ , which shows the dependence of energy consumption by fuels and sectors. If we could obtain the patterns of  $\mathbf{W}$ , in-depth analysis of energy consumption evolution would be conducted.

We explore the trends of fuels, sectors and transition matrix and finally summarize eight patterns with practical meanings (Figure 5).

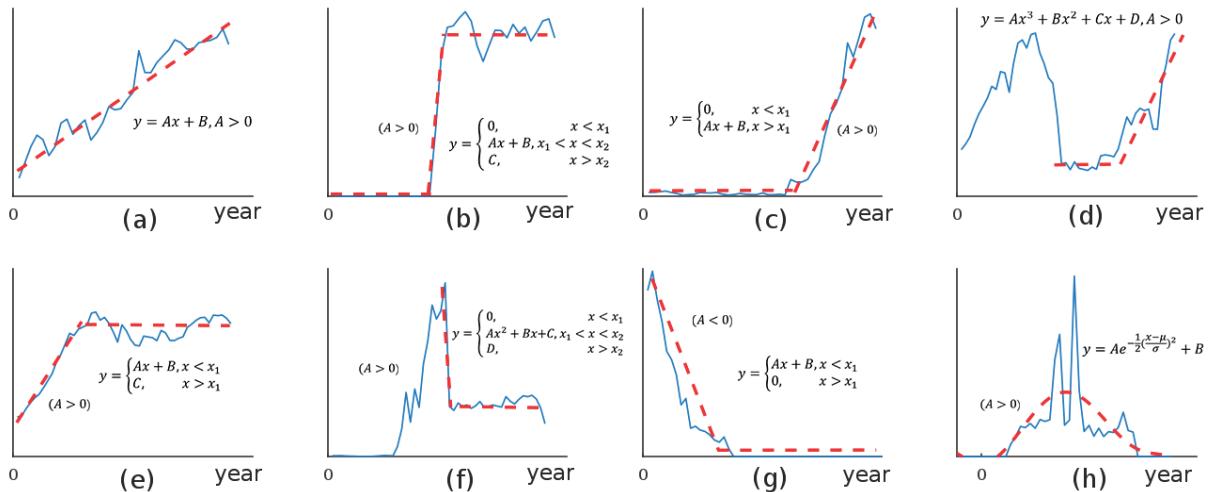


Figure 5: Energy consumption evolution patterns. The blue lines denote the actual curve, and red lines denote the fitting curve

In Figure 5, there are three trends, that is, increase (a, b, c, d and e), decrease (g) and increase at first then decrease (f and h). Different patterns in each trend reflects different rules. More specifically, (b) indicates that it boosts at some specific time and maintain almost constant. Similarly, (h) indicates that it springs up at some time but is replaced after. Other patterns can also be interpreted in the same way.

For instance, renewable energy in California:  $y = 8441.4 x + 376677.2$ ; the natural gas consumed for electricity generation in New Mexico:  $y = 4.8 x^3 + 3.5 \times 10^2 x^2 + 6.6 \times 10^3 + 2.4 \times 10^4$ . The units of regression formulas above are both billion Btu per year.

### 4.4 Applications of Our Model

MSAR is capable of characterizing complex relationships, which contains a large quantity of useful information. In this paper, we concentrate on the applications of energy consumption profile and cleaner & renewable energy.

Table 2 shows partial evolution patterns in energy consumption by five sectors of four states. It is obvious that there are similarities and differences between four states. More importantly, the pattern matrix implies variation tendency comprehensively, including fuels, sectors and their dependence.

Table 2: Different evolution patterns in energy consumed by different sectors

| State | electric |     | industrial |     |     | transportation |     | commercial |     | residential |     |
|-------|----------|-----|------------|-----|-----|----------------|-----|------------|-----|-------------|-----|
|       | coal     | gas | coal       | gas | oil | coal           | gas | coal       | gas | coal        | gas |
| CA    | /        | /   | /          | /   | /   | \              | /   | /          | /   | /           | /   |
| AZ    | /        | /   | /          | /   | /   | \              | /   | /          | /   | /           | /   |
| NM    | /        | /   | /          | /   | /   | \              | /   | /          | /   | \           | /   |
| TX    | /        | /   | /          | /   | /   | \              | /   | /          | /   | /           | /   |

Besides, more useful information can obtain by combining some of variables. For cleaner & renewable energy usage is one important focus in this paper, we give renewable consumption patterns and try different meaningful combinations in Table 3.

Table 3: Different patterns in different renewable fuels and total renewable statistics

| nuclear - electric      |    |    |    | wind - electric         |    |    |    | solar - C. & R.       |    |    |    |
|-------------------------|----|----|----|-------------------------|----|----|----|-----------------------|----|----|----|
| CA                      | AZ | NM | TX | CA                      | AZ | NM | TX | CA                    | AZ | NM | TX |
| /                       | /  | /  | /  | /                       | /  | /  | /  | /                     | /  | /  | /  |
| geothermal & solar - R. |    |    |    | geothermal & hydro - C. |    |    |    | renewable consumption |    |    |    |
| CA                      | AZ | NM | TX | CA                      | AZ | NM | TX | CA                    | AZ | NM | TX |
| /                       | /  | /  | /  | /                       | /  | /  | /  | /                     | /  | /  | /  |

Note: C. and R. represent commercial and residential sectors respectively in table.

In addition, the W can be visualized to show hierarchical structures. As shown in Figure 6, we provide an example of the stacked plot of cleaner & renewable energy.

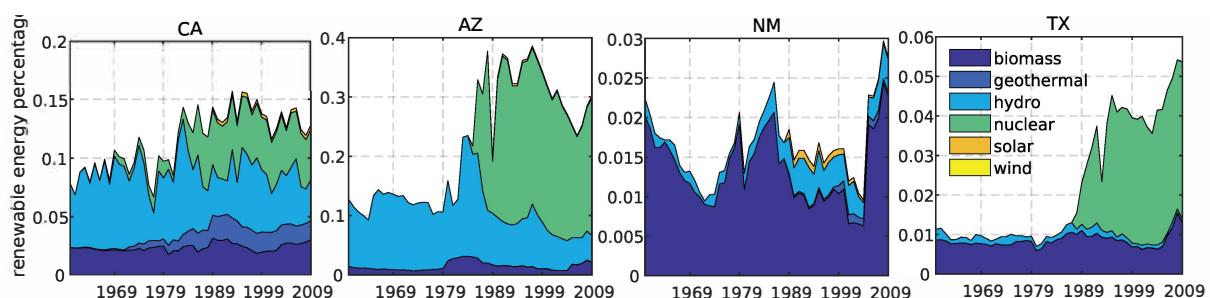


Figure 6: Cleaner & renewable energy percentage in four states

Due to the space limit, we don't display the regression results and all of the patterns in this section and list them in Appendix B. It is worthy to notice that different settings lead to different scenarios. Further studies could be conducted based on them.

## 4.5 Similarities and Differences

The similarities and differences result from several influential factors such as geography, industry, population, climate and energy policies.

Based on Table 3 and Figure 6, some remarkable phenomena are found leveraging MSAR and explained as follows.

- **Population and Industry:** These two factors are society influence, which determines the total energy consumption and usage structure. For instance, California has a largest population in U.S. and technology-oriented industry. As a result, the energy consumption and renewable energy usage surpass other states largely. On the contrary, Texas nuclear industry is well-developed, which leads to rapid improvement of nuclear energy compared to other states.
- **Geography and Climate:** These two factors natural influence, which implies energy distribution and potential renewable energy usage. For example, California has a Mediterranean climate with strong wind and solar. In consequence, the solar and wind power occupies larger portions. New Mexico possesses abundant fossil fuels, which results in coal power generation generation.
- **Policy:** To some extent, policy is a dominant factor and owns emergent property. For instance, Since 1990, all kinds of renewable energy in four states boosted greatly especially solar and wind, which is hard to explain without policy. So we searched the policies in 1990 and amazing found *Solar, Wind, Waste, and Geothermal Power Production Incentives Act of 1990* [7]. Besides, we find other polices using MSAR in similar way, such as coal ceasing program in 1979 [8, 9] and 40 billion expenditure for wind power generation in Texas [10].

## 5 Green Energy Usage Assessment

After characterizing the evolution of four states' energy profile from 1960-2009, we understand that change in proportional and total amount of each energy, especially cleaner and renewable energy can exactly reveal the development of states.

### 5.1 Green Indicators

Based on this knowledge, we step further and establish five critical indicators to grade four states in 2009.

- **Green Amount Index (GAI):** Intuitively, total consumption of cleaner and renewable energy is the most important indicator, that can directly reveal the level of sustainable development, so we employ this indicator as a critical judgment.
- **Green Ratio Index (GRI):** It is another important measurement that shows the percentage of total amount of cleaner and renewable energy consumption in the consumption of all energy sources.
- **Green Development Index (GDI):** It is calculated by the mean percentage of cleaner and renewable energy consumption in transportation, commercial, industrial, and residential sectors. This indicator reveals the significance of cleaner and renewable energy in the development of a state.

- **Green Usage Index (GUI):** We use the notion of entropy to characterize the balance and comprehensiveness of using cleaner and renewable energy in four states, to specify the entropy, we have:

$$GUI = \sum_i -\frac{N_i}{T} \log\left(\frac{N_i}{T}\right) \quad (2)$$

where  $i$  and  $N_i$  denotes a type of cleaner and renewable energy and its according consumption respectively, and  $T$  denotes total consumption of cleaner and renewable energy in one state.

- **Green Electric Index (GEI):** Since electricity plays a pivotal and indispensable part in the development of states and people's daily life, here we consider the portion of cleaner and renewable energy to total energy consumed in generating electricity as another indicator.
- **Green Loss Index\* (GLI):** It is the last indicator of our criteria, we would use this index to capture the rate of cleaner and renewable energy utilization. However, owing to the deficiency in data, we do not take it into consideration.

Table 4: Green criteria for four states in 2009

| State | GAI     | GRI    | GDI    | GUI    | GEI    |
|-------|---------|--------|--------|--------|--------|
| CA    | 999,346 | 0.1285 | 0.0235 | 1.4318 | 0.4771 |
| AZ    | 415,998 | 0.3013 | 0.0207 | 0.7160 | 0.3633 |
| NM    | 17,754  | 0.0275 | 0.0256 | 0.5692 | 0.0449 |
| TX    | 586,837 | 0.0536 | 0.1643 | 0.6617 | 0.1801 |

According to Table 4, we can easily conclude that in California, the total consumption of cleaner and renewable energy ranks first, at 999,346 billion Btu, which shows a dominant advantage. It is worth noting that Arizona gets a highest score on GRI, reflecting a high proportion of green energy in total energy consumption. However, California, though, is narrowly behind New Mexico in GDI, regains its edge by showing a great advantage in GUI and GEI, which means a balanced green energy structure and a clean and sustainable way of electricity generation.

To make it more clear and comparable, we integrate these indicators in Section 5.2.

## 5.2 Green Index

To compare and make the indicators computable, we utilize the available data [11] to calculate all the indicators of the whole country as a standard baseline, then calculate the relative indicators of four states referring to the baseline. Results are listed in Table 5.

Given these relative indicators, our goal is to integrate them into a synthetic indicator **Green Index (GI)**, so as to rank these four states in a direct way. The Analytic Hierarchy Process (AHP) is a powerful method to help make complicated decisions. In this paper, according to the correlated importance of indicators, we employ AHP to make final decision, the weights for GAI, GRI, GDI, GUI, and GEI are respectively product as (0.3607, 0.1296, 0.1840, 0.1160, 0.2097).

Table 5: Relative criteria for four states in 2009

| State | GAI           | GRI           | GDI           | GUI           | GEI           |
|-------|---------------|---------------|---------------|---------------|---------------|
| CA    | <b>2.2027</b> | 0.4670        | 0.1428        | <b>1.3159</b> | <b>1.0793</b> |
| AZ    | 0.9169        | <b>1.0951</b> | 0.1262        | 0.6581        | 0.8219        |
| NM    | 0.0391        | 0.1001        | <b>0.1558</b> | 0.5231        | 0.1016        |
| TX    | 1.2935        | 0.1950        | 0.0701        | 0.6082        | 0.4074        |

Table 6: Green Index and rank for four states in 2009

| State | CA     | AZ     | NM     | TX     |
|-------|--------|--------|--------|--------|
| GI    | 1.0162 | 0.8201 | 0.1725 | 0.5098 |
| Rank  | 1      | 2      | 4      | 3      |

As is clearly shown in Table 6, after integrating all indicators using AHP, California stands out from four states and undoubtedly has the best profile for use of cleaner, renewable energy in 2009.

## 6 DI-ARIMA: Energy profile prediction

In this section, we mainly focus on energy profile prediction based on Development Index ARIMA (DI-ARIMA).

### 6.1 DI-ARIMA Prediction Model

Assuming general time series  $\mathbf{X} = \{X_{t1}, X_{t2}, X_{t3}, \dots\}$  denotes each energy profile, DI-ARIMA is shown in Equation (3).

$$X_t = DI \cdot Reference_t = DI \cdot ARIMA(X_{t-1}) \quad (3)$$

which means we firstly apply **Autoregressive Integrated Moving Average (ARIMA)** model to predict reference value, then we use **Development Index (DI)** of each state to adjust reference and take both evolution history and differences between states into consideration.

#### 6.1.1 ARIMA Model

Since time series is non-stationary, which is shown in Figure 7 as an example, we use ARIMA [3, 12] to characterize fluctuation of time series in Equation (4).

$$\Phi(L)\Delta^d X_t = \delta + \Theta(L)u_t \quad (4)$$

where  $\Phi(L)$  and  $\Theta(L)$  denote **Auto Regressive (AR)** and **Moving Average (MA)** correspondingly and  $\Delta^d X_t$  denotes d-difference operation on time series.

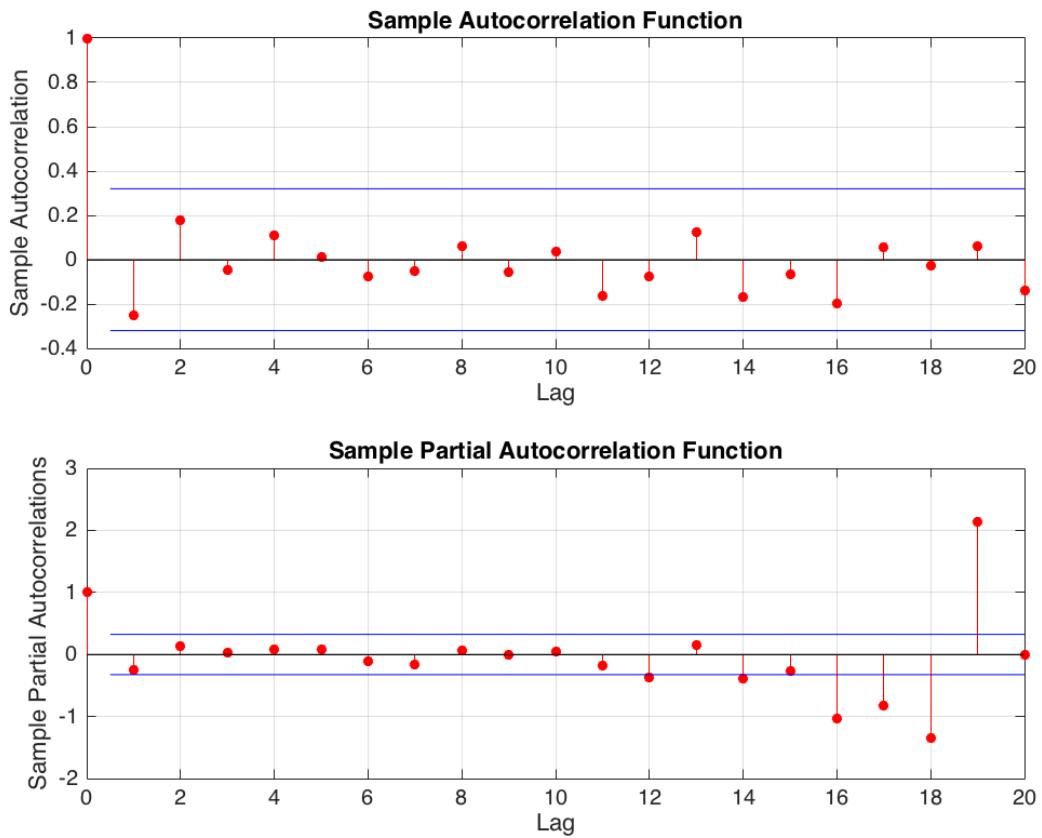


Figure 7: The non-convergence of autocorrelation and partial autocorrelation indicates that those time series are non-stationary, so we use difference operation to characterize fluctuation of time series.

### 6.1.2 Development Index (DI)

Once we get reference value, we can make out how energy profiles of each States develop. However, differences concluded in Section 4.5 should also be considered to modify reference value. We use some authoritative index to reflect influence from **Population, Industry, Climate, Geography** on energy profile.

- Population influence: Total energy consumption per capita (TETPB) is considered in fuel DI and total energy consumption per capita in each sector (TESTB) is considered in sector DI.
- Industry influence: We assume the more developed industry is, the higher the DI will be. We use Gross Industrial Production per State (GIPPS) to measure it.
- Climate & Geography influence: We assume the climate and geography will influence the distribution of available cleaner & renewable Energy. We measure it by Total Available Resources per States (TARPS).

We formulate such differences as **Development Index (DI)** in Equation (5).

$$DI_i = \begin{cases} Index(TESPB, GIPPS), & \text{if } DI_i \text{ is sector DI} \\ Index(TETPB, TARPS, GIPPS), & \text{if } DI_i \text{ is fuel DI} \end{cases} \quad (5)$$

where  $Index(A, B, C, \dots) = AHP(\frac{A}{\bar{X}}, \frac{B}{\bar{X}}, \frac{C}{\bar{X}}, \dots)$ , and  $\bar{X}$  means average quantity of X cross USA, and we use AHP to determine their weights.

## 6.2 Prediction for Energy Profile

We apply DI-ARIMA to predict consumption quantity of energy by sector and by fuel. In this part, we firstly exhibit some selected prediction result. Then we analyze potential reasons for results.

### 6.2.1 Prediction Result

Firstly, we predict the consumption quantity of energy by sector. The result is shown in Table 7.

Table 7: Forecasts for energy usage by sector (Trillion Btu)

| State          | CA            |               | AZ            |               | NM           |              | TX            |               |
|----------------|---------------|---------------|---------------|---------------|--------------|--------------|---------------|---------------|
| Year           | 2025          | 2050          | 2025          | 2050          | 2025         | 2050         | 2025          | 2050          |
| Transportation | <b>3438.0</b> | <b>3893.8</b> | 626.7         | 826.4         | 231.1        | 271.0        | 3206.4        | 3939.5        |
| Commerce       | 1988.2        | 2567.1        | 418.9         | 545.4         | 149.9        | 191.4        | 1895.3        | 2559.2        |
| Electric       | 2104.3        | 2604.7        | <b>1399.4</b> | <b>1918.0</b> | <b>501.9</b> | <b>684.1</b> | 4535.5        | 6176.5        |
| Industry       | 1926.0        | 2193.7        | 245.2         | 275.7         | 244.2        | 257.4        | <b>6162.8</b> | <b>6660.2</b> |
| Resident       | 1788.1        | 2237.3        | 543.1         | 785.0         | 134.4        | 160.9        | 2112.1        | 2796.3        |

Note: the bold number means most energy-consumed sector in each State.

Then we predict the consumption quantity of energy by fuel, shown in Table 8.

Table 8: Forecasts for energy usage by fuel (Trillion Btu)

| State       | CA            |               | AZ           |              | NM           |              | TX            |               |
|-------------|---------------|---------------|--------------|--------------|--------------|--------------|---------------|---------------|
| Year        | 2025          | 2050          | 2025         | 2050         | 2025         | 2050         | 2025          | 2050          |
| Biomass     | 270.6         | 344.3         | 48.1         | 75.5         | <u>19.5</u>  | <u>21.7</u>  | 144.4         | 185.9         |
| Geothermal  | 164.3         | 230.8         | 0.4          | 0.5          | 0.5          | 0.9          | 6.8           | 17.4          |
| Hydro       | 378.2         | 399.9         | 81.7         | 99.6         | 3.1          | 4.0          | 9.6           | 11.5          |
| Nuclear     | <b>424.2</b>  | <b>596.3</b>  | <b>378.1</b> | <b>488.6</b> | 0.0          | 0.0          | <b>567.1</b>  | <b>799.4</b>  |
| Solar       | 41.3          | 57.4          | 6.2          | 8.7          | 0.4          | 0.5          | 1.1           | 1.7           |
| Wind        | 72.9          | 98.1          | 0.2          | 0.4          | 17.7         | 16.4         | 1158.1        | 3478.9        |
| Coal        | 57.8          | 63.9          | 482.8        | 633.1        | <b>380.6</b> | <b>519.5</b> | 1447.6        | 2042.4        |
| Natural gas | 2982.8        | 3618.7        | 530.6        | 701.5        | 221.0        | 226.2        | 4735.8        | 4851.5        |
| Petroleum   | <b>4141.8</b> | <b>5028.8</b> | <b>668.2</b> | <b>880.6</b> | 303.0        | 378.1        | <b>7005.4</b> | <b>9113.6</b> |

Note: the underline number means most usage cleaner and renewable energy in each State;  
the bold number means most usage energy in each State.

### 6.2.2 Analysis of Prediction Result

According to forecasts in Table 7 and Table 8, we come to conclusions as follows:

- As for sector, although the quantity of each sector remain increasing, structure and distribution in each State remain stable in both 2025 and 2050. For example, transportation sector still consume most energy in California, and electric, electric, industry in Arizona, New Mexico, Texas respectively.

- As for fuels, all states will depend mainly on fossil fuels, especially natural gas and petroleum. However, some cleaner and renewable energy quantity will increase dramatically, such as biomass in California and Arizona, geothermal energy in New Mexico, nuclear in Texas and wind in Texas.

### 6.3 Prediction for Cleaner & Renewable Energy

Since cleaner & renewable energy plays an increasingly significant role in future society, we exhibit and analyze the forecasts of cleaner & renewable energy in California, shown in Figure 8, while others (14 prediction figures) are displayed in Appendix A.

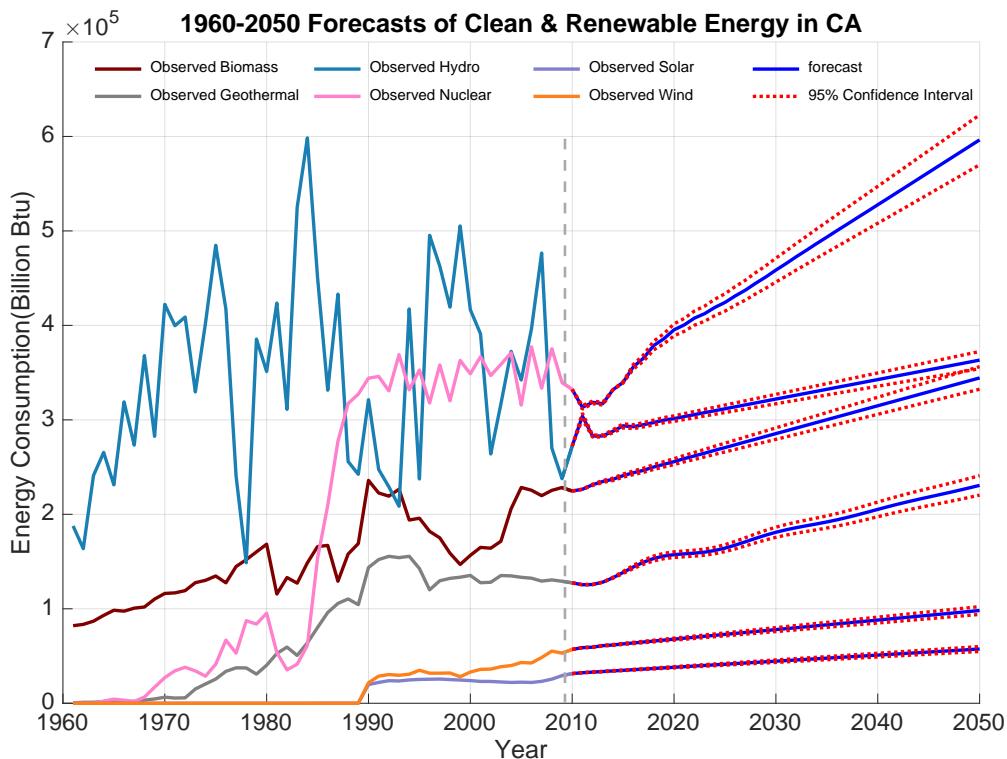


Figure 8: Forecasts of cleaner & renewable energy in California

All cleaner & renewable energy remain increasing in the new 40 years. Amazingly, there are several observed real life certification towards the predicted fluctuation:

- Investment of 4 billion dollars from Hudson Ranch geothermal energy company in California since 2010 largely stimulates usage of Geothermal Energy [13];
- In spite of dramatical fluctuation of hydro energy usage as blue line indicates, [14] confirms that hydro energy will remain stably increasing, which is as same as our forecast.
- Admittedly, although we predict a huge increase of nuclear energy, California government plans to reduce its nuclear plants in the future.

Additionally, we use 2010-2015 data to quantitatively verify our results in Section 8.

## 7 Green Targets and Actions

### 7.1 Green Targets for Four States

Based on the prediction results, four states' energy profile, natural geography, social condition, as well as our understanding, we set future targets for four states to develop their renewable energy. Note that renewable energy here does not include nuclear energy.

#### 7.1.1 Raise the amount and ratio of renewable energy utilization

Based on the present situation (Figure 6 and Table 4), the amount and the ratio of renewable energy utilization are pretty low. For instance, New Mexico have an extremely low ratio about 2.75%, as well as a low total amount at around 17,754 billion Btu. The first and most urgent goal is to raise the amount and the ratio of renewable energy utilization in four states. We set the target amount and ratio for these four states based on their energy profile, results of prediction, Green Amount Index and Green Ratio Index. Goals are listed as follows:

Table 9: Targets to raise renewable energy utilization(unit of amount: MW)

| State  | CA-2025 | AZ-2025 | NM-2025 | TX-2025 | CA-2050 | AZ-2050 | NM-2050 | TX-2050 |
|--------|---------|---------|---------|---------|---------|---------|---------|---------|
| Amount | 50,000  | 10,000  | 7,500   | 35,000  | 150,000 | 35,000  | 20,000  | 110,000 |
| Ratio  | 35%     | 50%     | 10%     | 25%     | 90%     | 80%     | 50%     | 75%     |

#### 7.1.2 Keep a balance of different renewable energy and exploit new energy

As is shown in Figure 6, four states all have a tendency to use a wider range of renewable energy. However, it is still not enough since different renewable energy have exactly distinct amount of consumption. Our goal in the future is to keep a balance of different renewable energy and to exploit new energy. Targets below are all based on total renewable energy utilization.

- **California 2025's target:** Increase the utilization of solar and wind energy to 25%; stay ahead and keep the relative diversity of renewable energy usage.
- **California 2050's target:** Keep increasing the utilization of solar and wind energy to 40%; keep leading and exploit new energy from deep ocean and outer space.
- **Arizona 2025's target:** Reduce the dependence in nuclear energy to 10%; start to increase the utilization of solar and wind to 10%; comprehensively develop all types of renewable energy.
- **Arizona 2050's target:** Reduce the dependence in nuclear energy to 5%; increase the utilization of solar and wind to 30%; start to exploit energy from marine.
- **New Mexico 2025's target:** Increase the utilization of solar and wind energy to 20%; keep using hydraulic power to 25%; start to use solar-thermal or geothermal power.

- **New Mexico 2050's target:** Increase the utilization of solar and wind energy to 30%; keep using hydraulic power to 30%; increase the utilization of thermal power to 10%.
- **Texas 2025's target:** Increase the utilization of wind energy to 50%; start to use solar energy to 2.5%; reduce the dependence on nuclear energy to 15%; increase the utilization of hydraulic energy to 2.5%.
- **Texas 2050's target:** Increase the utilization of wind energy to 80%; start to use solar energy to 5%; reduce the dependence on nuclear energy to 5%; increase the utilization of hydraulic energy to 5%.

### 7.1.3 Increase renewable usage in electricity generation

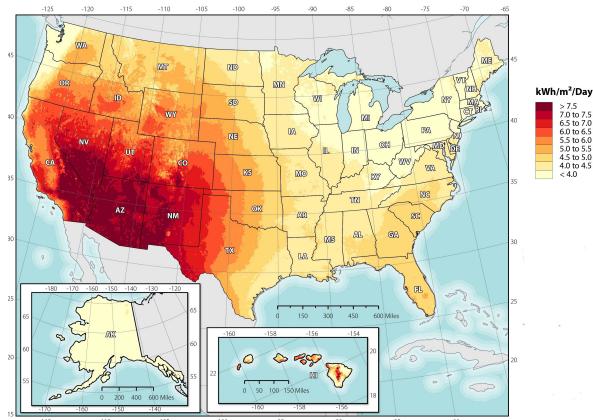
Electricity is of great significance, since it serves as a bridge which connects various energy resources and different sectors (Figure 2). Referring to Table 4, we conclude that in present condition, these four states generate electricity mainly depending on traditional energy, such as coal. Therefore, the last targets are supposed to focus on Green Electricity Index.

- **California green electricity target:** Since California has the best renewable energy profile and due to its natural geography and development advantage, we set ratio of renewable energy in electricity generation at 55% in 2025 and 100% in 2050 respectively.
- **Arizona green electricity target:** Based on our analysis and prediction, we deem that Arizona's first task is to develop more available renewable energy, thus we consider to set goals for Arizona at 17% in 2025 and 50% in 2050.
- **New Mexico green electricity target:** New Mexico is a special state with plenty of natural resources, leading to its heavily dependence on traditional energy, such as coal and natural gas. Taken this into consideration, we reasonably set 12% in 2025 and 35% in 2050 for New Mexico's development.
- **Texas green electricity target:** In the past few decades, Texas leads the nation in wind-powered electricity generation [15]. We optimistically estimate that the electricity generated from Texas will keep increasing in the next few decades, thus we respectively set 30% in 2025 and 80% in 2050 for Texas future green electricity generation.

## 7.2 Green Actions for Four States

To meet the renewable energy targets on Section 7.1, we dig more deeply and give several proposals concerning renewable energy usage in the next few decades for California, Arizona, New Mexico and Texas.

- **Deep development of solar energy:** First and foremost, located in Southwest part of the United States, these four states are naturally rich in solar energy (Figure 9a). The first action we identifies is that these four states should strive to develop solar resources, such as photovoltaic power generation, like Figure 9b.



(a) Concentrating solar resources of US [16]



(b) Example of photovoltaic systems [17]

Figure 9: Solar energy and usage in Southwest US

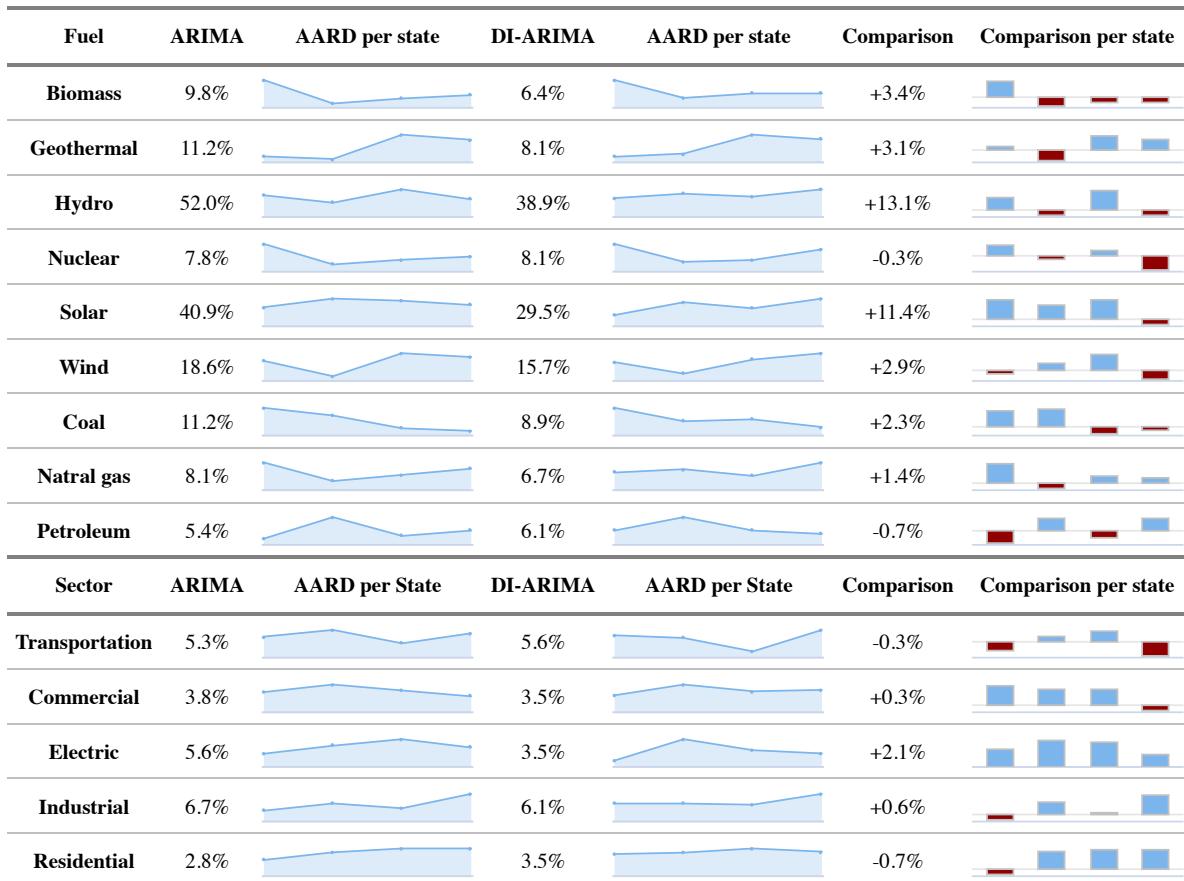
- **Actions suitable for states' conditions:** Secondly, four states are supposed to take actions according to their own conditions. **California** shall keep a leading role in renewable energy usage by developing high-tech strategies, so as to improve green energy efficiency and reduce waste and loss. As for **Arizona**, Loan Programs [18], which offers lower interest loans or other financing options to individuals and businesses for reducing the costs of purchasing and installing renewable energy technologies, may be a good idea for accomplishing its goal. In terms of **New Mexico**, with a very low level of clean energy dependence, we propose that exploiting and utilizing various renewable energy shall be a urgent and practical measure. **Texas** begins its wind power history since the formation of the Alternative Energy Institute (AEI) in 1977, and eventually becomes the leading producer of wind powered electricity in the country [15]. Therefore, we pin the future renewable energy usage in Texas on its wind power.
- **Cooperation and complementation:** Frequent cooperation and efficient complementation are another essential part in order to make better use of renewable energy. In detail, four states could jointly develop solar resources by sharing ideas and techniques. Texas, known for its wind power, could provide their experience and facilities for other states, while California may help optimize renewable energy structure by offering high-tech as well as great strategies.
- **Smart policies:** Further, to meet energy goals and make better use of renewable energy, we can also consider from the perspective of government policies. We put forward that smart policies need to be taken to protect the exploitation and utilization of renewable energy, as well as banning the waste.
- **Exploration of new green energy:** Finally, more resources mean more chooses and usage. We firmly suggest that energy scientists, accompanied with experts from other areas, could work together, aiming to find more cleaner, renewable resources from deep oceans or outer space.

## 8 Model Analysis

### 8.1 Forecasts Evaluation

In this part, we evaluate our forecast accuracy and analyze some unexpected future evolutions. Firstly, we compare our DI-ARIMA model's performance with naive ARIMA model' in detail. Furthermore, we analyze the results.

Table 10: Comparison Results Based on AARD



Note: ARIMA and DI-ARIMA parts show average absolute relative deviation (**AARD**) correspondingly, while comparison part shows improvement of DI-ARIMA over ARIMA, and comparison per state shows improvement per state (blue means increases while red means decreases).

Table 10 indicates that our DI-ARIMA model outperforms ARIMA model in most forecast tasks, especially in hydro and solar prediction. Obviously, the extra DI considering differences between states plays a vital role in our DI-ARIMA model, as it contains difference expectation to different circumstances. Additionally, AARD results are also analyzed:

- **Compared to fuel, AARD of sectors are smaller.** Because development of sector remain stable relatively.
- **Some AARD of fuel are obviously large**, such as hydro and solar. One reason for it is that such fuel change periodically, we can not predict it accurately for a lack of time series data such as hydro energy.

- **ARRD over states varies largely in some fuel prediction**, which is a consequence of different policies in each state. For example, California plans to ban its nuclear plants by 2050 [19]; California limits its coal usage in order to control its emission of greenhouse gas [20].

## 8.2 Strengths and Weaknesses

### 8.2.1 Strengths

- Major but succinct features are considered. We carefully and self-consistently select major features, 63 out of 605, as what we study in this paper.
- Our self-adaptive regression model maintains both customized and robust. Once given a historical evolution series, our model can characterize it using one specific pattern and reflect its internal law of evolution automatically. It significantly helps to characterize how the energy profile of each of the four states has evolved.
- We consider six critical indicators in our Green Index (GI) criteria, which gives a comprehensive evaluation of cleaner & renewable energy utilization in each state. Besides, we employ AHP to make final decision, making the problem more clear and comparable.
- We consider both the historical evolution of energy use and specific circumstances including population, industry, geography and climate in each state in our prediction model DI-ARIMA. Besides, we use 2010-2015 statistics to evaluate our forecast model, proving that our model outperforms ARIMA which is viewed as the best time series regression model.

### 8.2.2 Weaknesses

- To maintain simplicity, we only consider three kinds of energy profile. More features may need to be considered to analyze energy use more specifically.
- Our MSAR model need to fit the historical evolution records for 8 times, so it is inefficient. An extra sampling algorithm and an efficient search algorithm can be added to reduce time complexity of our model.
- We limit our discussion and prediction into the influence of population, industry, geography and climate mainly depending on Development Index. More comprehensive and more official factors can be considered in Development Index in order to make more accurate prediction.

## 9 Conclusion

In this paper, we mainly focus on energy consumption in four states: California, Arizona, New Mexico and Texas. Firstly, we define our energy profile as energy consumption by sector, energy consumption by fuel and traditional and renewable energy use. Secondly, we characterize and predict the evolution of four states' energy profile based on MSAR and DI-ARIMA models. Then we select California as the state which has the best cleaner & renewable energy profile based on Green Index. Finally, we provide practical goals and suggestions for each states.

# Energy Report Memo

To: Governors

From: Team #72992

Subject: summary, projections, and targets for four states

Date: February 13, 2018

Dear governors,

It is our pleasure to provide some references for your goal of renewable energy. We do accomplish the task of data analysis and successfully model the usage of clean and renewable sources. A summary of four states' profile in 2009, a report on future energy use prediction, and a list of recommended energy targets are here for you.

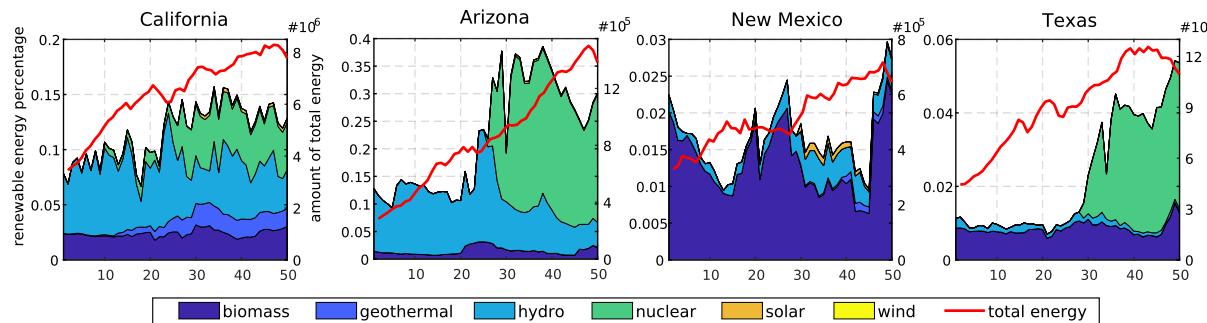


Figure 10: Renewable energy percentage and amount of total energy

First of all, we present a brief energy summary of each state (shown in Figure 10). In general, we help to conclude that each of the states shows a rising trend in terms of both total and renewable energy consumption. However, the structure of renewable energy differs a lot among four states. It is worth noting that California keeps a relatively balanced renewable structure, while Arizona and Texas depend heavily on nuclear power, even worse, New Mexico's renewable energy is almost entirely made of biomass, which shows an unbalanced and irrational renewable energy utilization.

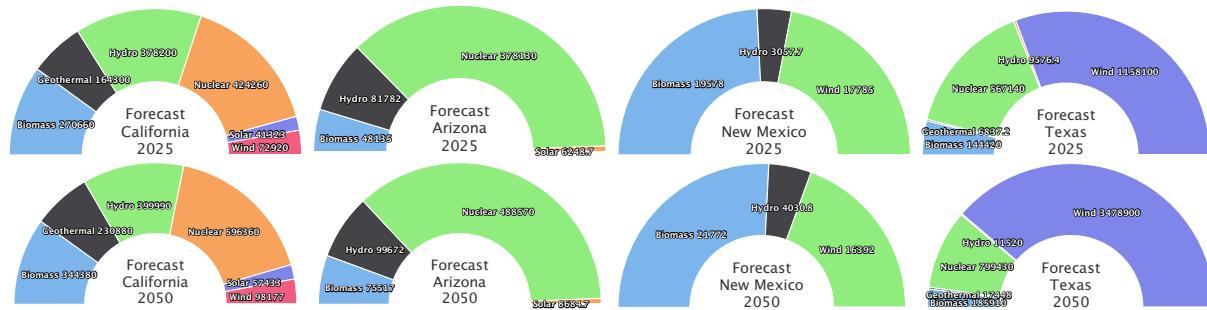


Figure 11: Solar energy and usage in Southwest US

Also, we predict the energy profile for each state in 2025 and 2050, shown in pie charts (refer to Figure 11). We deem that the predicting results of 2025 is similar to 2050 if absent any policy changes. California will still hold the advantage of keeping a balanced renewable structure, while we can clearly foresee that Texas may increase the use of wind power to make up for the deficiency of other renewable energy sources.

Further, based on current situation and prediction results, we provide our feasible targets for four states. To begin with, we propose that four states are supposed to raise the amount and ratio of renewable energy utilization by employing high-tech or reducing waste, especially for New Mexico. Next, keeping a balance of renewable energy and exploiting new energy can be a tough but essential task, where California is asked to play a leading role. Finally, since electricity serves a lot in the development of states, we expect that four states can increase renewable usage in electricity generation, detailedly, to take advantages of natural conditions, we focus on solar power.

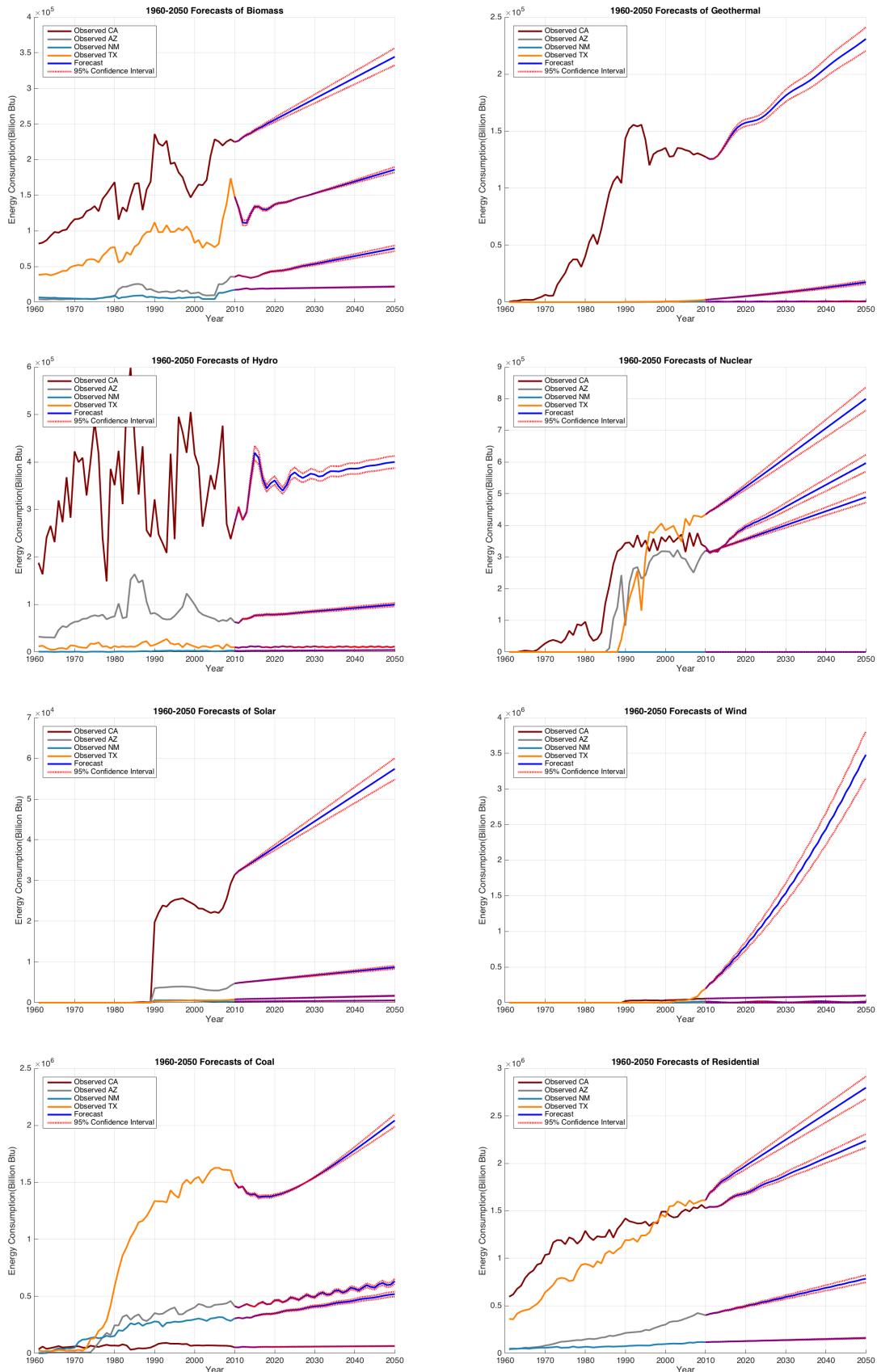
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# Appendices

## Appendix A Forecasts of Energy Profile Evolution



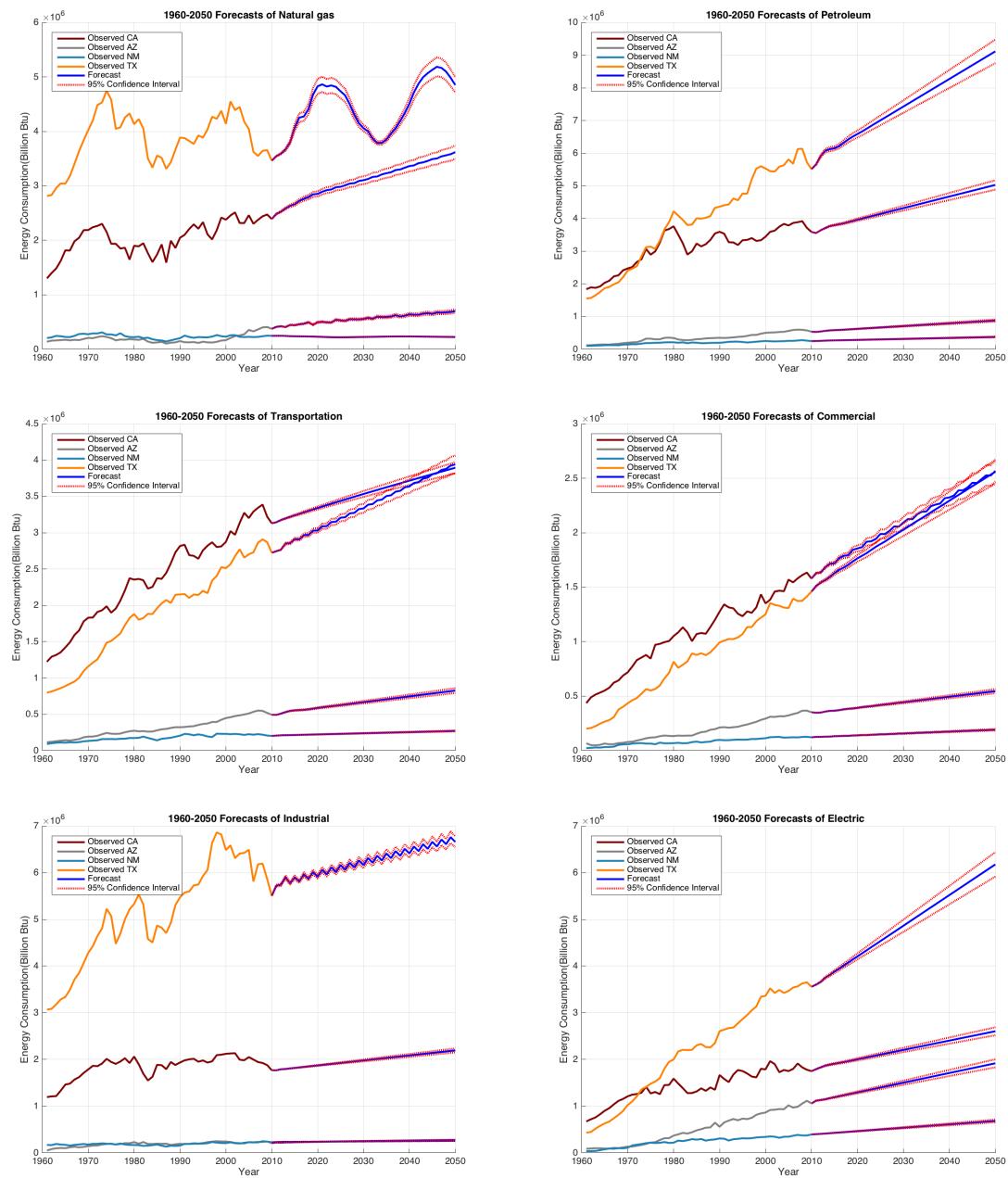


Figure 12: Predicted energy profile evolution

## Appendix B Regression Results of MSAR

Table 11: Partial Regression Results of MSAR

| Source     | Sector   | State | Pattern | Billion Btu | Point1 | Point2 |
|------------|----------|-------|---------|-------------|--------|--------|
| coal       | electric | ZA    | 1       | 8714.3      |        |        |
| coal       | electric | CA    | 2       |             | 1989   | 1995   |
| coal       | electric | NM    | 1       | 6799.8      |        |        |
| coal       | electric | TX    | 2       | 42457       |        | 1977   |
| nature gas | electric | ZA    | 3       | 23939       |        | 1997   |
| nature gas | electric | CA    | 1       | 7845        |        |        |
| nature gas | electric | NM    | 4       | 1865.1      |        | 1987   |

|                |               |    |   |         |      |      |
|----------------|---------------|----|---|---------|------|------|
| nature gas     | electric      | TX | 5 |         | 1975 |      |
| coal           | industrial    | ZA | 6 |         | 1986 | 1989 |
| coal           | industrial    | CA | 1 | -205.75 |      |      |
| coal           | industrial    | NM | 6 |         | 1985 | 1997 |
| coal           | industrial    | TX | 6 |         | 1987 | 2009 |
| crude oil      | industrial    | ZA | 8 |         | 1985 | 1999 |
| crude oil      | industrial    | CA | 8 |         | 1960 | 1960 |
| crude oil      | industrial    | NM | 8 |         | 1985 | 1999 |
| crude oil      | industrial    | TX | 8 |         | 1981 | 1985 |
| natrue gas     | industrial    | ZA | 4 | -639    | 1987 |      |
| natrue gas     | industrial    | CA | 4 | 16840   | 1983 |      |
| natrue gas     | industrial    | NM | 4 | 2247    | 1987 |      |
| natrue gas     | industrial    | TX | 6 |         | 1999 | 2009 |
| coal           | transpotation | ZA | 7 |         | 1979 |      |
| coal           | transpotation | CA | 7 |         | 1979 |      |
| coal           | transpotation | NM | 7 |         | 1979 |      |
| coal           | transpotation | TX | 7 |         | 1979 |      |
| natrue gas     | transpotation | ZA | 1 | 16.289  |      |      |
| natrue gas     | transpotation | CA | 1 | 22.267  |      |      |
| natrue gas     | transpotation | NM | 6 |         | 1991 | 2009 |
| natrue gas     | transpotation | TX | 1 | 192.62  |      |      |
| coal           | commercial    | ZA | 8 |         | 1996 | 2005 |
| coal           | commercial    | CA | 8 |         | 1999 | 2005 |
| coal           | commercial    | NM | 8 |         | 1984 | 2009 |
| coal           | commercial    | TX | 8 |         | 2003 | 2007 |
| geo. and solar | residential   | ZA | 2 |         | 1990 | 1991 |
| geo. and solar | residential   | CA | 2 |         | 1990 | 1991 |
| geo. and solar | residential   | NM | 2 |         | 1990 | 1991 |
| geo. and solar | residential   | TX | 3 | 61.768  | 1990 |      |
| natural gas    | commercial    | ZA | 1 | 229.79  |      |      |
| natural gas    | commercial    | CA | 1 | 1985.2  |      |      |
| natural gas    | commercial    | NM | 6 |         | 1967 | 1977 |
| natural gas    | commercial    | TX | 1 | 2122.4  |      |      |
| coal           | residential   | ZA | 8 |         | 1994 | 2009 |
| coal           | residential   | CA | 8 |         | 1997 | 2002 |
| coal           | residential   | NM | 7 |         | 22   |      |
| coal           | residential   | TX | 8 |         | 1989 | 2007 |
| natrue gas     | residential   | ZA | 1 | 145.4   |      |      |
| natrue gas     | residential   | CA | 1 | 536.08  |      |      |
| natrue gas     | residential   | NM | 1 | 136.21  |      |      |
| natrue gas     | residential   | TX | 1 | -294.72 |      |      |
| nuclear power  | electric      | ZA | 3 | 8040    | 1986 |      |
| nuclear power  | electric      | CA | 2 |         | 1983 | 1991 |
| nuclear power  | electric      | NM | 1 | 0       |      |      |
| nuclear power  | electric      | TX | 3 | 15623   | 1989 |      |
| solar power    | com. & res.   | ZA | 2 |         | 1990 | 1991 |
| solar power    | com. & res.   | CA | 2 |         | 1990 | 1991 |
| solar power    | com. & res.   | NM | 2 |         | 1990 | 1991 |
| solar power    | com. & res.   | TX | 2 |         | 1990 | 1991 |
| wind           | electric      | ZA | 2 |         | 2008 | 2009 |

|           |            |    |   |        |      |
|-----------|------------|----|---|--------|------|
| wind      | electric   | CA | 3 | 1407   | 1990 |
| wind      | electric   | NM | 3 | 2413   | 2003 |
| wind      | electric   | TX | 3 | 19319  | 2008 |
| renewable |            | ZA | 5 |        | 1986 |
| renewable |            | CA | 1 | 8441.4 |      |
| renewable |            | NM | 3 | 4525.9 | 2003 |
| renewable |            | TX | 3 | 25741  | 2003 |
| geo-hydro | commercial | ZA | 3 | 3.2869 | 1980 |
| geo-hydro | commercial | CA | 3 | 17.92  | 1980 |
| geo-hydro | commercial | NM | 3 | 2.3972 | 1980 |
| geo-hydro | commercial | TX | 3 | 32.116 | 1980 |

## Appendix C Supplementary Notations

Table 12: Supplementary MSN codes and relationships used in this paper.

| Renewable | Electric | Commercial | Industrial | Residential | Transportation |
|-----------|----------|------------|------------|-------------|----------------|
|           | REEICB   | RECCB      | REICB      | RERCB       | REACB          |
| Geo.      | Hydro    | Nuclear    | Solar      | Wind        | Coal           |
| Elec.     | GEEGB    | HYEGB      | NUEGB      | SOEGB       | WYEBG          |
|           |          |            |            | CLEIB       | NGEIB          |
|           |          |            |            | ESACB       | PAEIB          |
|           |          | Commercial | Industrial | Residential | Transportation |
| Electric  | ESCCB    | ESICB      | ESRCB      | ESTCB       | Total          |

## Appendix D Code

### DI-ARIMA Prediction

```

function data=predict(sector,a,p,q)
%clc
figure
%% data
[M,N]=size(a);
for i=1:4
b=a(i,:)';
da=diff(b);
n=length(da);
k=6; %k
Mdl = di_arima(p,0,q);
EstMdl = estimate(Mdl,da);
[YF,YMSE] = forecast(EstMdl,k,'Y0',da);

af(1)=b(end);
af_pos(1)=b(end);
af_neg(1)=b(end);
for j=2:(k+1)
af(j)=af(j-1)+YF(j-1);
af_pos(j)=af_pos(j-1)+YF(j-1)*1.10;
af_neg(j)=af_neg(j-1)+YF(j-1)*0.90;
end

```

```

data(i,:)=af(2:7);
end
csvwrite(['error_' sector '.csv'],data)

%csvwrite([sector '.csv'],data)

hold on
switch (i)
    case 1
        hCA=plot(1:size(b),b,'Color',[0.5 0 0],'LineWidth',2);
    case 2
        hAZ=plot(1:size(b),b,'Color',[0.5 0.5 0.5],'LineWidth',2);
    case 3
        hNM=plot(1:size(b),b,'Color',[0.1 0.5 0.7],'LineWidth',2);
    case 4
        hTX=plot(1:size(b),b,'Color',[1 0.5 0],'LineWidth',2);
end
h1=plot(n+1:n+k+1,af','b','LineWidth',2);
h2=plot(n+1:n+k+1,af_pos','r:','LineWidth',2);
h3=plot(n+1:n+k+1,af_neg','r:','LineWidth',2);

end
grid on
legend([hCA hAZ hNM hTX h1 h2 ],'Observed CA','Observed AZ',...
    'Observed NM','Observed TX','Forecast','95% Confidence Interval',...
    'Location','NorthWest');
title(['1960-2050 Forecasts of ' sector])
set(gca,'xticklabel',[1960,1970 1980 1990 2000 2010 2020 2030 2040 2050])
ylabel('Energy Consumption(Billion Btu)')
xlabel('Year')
hold off
fn = ['fig/' sector '_forecast.png'];
%print( gcf,'-dpng', fn );
N=2010:2050;
%csvwrite(['data/' sector '_forecast.csv'],[N',af'])

```

---

## Visualization

---

```

import numpy
import csv
import matplotlib.pyplot as plt

#data extraction:
label=['BMTCB','GETCB','HYTCB','NUEGB','SOTCB','WYTCB','CLTCB','NGTCB',
'PATCB']
for item in label:
    print(item)
    for key in plotdata:
        plotdata[key][item]=[]

for index in label:
    with open("data/"+name[index]+".csv", "w") as csvfile:
        writer = csv.writer(csvfile)
        writer.writerows([plotdata['CA'][index],plotdata['AZ'][index],
            plotdata['NM'][index],plotdata['TX'][index]])

#plot:

```

```
j=0;
fig = plt.figure(frameon=False)
fig.set_size_inches(14, 4)
#ax = plt.gca()
#ax.yaxis.grid(color='gray', linestyle='dashed')
#ax.xaxis.grid(color='gray', linestyle='dashed')

color=['#e41a1c','#377eb8','#4daf4a','#984ea3','#ff7f00','#ffff33',
'#a65628','#f781bf','#999999']

for key in plotdata:
    j+=1;

    # fig = pylab.figure()
    bx = fig.add_subplot(1, 4, j)
    #bx.set_size_inches(5, 3)
    bx.yaxis.get_major_formatter().set_powerlimits((2,2))
    #bx.yaxis.set_major_formatter(plt.FormatStrFormatter('%1.1f'))
    plt.plot([])
    for i in range(len(label)):
        print(key)
        plt.plot(year,plotdata[key][label[i]],color[i],
                 label=name[label[i]])

    bx.yaxis.grid(color='gray', linestyle='dashed')
    if j==1:
        plt.ylabel('Consumption(Billion Btu)', fontsize=18)
        plt.title(key, fontsize=18)
        plt.xticks(fontsize=14)
        plt.yticks(fontsize=14)
    plt.legend(loc='lower center', bbox_to_anchor=(-1.3, -0.40),
               ncol=9, fancybox=True, shadow=True, prop={'size':13})
    plt.subplots_adjust(left=0.05, right=0.98, top=0.90, bottom=0.3)
    plt.savefig('fig/Fuel.pdf')
    plt.show()
```

---