Comparative Studies of Renewable Energy Development between China and the United States of America

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Abstract: Current status of renewable energy development in China and US is analyzed via comparative studies. Past trend for each country is analyzed based on available data. The trajectory for the renewable energy development is different. In order to meet the demand of renewable energy and protect environment, a mathematical model is established to forecast the renewable energy consumption. This model exhibits characteristics of essential physical concept and provides predictions for rapid growth in renewable energy consumption in the future. Furthermore, if China and the US can jointly develop the renewable energy, there will be mutual benefits. Areas of co-development are explored in terms of technologies, markets and investments. This study may provide insightful information on renewable energy consumption in the future.

Keywords: Renewable energy consumption; Forecast; China; US

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1. Introduction

To achieve sustainability, renewable energy should be a part of energy profile in China and US [1-2]. Currently, these two countries are top two energy consumers in the world, and heavily depend on imported oil. For the future energy security and economy growth, it is desirable to correctly predict dynamic characteristics of renewable energy demand in both countries.

Previous studies addressed different aspects of energy consumption forecasting. Messner [3] utilized growth factor, economics and technology as variables to analyze energy, Zachariadis [4] explored dynamic evolutions of transport modes, and Sari [5] developed error variance decomposition techniques to determine the rate of growth. Various models were considered in different countries and regions. Kaboudan predicted Zimbabwe's electricity consumption via a non-linear dynamic econometric forecasting model [6], Tamimi predicted Jordan's energy consumption via an exponential forecasting model [7], Chavez predicted Spain's energy production and consumption via univariate Box–Jenkins time series analyses [8], and Ediger predicted Turkey's energy demand via semi-statistical techniques [9].

For energy consumption problems in China, there are limited studies [10]. In Crompton's work [11], Bayesian vector autoregressive methodologies were used to forecast China's energy consumption. In Adams' work [12], an econometric model was established to forecast Chinese energy consumption and imports to 2020. Due to rapid growth in economy, the need for oil and gas imports will be very high to meet the energy consumption demand in China. Some of the Chinese development stages may be similar to those experienced in US.

For US, Winebrake [13] applied an error decomposition technique to forecast energy consumption in major sectors such as commercial, industrial, residential, and transportation sectors. O'Neill [14] found that futuristic energy consumption projection is usually lower than the actual value. Saunoris [15] examined the dynamics of electricity demand in terms of growth and conservation.

Among all models for predictions, Logistic models seem to be appropriate to initiate studies due to their simplicity [16, 17]. For example, Bodger [18] used such models to forecast electricity consumption in New Zealand. Since renewable energy consumption is at its early stage in China and US, it is reasonable to consider a Logistic model as a prediction tool.

2. Method

In economy, biology and ecology, a logistic curve is often used to describe a growth process [19-24]. Such curve usually has three sections: slow growth at the beginning, rapidly increasing in the middle and reaching a steady state towards the end.

Because the curve has an "S" shape, it is also known as "S-curve."
A Logistic model is utilized to forecast renewable energy consumption. The basic assumption is that the renewable energy development process will follow an S curve in China and US. The growth may be slow at the begging due to difficulty in technology development and capital acquisition, fast in the middle due to available technology and monetary funds, and slow at the end due to saturation in technology deployment and market penetration. The logistic growth rate equation of renewable energy consumption is as follows.

$$\frac{dx}{dt} = rx\left(1 - \frac{x}{K}\right) \qquad (1)$$

where x is the renewable energy consumption at any given time t, r is inherent growth rate for renewable energy consumption, and K is the maximum renewable energy consumption at the end when the growth reaches saturation point. At t = 0, the energy consumption is x_o; or $x_0 = x|_{t=0}$. After solving Equation (1), an answer can be obtained as follows.

$$x = \frac{K}{1 + \left(\frac{K}{x_0} - 1\right)\exp(-rt)} \qquad (2)$$

Assuming $y = \ln\frac{K - x}{x}$ and $\frac{K}{x_0} - 1 = e^a$, Equation (2) can be rewritten as follows.

$$y = a - rt \qquad (3)$$

3. Results

3.1 Existing renewable energy consumptions in China and US

Renewable energy is an energy source which can be regenerated and sustained. In this paper, solar, wind, biomass, geothermal and tidal energy are considered. Between 2005 and 2012, the annual renewable energy consumptions for China and US are tabulated in Table 1 with the data from BP energy system yearbooks. All values are given in MTOE (Million Tons of Oil Equivalent). Each country had a different x_o value for t_o (year 2005), i.e., 1.06 MTOE for China and 20.62 MTOE for US. Seven years later, the Chinese annual renewable energy consumption was 31.90 MTOE, less than that of US (50.72 MTOE). Notice that the rate of change for China was larger than that for US.

Table1. Renewable Energy Consumption (MTOE)

Year	China	US
2005	1.06	20.62
2006	1.46	22.73
2007	1.86	24.73
2008	3.61	29.49
2009	6.94	33.65
2010	14.11	38.9
2011	25.43	45.03
2012	31.9	50.72

3.2 Estimation of K parameter in Logistic model

In order to establish a Logistic model for renewable energy consumption, one needs to estimate the ranges of the K parameter. Before running logistic iterations, the initial K value should be placed between two limits: K_{low} and K_{high}, with $K_{low} > x_o$ and $10\ x_o > K_{high} > 2\ x_o$. After iterations, different K values are obtained with different determination coefficients R^2 as tabulated in Table 2 for US. For US, the largest coefficient is $R^2 = 0.9939$ and the corresponding K value is 500 MTOE.

Table 2

Statistical examination of renewable energy consumption in US

K (MTOE)	R^2	a	r
100	0.9869	1.639	-0.2016
150	0.9912	2.072	-0.1717
200	0.9924	2.378	-0.1600
250	0.9928	2.613	-0.1538
300	0.9933	2.804	-0.1500
350	0.9936	2.964	-0.1474
400	0.9937	3.102	-0.1455
450	0.9938	3.224	-0.1440
500	0.9939	3.332	-0.1429
550	0.9937	3.430	-0.1419
600	0.9934	3.519	-0.1412

In Table 2, corresponding to the largest R^2 value, a = 3.332 and r = - 0.1429; or y=3.332 - 0.1429 t. Therefore, Logistic prediction model of renewable energy consumption for US is as follow.

$$X = \frac{500}{1 + e^{3.332 - 0.1429t}} \qquad (4)$$

In Figure 1, Equation (4) is plotted as a theoretically predicted curve, which is close to that based on the actual data.

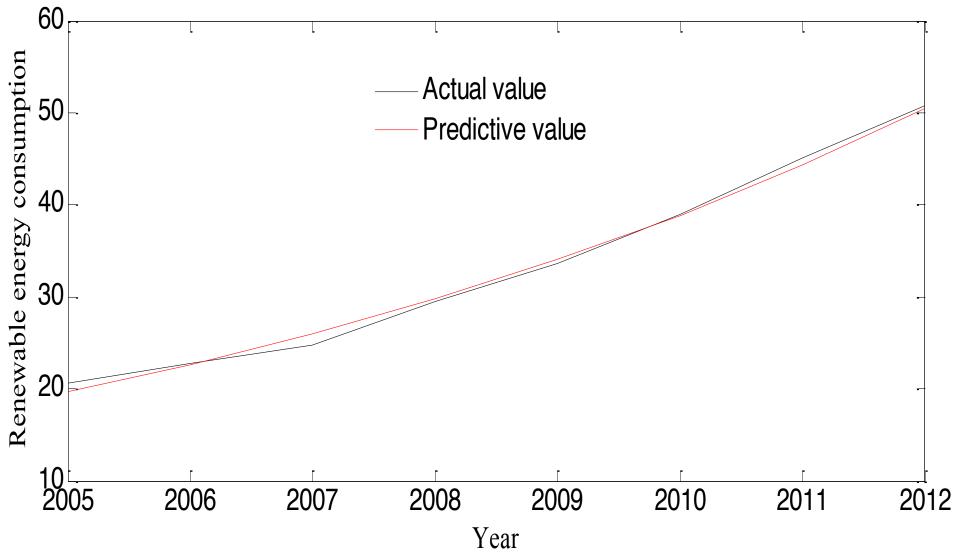

Figure1: Actual and predictive value of renewable energy consumption in the US

The Chinese renewable energy development is rather fast. After iterations, different K values are obtained with different determination coefficients R^2 as tabulated in Table 3. The largest coefficient R^2 is 0.9759, and the corresponding K value is 300 MTOE.

Table 3

Statistical examination of renewable energy consumption in China

K (MTOE)	R^2	a	r
100	0.9717	5.523	-0.4837
150	0.9739	5.915	-0.4766
200	0.9749	6.197	-0.4731
250	0.9755	6.416	-0.4711
300	0.9759	6.596	-0.4698
350	0.9756	6.749	-0.4688
400	0.9753	6.881	-0.4681

As illustrated in Table 3, a = 6.596 and r = - 0.4698; or y = 6.596 - 0.4698 t. Therefore, Logistic prediction model of renewable energy consumption for China is as follow.

$$X = \frac{300}{1 + e^{6.596 - 0.4698t}} \qquad (5)$$

In Figure 2, Equation (5) is plotted as a theoretically predicted curve, which is close to that based on the actual data.

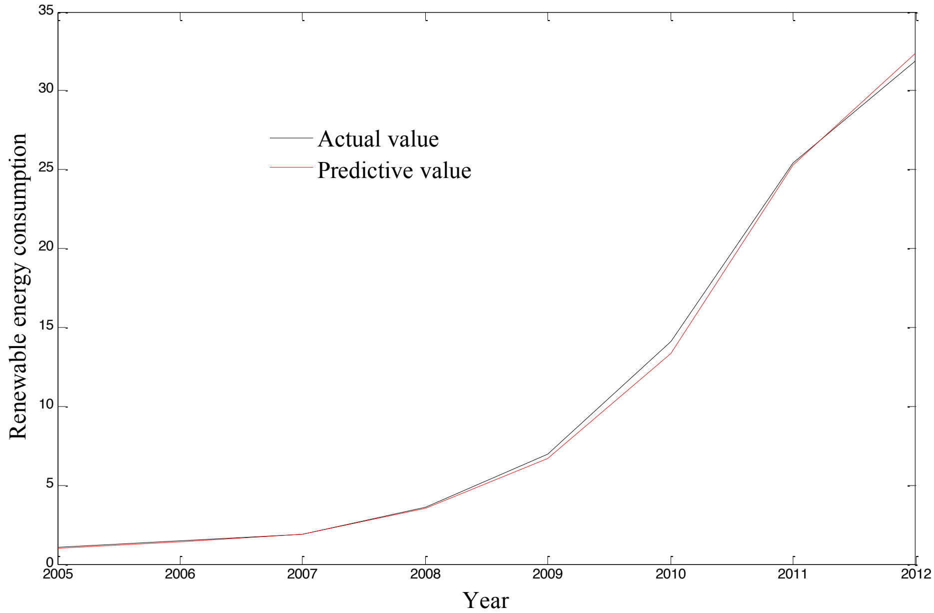

Figure2: Actual and predictive value of renewable energy consumption in China

4. Renewable Energy Consumption Predictions

Using models obtained above, one can then predict the renewable energy consumptions in the future. In Figure 3, the consumption for US is plotted as a function of duration. The predicted values (up to year 2030) and actual values (Year 2005 - 2012) can be viewed along one smooth curve without any apparent discrepancies. Additionally, for China, the predicted values (up to year 2030) and actual values (2005-2012) may be fitted to a curve with some kinks due to recent rapid development.

Between 2015 and 2020, the growth trend for China is much faster than that for US. By year 2030, the total amount of renewable energy consumption for each country will be very close. Such predictions can be related to the realistic situations in both countries. For China, rapid economic growth requires more energy resources, and leads to environmental pollutions. To solve both problems simultaneously, Chinese government places emphasis on renewable energy deployment. As a result, there will be accelerated development. For US, the economy is relatively stable, and the pace of renewable energy development will be increased slowly and gradually.

In Figure 3, the most important predictions are the trends, rather than the precise numerical values provided by the simulations. The maximum consumption value for China may be larger than that of US in the future because Chinese energy resources are less than that in US. Furthermore, it may take longer time for US to reach its maximum value than it is for China because US business emphasizes on longer term investments for energy than that in China.

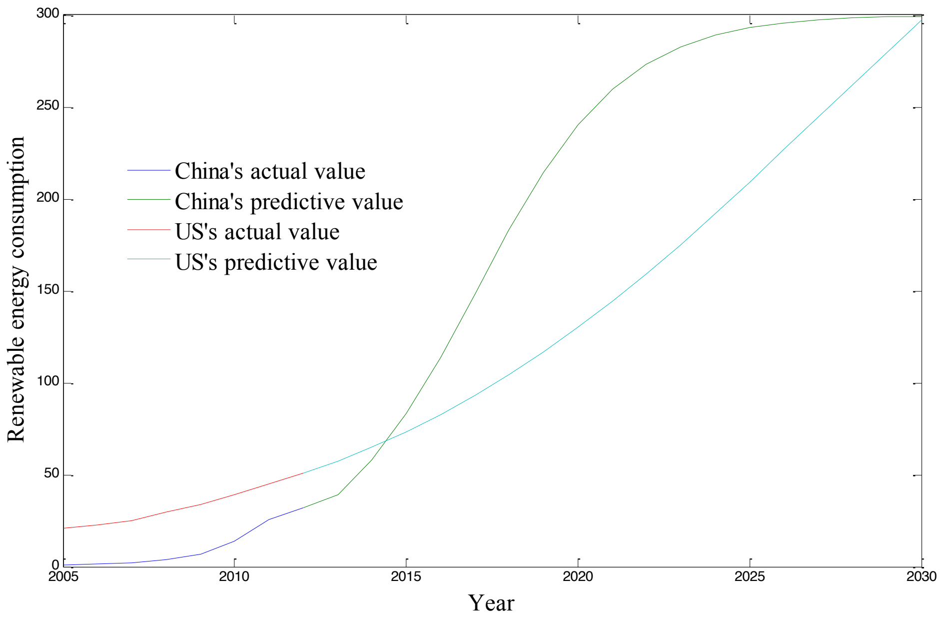

Figure3: Renewable energy consumptions in US and China

At this moment, the curves in Figure 3 are regarded as most probable trends based on available energy resources and relative costs of renewable energy deployment in these two countries. Other deviations from Figure 3 may exist as illustrated in Figure 4. The Chinese K parameter is between 200 and 400 MTOE, and the US parameter is between 400 and 600 MTOE. Around year 2015, the consumptions of both countries will be close regardless the K parameters. However, after 2015, the trajectories will depend on K parameters. With the same K parameter of 400 MTOE, Chinese consumption will always exceed that of US. With Chinese K parameter being 350 MTOE, Chinese consumption will still exceed US. At year 2030, with Chinese K parameter of 250 MTOE or less, the predicted Chinese consumption will be less than that of US. In the near future, such predictions may be modified with new breakthrough in technologies for renewable energy harvesting and deployment.

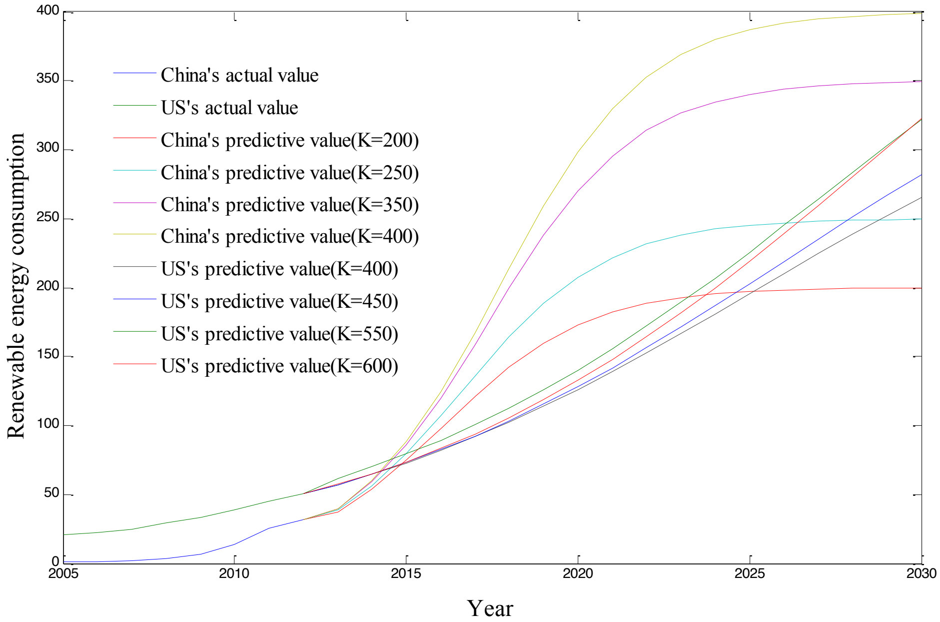

Figure 4: Renewable energy consumptions with different K parameters

5. Conclusions and Discussions

Based on the above analysis, renewable energy consumptions in China and US will increase with different trajectories. Around 2015, the consumptions in both countries will be close. Between 2015 and 2030, the growth rate in China may exceed that in US. For renewable energy development, experiences gained in one country may be useful in the other country. It would be beneficial if these two countries can cooperate in policies and technologies as they have the common interests in economy and environment. China gradually realizes that renewable energy may help its economy and environment. US may find a vast market for its renewable energy technologies. The fast growth in China is mainly due to the stimulus from its government. To sustain the growth, China should consider cooperation with US in technologies and investment. The steady growth in US is due to government policies and industrial needs. To increase the growth rate, US should consider cooperation with China in technology transfers and market development. Furthermore, if China and the US can jointly develop the renewable energy, there will be mutual benefits. Because two countries are similar in geological and geographical characteristics, cooperation between a Chinese province and a US state would be possible. Testing and measurement standards should be unified between China and US in order to promote the cooperation in renewable energy. Currently, we are exploring other modeling tools to compare development of hydroelectricity and smart grids. This study may provide insightful information on renewable energy consumption in the future.

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