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CAN CHINA USE ALTERNATIVE ENERGIES INSTEAD OF COAL TO PROVIDE MORE ELECTRICITY BY 2030?

By

Yan Wu

A THESIS

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ABSTRACT

Following the rapid growth of China's economy, energy consumption, especially electricity consumption of China, has made a huge increase in the past 30 years. Since China has been using coal as the major energy source to produce electricity during these years, environmental problems have become more and more serious. The research question for this paper is: "Can China use alternative energies instead of coal to produce more electricity in 2030?" Hydro power, nuclear power, natural gas, wind power and solar power are considered as the possible and most popular alternative energies for the current situation of China. To answer the research question above, there are two things to know: How much is the total electricity consumption in China by 2030? And how much electricity can the alternative energies provide in China by 2030? If the electricity provide by alternative energies can occupy more than fifty percent of the total electricity consumption, then the answer for the search question is yes otherwise it is no.

For a more reliable forecast, an econometric model using the Ordinary Least Squares Method is established on this paper to predict the total electricity consumption by 2030. The predicted electricity coming from alternative energy sources by 2030 in China can be calculated from the existing literatures. The research results of this paper are analyzed under a reference scenario and a max tech scenario. In the reference scenario, the combination of the alternative energies can provide 47.71% of the total electricity consumption by 2030. In the max tech scenario, it provides 57.96% of the total electricity

consumption by 2030. These results are important not only because they indicate the government's long term goal is reachable, but also implies that the natural environment of China could have an inspiring future.

Chapter 1: Introduction

1.1 Background

After over thirty years of rapid development, China replaced Japan as the second largest economy in the world.[1] The world has been astonished by China's average annual GDP growth rate of over 9% since year 1980, and China is proud of it.[2] Sufficient energy supply is very important to a country's economic development, especially the electricity supply, which is crucial to industrial activities and people's daily lives. To satisfy this electricity need, China has to use a lot of coal, which is cheaper and easier to convert to electrical power than other energy sources. The side-effect of burning coal leads to a series of environmental problems that will be elaborated upon in the next chapter. Most of the people didn't really see the consequences of coal-burning. Finally, the country-wide haze that appeared for a couple of weeks before the 2013 Chinese spring festival is sounding the alarm to people: Environmental problems are not just a research topic; they are happening now in your daily life and are threats to your health.

In fact, as early as China's ninth "Five-Year Plan"[3], the framework which dictates China's social and economic policies, during the period from 1995 to 2000, the government had

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[1] The Institute of Developing Economies, *Trade patterns and global value chains in East Asia: From trade in goods to trade in tasks*, (World Trade Organization, 2011).

[2] Liu Zhen, *A Study on China's Economy Development*, (IEEE, 2010).

[3] *Ninth Five-Year Plan in Retrospect*, China Internet Information Center, 2009, http://www.china.org.cn/95e/index.html (accessed March 12, 2013).

already started to encourage the development of clean energy. The government promoted the idea of sustainable development and strengthening comprehensive management. The main concepts of the energy part of the "Ninth Five-year Plan" report were natural resource conservation and environmental protection. Therefore, many small coal mines had been shut down and all the big coal thermal stations were asked to improve the combustion efficiency and emissions treatment since that period. At the same time, many significant alternative energy programs were carried out. These included the world's biggest hydropower project, Three Gorges hydroelectric power station and four nuclear power station projects (Qinshan Phase II station, Qinshan Phase III station, Lingao station and Tianwan station).[4]

The first nuclear power station began operations in 1994, and today "mainland China has 17 nuclear power reactors in operation, 28 under construction, and more about to start construction."[5] The hydroelectricity installed capacity in 1995 was 52 million kilowatts, and in 2010, the number increased to 219 million kilowatts.[6] In recent years, some other alternative energies such as wind power and solar power were also added to the electricity generation industry. The wind power generation in China went from barely nothing to 73.2

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[4] *Nuclear Power in China,* World Nuclear Association, 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/ (Accessed July 2013)

[5] Ibid

[6] XiaoLin Chang, XingHong Liu and Wei Zhou, *Hydropower in China at present and its further development,* (Energy, 2010), pages 4400-4406.

billion kilowatt-hours from 2005 to 2010.[7] As the cost of solar power keeps declining due to the technology progress, solar power also has a bright future. Right now, we can see the government's determination to build a more energy efficient and low carbon society in the recent "Twelfth Five-Year" plan. However, as long as China has massive energy needs, it will not be easy.

1.2 Problem statement

Therefore, the topic of this paper is: Can China use alternative energy to provide more electricity instead of coal by 2030? In this paper, hydro power, nuclear power, natural gas, wind power and solar power will be studied and analyzed as the primary alternative energy sources to coal in the electricity generation industry. The reasons to pick these energy sources are as follows: Hydro power in China has been widely used for many years and it is the energy source which contributes the most electricity except coal. Nuclear power development is the current major project of the Chinese government and the newest "Five Year Plan" still encourages the progress of nuclear power. Natural gas is the cleanest fossil fuel and China has a great ambition to use it as the replacement of coal and oil in many industry. Wind power as an encouraged policy has made dramatic progress in recent years. Solar power also has made great progress relying on the advantages of easy implementation

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[7] Li Junfeng, Shi Pengfei and Gao Hu, *2010 CHINA WIND POWER OUTLOOK,* (Chinese Renewable Energy Industries Association, 2010).

and the low cost possibility for the future. All of these energies will be discussed in later Chapter.

To answer the topic question, there are two things needs to know: How much electricity can coal provide in China by 2030? And how much electricity can alternative energy provide in China by 2030? Since the total electricity generation in China can only divide into these two part and basically the total generation is equate to the total consumption in electricity industry, the two question can be slightly change to these two: How much is the total electricity consumption in China by 2030? And how much electricity can alternative energies provide in China by 2030?

1.3 Motivation for the study

The primary motivation for this research is my concern for the environmental problems in China. As we know, in China, almost all of the thermal power stations use coal to generate electricity and using coal creates many harmful issues. According to the Chinese government's development principle which is "promote social harmony and stability,"[8] a low carbon environment has to be a goal. Thus, the age of using coal as a major energy source has to be in the past. Second, the result of this topic is very interesting to me. It relates not only to the natural environmental situation of China in the future, but also to the stability of the Chinese society. In recent years, public discontent and social issues have

[8] Yao Chun, *Full text of Hu Jintao's report at 18th Party Congress,* People's Daily Online, 2012, http://english.people.com.cn/102774/8024779.html (accessed March 22, 2013).

increased because of the worsening pollution problem and the government's lack of supervision over environmental control. Third, about two and half years ago, I did a four-month internship in a hydro power station construction project during the summer in China, so this topic is suitable for me because of my experiences during that time. Finally, I hope to apply the knowledge which I learned from class to pressing societal issues.

1.4 Research result

As mentioned before, the research result of the topic question is related to the answer of the two fundamental questions. To forecast the electricity generated by alternative energies in China by 2030. The method is relatively straight-forward. All the five alternative energies are researched and analyzed from existing literatures. There is a conclusion table in a later chapter. However, to forecast the total electricity consumption in China by 2030 is not that easy. As there are many different opinions about China's economic future, the energy needs or specifically, the electricity needs are quite different depending on which opinions are held. In this paper, an econometric model will be built due to make a more reliable prediction of the China's total electricity consumption in 2030 based on a series of historical data. The final research result is: In the reference scenario, the combination of the alternative energies can provide 47.71% of the total electricity consumption by 2030. In the max tech scenario, it provides 57.96% of the total electricity consumption by 2030. In another words: China has a high possibility to use alternative energies instead of coal to provide more electricity by 2030.

This result is important not only because it is a policy goal, but also it is a crucial answer to the Chinese people. In recent years, the natural environment in China has gone from bad to worse, especially the air pollution in many major cities. The pressures from public, national media and even international media has forced the government to make a strong effort to deal with the problem. The policy goal of more use of alternative energy would achieve a cleaner natural environment in China, especially air quality than today.

Chapter 2: China's economy and electricity history and environmental problems

2.1 The development of China's economy

After the "Reform and Opening Up"[9] idea raised by Deng Xiaoping in 1978, China's economy began its astonishing improvement. Increasing from a GDP of $176 billion USD in 1979 to $7.3 trillion USD in 2011, China has maintained an average GDP growth rate of more than 9% for more than thirty years.[10] Right now, China is the second-largest economy and the biggest manufacturer in the world. As long as the economy progresses, the energy demand will increase explosively, especially the electricity demand for industrial activity.

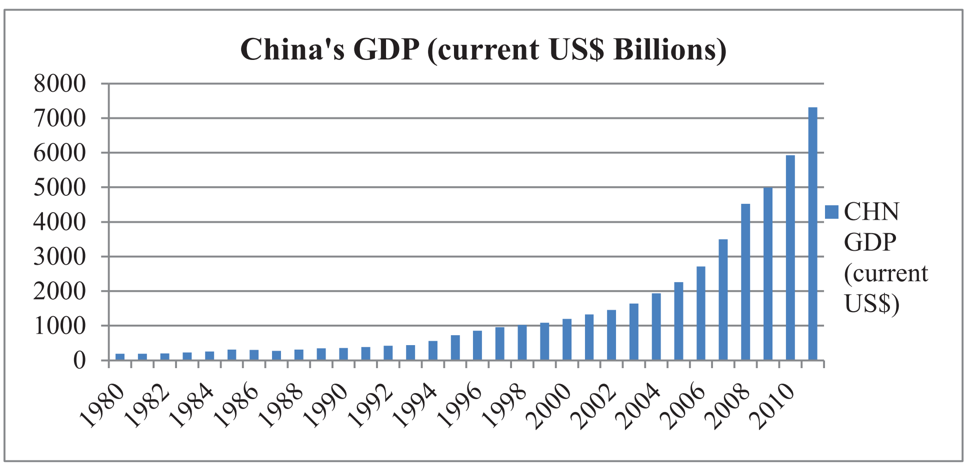

Figure 2.1.1 China's GDP (current US$ Billions)[11]

[9] Clem Tisdell. *Economic Reform and Openness in China: China's Development Policies in the Last 30 years* (Economic Analysis & Policy, 2009).

[10] Ibid

[11] Source: The World Bank, 2011, http://www.worldbank.org/ (accessed April 3, 2013)

2.2 The development of China's Electricity

In the mid-1990s, China became the world's second largest electricity consumer.

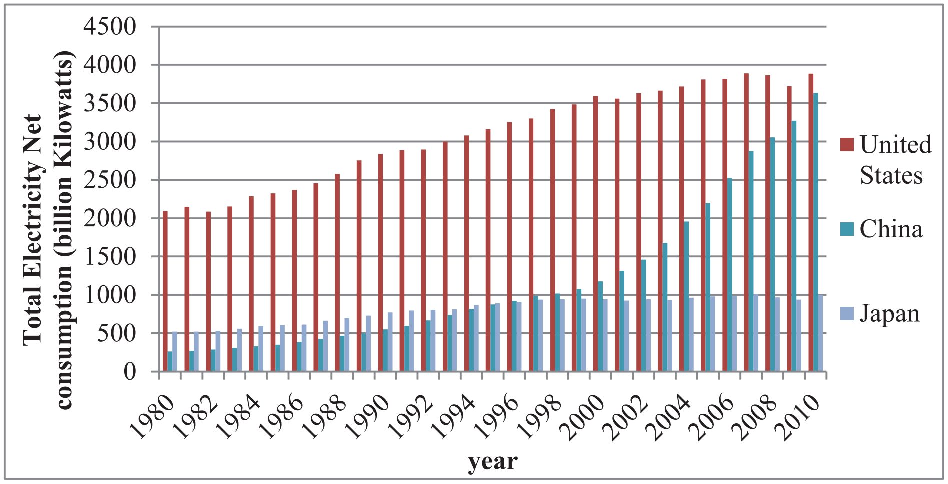

Figure 2.2.1 Total Electricity Net Consumption (Billion Kilowatts)[12]

Although China has abundant hydroelectric resources, coal is cheap and easy to obtain. Coal is a high reservation energy resource which is much more useful to generate electricity in China.

The government tried to use alternative energies resources many years ago, but at the same time, the developing economy needed more and more energy. Energy shortages can have a damaging effect to a growing economy. In the ecological economist David Stern's paper, "The role of energy in economic growth", he concludes that "when energy is scarce it imposes a strong constraint on the growth of the economy but when energy is abundant its

[12] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed April 7, 2013)

effect on economic growth is much reduced."[13] So at that time, the Chinese government chose to sacrifice the environment to keep the economy growing, while still using more coal. Step to the 21st century and energy supply is still a serious problem for China. But after over 30 years of economic development and technological improvement, the Chinese government is much stricter on the efficient use of coal and they invest more and more money in the alternative energy industry. Many major hydro plant projects are in progress, and a couple huge nuclear plants are also on the agenda. I believe in the long term future the government's general principle of "promoting social harmony and stability"[14] will not change. As China finishes its industrial development, economic growth will inevitably slow down. Although the policy on family planning continues to loosen, the willingness of young people to have more children is still declining, so the population in China will settle down around 1.4 billion.[15] All in all, the energy demand from China will have a limit. So, with the development of technology and the completion of many alternative energy projects, the age of using coal as a major energy source will be gone. The combination of using alternative energies may supply more than half of the total electricity needs in 30 years.

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[13] David I Stern, *The Role of Energy in Economic Growth* (Centre for Climate Economics & Policy, 2010).

[14] Mu Xuequan, *Senior Chinese leader calls for stability, social harmony*, Chinese Government's Official Web Portal, 2012, http://english.gov.cn/2012-05/23/content_2143121.htm (accessed April 13, 2013)

[15] David Fridley, Nina Zheng, Nan Zhou, Jing Ke, Ali Hasanbeigi, Bill Morrow and Lynn Price, *China Energy and Emissions Paths to 2030* (Lawrence Berkeley National Laboratory, 2012).

2.3 Introduction of China's thermal stations situation

In the paper, "Hydro Power Vs. Thermal Power: A Comparative Cost-Benefit Analysis"[16], it can be seen that a thermal station has a much cheaper construction price, more flexible design and shorter construction cycle as compared to a hydro power station; plus China has the world's third largest coal reserves. The development of coal thermal stations has been fast during the past years, as shown in Figure 2.3.1.

The cumulative thermal installed capacity (in million kilowatts) in China leapt from 65 in 1980 to 987 in 2011. The vice minister of the Chinese environmental division Xiaoqin Wu says: "Until 2010, the coal thermal installed capacity occupied 73% of the total installed capacity and more than 80% of the total electricity generation comes from coal thermal stations. Although China has become the world's second largest electricity generating country, the per capita electricity consumption is very low (0.74 KW) compared to the U.S. (3.5 KW), Japan (2.0 KW) and the European Union (1.4 KW)."[17] His point in that speech is there is a lot of work to do to in the future to reduce the pollution that comes from the coal thermal industry since it will keep growing very quickly. By the end of 2012, the total installed capacity in China reached 1145 million kilowatts (MK), with year-on-year growth of 7.8%. Hydroelectricity shares 21.7% of the total capacity which is 249 MK, thermal

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[16] Adesh Sharma, *Hydro Power vs. Thermal Power: A comparative Cost-Benefit Analysis* (International Journal of Arts and Sciences, 2010).

[17] *Coal Thermal plant emission standards*, Chinese Government's Official Web Portal, 2011, http://www.gov.cn/gzdt/2011-09/21/content_1953217.htm (accessed April 22, 2013).

power shares 71.5% which is 819 MK and nuclear power contributes 13 MK; wind 61 MK; solar 3.3 MK.[18]

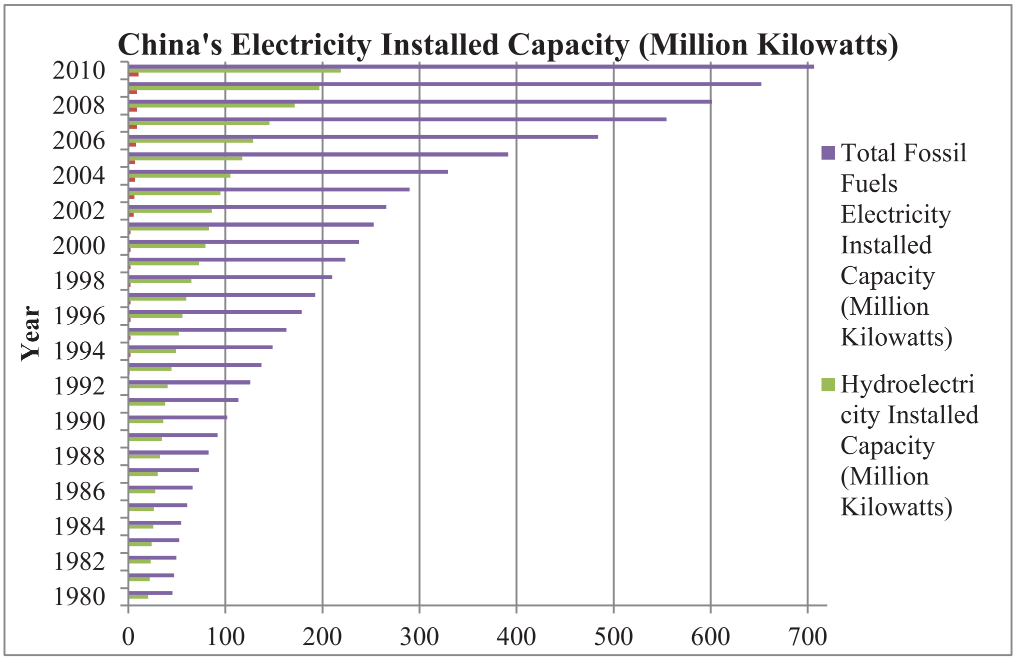

Figure 2.3.1 China's Electricity Installed Capacity (Million Kilowatts)[19]

Although, as the technological level keep improving and the efficiency of using coal keeps growing, the production of coal still increased significantly due to the massive electricity needs in past years. Due to the great improve of China's industrial development, the Figure 2.3.2 shows the production of coal increased rapidly after 2000.

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[18] *Coal Thermal plant emission standards*, Chinese Government's Official Web Portal, 2011, http://www.gov.cn/gzdt/2011-09/21/content_1953217.htm (accessed April 22, 2013).

[19] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed April 17, 2013).

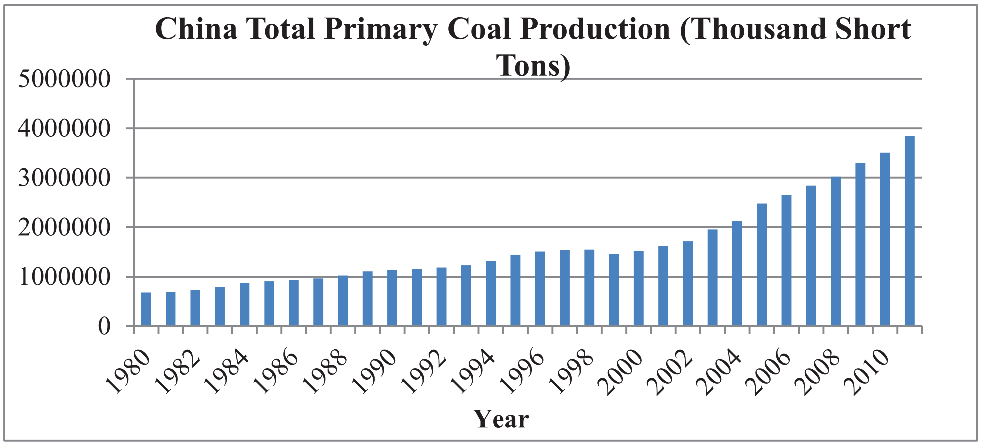

Figure 2.3.2 China Total Primary Coal Production (Thousand Short Tons)[20]

2.4 The environmental problems caused by using coal in China

Most of the electronic power in China comes from coal thermal stations. Using coal leads to a series of environmental problems. Sulfur dioxide, carbon monoxide, fumes, radioactive dust, nitric oxide and carbon dioxide come out when burning fossil fuels. These emissions are very harmful, both to humans and livestock. Fumes and radioactive dusts accumulated in the body can lead to cancer (especially lung cancer) and radiation damage.

In the past 30 years, the mortality of lung cancer has risen 465% and has become the first leading cause of death for all cancers. There are 3.12 million new diagnosed cases per year in China, which means 8550 per day, which means there are 6 people diagnosed with cancer every minute. The tables above come from a paper "China's Environmental Costs: Cancer". Cancer has already become a big threat to people's health in China.

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[20] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed April 22, 2013).

Table 2.4.1 Leading Sites of New Cancer Case in China over the Last 30 Years[21]

The Leading Sites of New Cancer Case in China over the last 30 years.		
1970s	1990s	2000s
Stomach Oesophagus Liver Lung Cervix	Stomach Liver Lung Oesophagus Colorectal	Lung Liver Stomach Oesophagus Colorectal

Table 2.4.2 Percentage of Change in Annual Mortality Rates among Urban and Rural Areas[22]

The percentage of change in annual mortality rates among urban and rural areas		
Type of Cancer	Annual mortality Rate (%)	
	urban	Rural
Cervix	-27.5	-17.3
Lung	+29.4	+47.7
Liver	+13.0	+17.1
Colorectal	+31.2	+17.5
Breast	+38.9	+39.4
Bladder	+23.5	+19.9

Sulfur dioxide is the main cause of acid rain. The acidic gases are released into the atmosphere, carried by the wind and dissolved in rainwater to form acid rain. Acid rain can kill plant life, aquatic animals and infrastructure. The picture below shows the SO_2 emissions from the Chinese power sector.

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21 *China's Environmental Costs: Cancer, Collective Responsibility*, 2009, http://www.collectiveresponsibility.org/2009/02/09/chinas-environmental-costs-cancer/ (accessed April 28, 2013).

22 Ibid

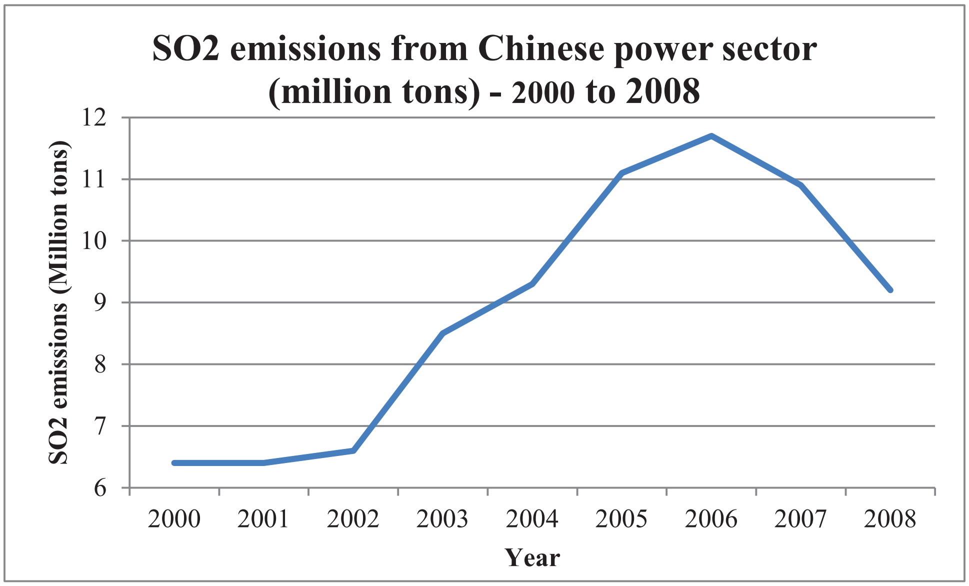

Figure 2.4.1 SO2 emissions from Chinese power sector - 2000 to 2008[23]

We can see the emissions decreased after year 2006. That decrease is because more and more coal thermal stations are implementing new de-sulfur equipment to satisfy requirements from the MEP (Ministry of Environmental Protection).

Carbon dioxide is the primary greenhouse gas that leads to the global warming effect. It can reduce the outward radiation of heat which means warming the earth's surface. Since China is the biggest coal consumer country, the CO_2 emissions from coal are also large.

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[23] Source: Climate Connect, 2009, http://www.climate-connect.co.uk/Home/ (accessed May 1, 2013)

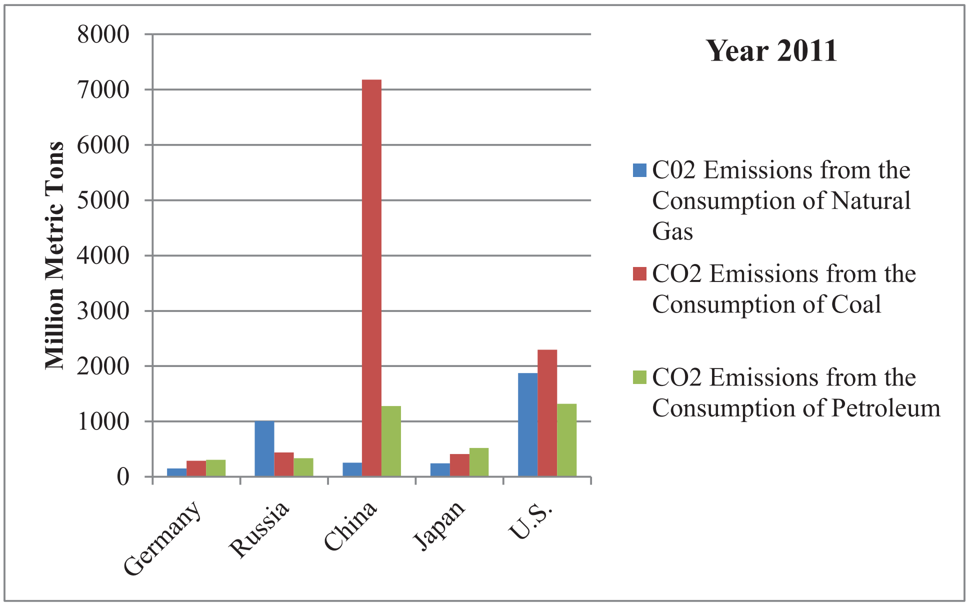

Figure 2.4.2 CO_2 Emissions[24]

Years ago, these hazards were more like a paper title in some unpopular science magazine. But the country-wide horrible haze weather that lasted a couple of weeks just before the 2013 Chinese spring festive pulled people to the reality of the cost of rapid economy development. "The PM 2.5 (particles less than 2.5 microns) data in Beijing hit 450 on that day, which means heavily polluted air quality. Four cities reached 500 API (Air pollution Index), which is the maximum number on the index. An API reading below 50 means excellent air quality, 50 to 100 indicates healthy air, and above 100 means polluted air."[25]

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[24] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed May 3, 2013)

[25] KaiJing Xiao, *China's Filthy Air Prompts Mask Rush and Sale of Fresh Air in Cans*, abcNews, 2013, http://abcnews.go.com/International/chinas-filthy-air-prompts-mask-rush-cans-fresh/story?id=18352787 (accessed May 3, 2013).

In fact, there are lessons of history. During the 1950-60s period of the 20th century, because of heavy use of coal as fuel, London had been called the city of fog. A great smog event in December 1952 in London killed 4000 people.[26]

As it shows above, the negative impacts of using coal to generate electricity have far-reaching effects on China's natural environment. The following chapters will show how this situation may change in future based on the investigations of the exciting literatures and the forecast models.

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[26] *The Great Smog of 1952*, Met Office, 2012, http://www.metoffice.gov.uk/education/teens/case-studies/great-smog (accessed May 3, 2013).

Chapter 3: Literature review

As mentioned earlier, an econometric model will be built to make a more reliable prediction of the China's total electricity consumption in 2030 based on a series of historical data. In the paper "Electricity Demand in the People's Republic of China: Investment Requirement and Environmental Impact", an econometric model of a long-term electricity consumption function for China was constructed by Bo Q. Lin in 2003.[27] The author concludes that there are five main factors determining the electricity consumption based on his research. These are Gross Domestic Product, electricity price, population, structural changes in the economy and efficiency improvement. The function for China's electricity consumption could be established as:

$$Q = f(GDP, P, POP, M2, EF) \quad (3.1)$$

Where, Q is electricity consumption.

GDP is gross domestic product.

P is the fossil fuel price indexes.

POP is population.

M2 is the total industry share minus the share of the heavy industry in GDP.

EF is value-added produced by industry divided by electricity consumed by industry.

[27] Bo Q. Lin, *Electricity Demand in the People's Republic of China: Investment Requirement and Environmental Impact* (Asian Development Bank, 2003).

This model was built about 10 years ago and it will not be appropriate for current usage today, but the original thought is still praise worthy. The author uses the fossil fuel price indexes as a proxy of electricity because the electricity tariffs in China are very complex. The price of Chinese electricity is different for different administrative regions. The price is decided by the local administration but it cannot go over the limit provided by central authorities. This price includes all of the fees for resources, operation, maintenance and the operator's reasonable profit. Industrial electricity prices are higher than commercial electricity, and commercial electricity prices are higher than residential electricity. Thus, using the fossil fuel price indexes was quite reasonable at that time. In this thesis, the final goal of the government is to use more low carbon energy, thus the price of fossil fuel price is no longer significant. Some other changes will also be made and these will be discussed in next chapter.

To make the predicted results more credible, it is better to use two scenarios, one is based on existing achievement and another one is based on a better technological level. In the Berkeley Lab's report "China Energy and Emissions Paths to 2030 (2nd Edition)", it provides inclusive details about the energy and emissions.[28] In this report, two different prediction scenarios are provided. One is the reference scenario using a comparatively conservative model and the other is the max tech scenario using a slightly radical model in

[28] David Fridley, Nina Zheng, Nan Zhou, Jing Ke, Ali Hasanbeigi, Bill Morrow and Lynn Price, *China Energy and Emissions Paths to 2030* (Lawrence Berkeley National Laboratory, 2012).

some aspects. Therefore, it is a good example for this thesis. There are some predicted data from this literature which is utilized into this thesis's model to provide the goal variable needed to produce a more reliable predicted result.

To understand the development of China better, the book "China 2030 – Building a Modern, Harmonious, and Creative Society"[29] was read. China is described from 1978 to 2030. The authors summarized the achievements that China has made and look forward to the future. Six important messages emerged from the analysis and they are: "First implement structural reforms to strengthen the foundations for a market based economy. Second, accelerate the pace of innovation and create an open innovation system. Third, seize the opportunity to 'go green'. Fourth, expand opportunities and promote social security for all. Fifth, strengthen the fiscal system. Sixth, seek mutually beneficial relations with the world." This book is so fascinating with abundant contents and thoughts. The predicted Chinese economic structure in 2030 will be used in a later chapter.

Considering the hydro power, in the paper "Hydropower in China at present and its further development", the authors described the situation of hydropower in China in great detail.[30] The authors show their blueprint of the Chinese hydropower industry in the future based

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[29] Development Research Center of the State Council, *China 2030 – Building a Modern, Harmonious, and Creative Society* (The World Bank, 2013).

[30] XiaoLin Chang, XingHong Liu and Wei Zhou, *Hydropower in China at present and its further development* (Energy, 2009), pages 4400-4406.

on their understanding of the present hydropower industry's structure. They believe that the abundant hydroelectricity resource and huge market demand will lead the development of the Chinese hydropower industry. At the same time, they also give their opinions about the problems and suggestions in China's hydropower development. The paper "Research on Prospect and Problem for Hydropower Development of China"[31] provides more perspectives and suggestions about the problems of China's hydropower development compared to the previous paper. In this paper, there are more details about the problems before a hydropower construction begins. Lots of knowledge about China's hydroelectricity industry came from these two sources. The predicted hydroelectricity generation in 2030 is based on the investigation of the hydro power reserves capacity in this these sources.

There is more data and development details about nuclear, natural gas, solar power and wind power which comes from the IEA web site, IAEA web site and other sources.

[31] LI Jia-kun, *Research on Prospect and Problem for Hydropower Development of China* (Procedia Engineering, 2012).

Chapter 4: Theory and Variables

4.1 Theory Assumption

As mentioned before about this topic, there are two things to consider: How much is the total electricity consumption in China by 2030? And how much electricity can alternative energies provide in China by 2030? The first question is the most difficult part because there are so many different opinions from many economists and researchers all over the world. Some people with an optimistic view believe that China will keep this rapid development due to the huge domestic market and continuous reforms, other people with a pessimistic view believe China's development will quickly slow done due to her having exhausted the demographic dividend and the population aging will be a serious problem for future China. In this paper, all the opinions are set aside and the choice is to use the analysis of historical data to build an econometrics mode, using moderation forecasted data from an authoritative sources lab to predict the total consumption in China by 2030.

After that, the question of how much electricity can alternative energies provide in China by 2030 will be split to five parts. Each part will investigate the performance of the different alternative energy source in electricity generation industry. A summary table will be given after the serial analysis. Once the answers for the two question are reached, the final result of this paper can be determined.

4.2 Variables in models

As mentioned in the last chapter, Bo's model used GDP, population (POP), structure (STR), price (P) and efficiency (EF) to predict electricity consumption. In the models of this paper, there will be some changes.

Since the increase rate of China's population is slowing down in recent years and according to the research paper from the World Bank, the peak population of China will be arrive even before 2030. Therefore, POP is excluded in the new model.

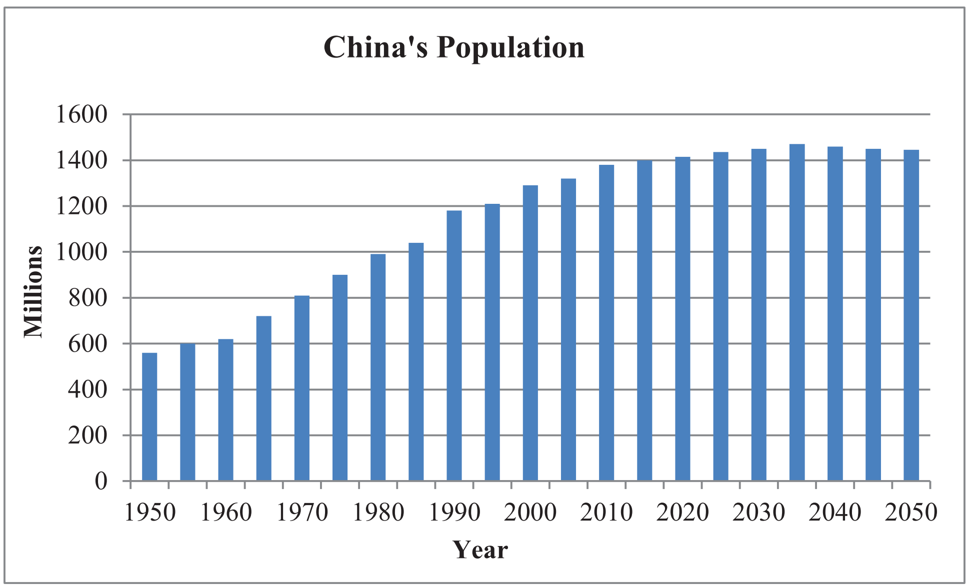

Figure 4.2.1 China's Population[32]

In Bo's models, EF is value-added produced by industry divided by electricity consumed by industry. This variable represents the efficiency of the industry aspect more than the indicator of electricity consumption. Thus, EF is also excluded in the new model. The new

[32] Source: The World Bank, 2011, http://www.worldbank.org/ (accessed June 3, 2013)

model is dedicate to predict the electricity consumption in future China which should be less sensitive with coal, so the P that represents the fossil fuel price indexes needs to be excluded.

The original thought of this new model only uses GDP as the independent variable to predict the electricity consumption. However, as the graph shows below, after 2004, the difference of these two lines is substantial. So there should be another significant independent variable.

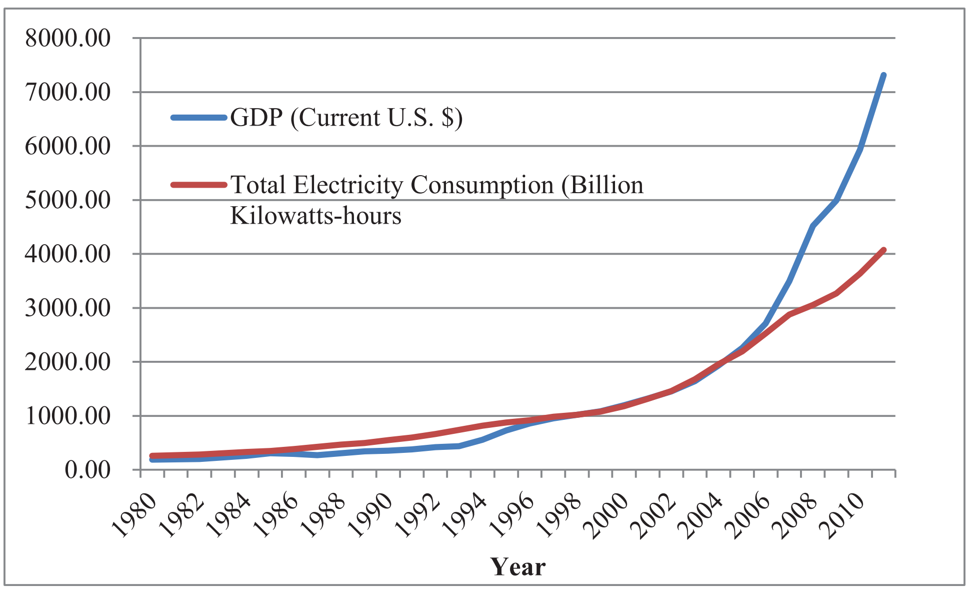

Figure 4.2.2 China's GDP against Total Electricity Consumption[33]

In Bo's models, STR was represented by total industry share minus the share of the heavy industry in GDP. In the new models, STR is a ratio calculated by the sum of value-added industry GDP plus value-added services GDP divided by value-added agriculture GDP.

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[33] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed June 7, 2013)

The rapid progress of urbanization in China leads to very quick service industry growth; at the same time, the electricity consumption for the service industry also increases rapidly. Meanwhile, the agriculture industry of China is a minor electricity consumer. Most cultivations are still manual work. So the new STR is very significant for the new models. In Bo's regression function, all the independent variables are using the value at time t to calculate the dependent variables at time t. In the models of this paper, GDP_t and STR_{t-1} will be used to predict the Q_t (Total electricity consumption in time t), because the electricity consumption in year t is always determined by the GDP in year t and based on the structure in year t-1.

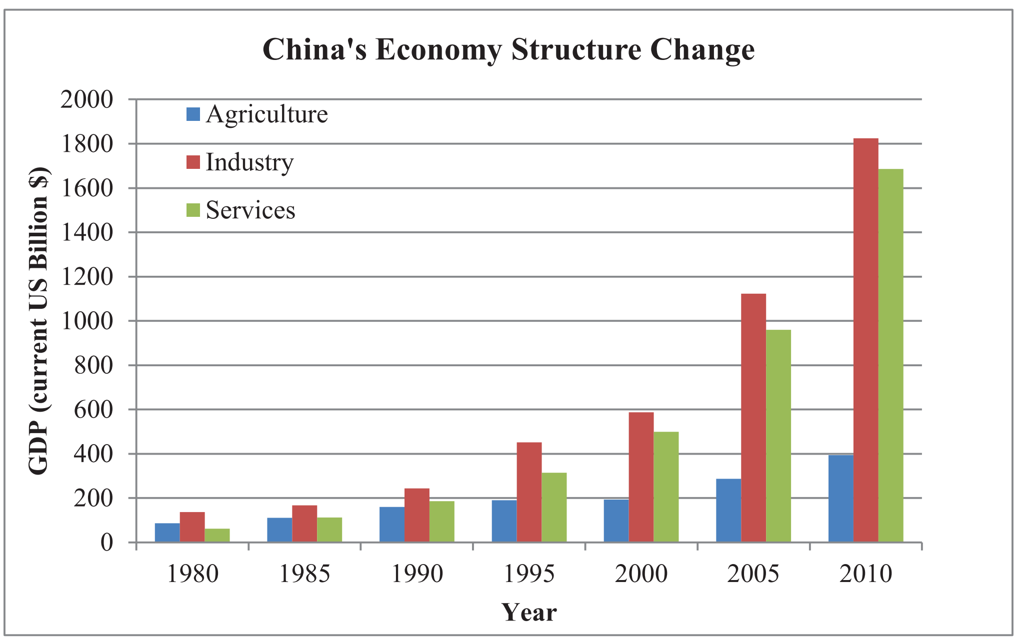

Figure 4.3.1 China's Economy Structure Change[34]

[34] Source: The World Bank, 2011, http://www.worldbank.org/ (accessed June 7, 2013)

4.3 Data Collection

Based on the theory discussed, the independent variables for estimating the total electricity demand are GDP and STR. All of the data is collected in a time series form. The sample range is from 1980 to 2010. Various sources are used to find these data such as the IEA, the World Bank and China Statistical Year Books and the raw data can be find in appendix 1.

GDP, as the most important determinant for economic activities, is obtained from the World Bank. The unit for this independent variable is current U.S. billion dollar. Population (POP) data is also obtained from the World Bank and the unit is in a million people. China's economy structure change (STR) is a ratio calculated by value-added industry GDP, value-added services GDP and value-added agriculture GDP. Both of the two values are obtained the World Bank. The dependent variable, total electricity consumption (Q), is obtained from IEA and the unit is in Billion Kilowatt-hours.

Chapter 5: Modeling, tests and analysis

5.1 Method Chosen

There are many methods for regression analysis. For this model, the Ordinary Least Squares (OLS) method has been chosen because the advantage of OLS. It has been the most widely used method for estimating the unknown parameters in a linear regression model for many years. OLS is the best method because it minimizes the sum of squared errors and it is relatively easy to do by modern software. To implement the OLS method in the model, there are some necessary assumptions and conditions:

Table 5.1.1 Classical Assumptions of OLS[35]

1. The regression model is linear in the coefficient, is properly specified, and has an additive error term.
2. The error term ε has a zero population mean.
3. All explanatory variables are uncorrelated with each other.
4. Observations of the error term are uncorrelated with each other.
5. The error term has a constant variance.
6. No explanatory variable is a perfect linear function of any other explanatory variables.
7. The error term is normally distributed.

The assumptions and conditions in table 5.1 are very important when a model uses an OLS method. There are a series of tests to verify if a model will meet all these assumptions. If a model can't meet all of the assumptions, it can reflect many possible problems about the

[35] A. H. Studenmund, *Using econometrics: A Practical Guide. 6th edition* (Addison-Wesley Longman, Inc., 2010).

model such as there are omitted or irrelevant variables in the function or the model is with a weak theory assumption.

5.2 Choosing Appropriate Functional Form

As discussed in Chapter 3 and Chapter 4.2. For China's total electricity consumptions model, the equation can be explained as below:

$$Q_t = f\ (GDP_t, STR_{t-1}) + \ \varepsilon_t \qquad (5.1)$$

Where, Q_t is the quantity of total electricity consumption in time period t.

GDP_t is the Gross Domestic Product in time period t.

STR_{t-1} is the economy structure ratio in time period t-1.

ε_t is the stochastic error term in time period t.

In Chapter 3, Bo's model, he uses the equation 3.1 to do the regression and generate function 3.2 and 3.3. Both of the two functions are in double log form. Since the equation 5.1 is modified from equation 3.1, a rethinking of the functional form is necessary. It violates the first assumption if an inappropriate functional form is used. Several functional forms can be chosen besides double log form. They are linear form, semi-log form, polynomial form and inverse form. Usually speaking, the theoretical relationship between the dependent variable and independent variables is the most important factor to choose the functional form. However, it is very hard to tell what kind of relationship is between the electricity consumption and all the other variables. So, plotting some visual graphs will be helpful.

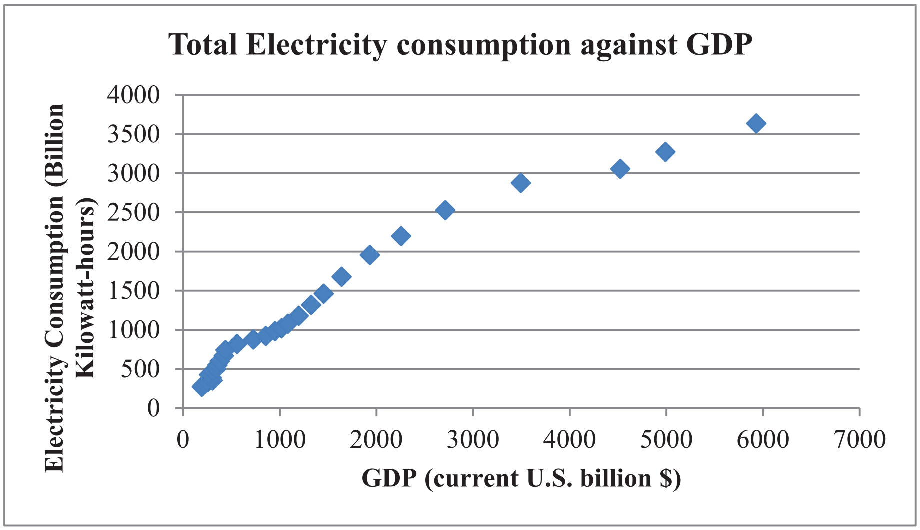

Figure 5.2.1 Total Electricity Consumption against GDP[36]

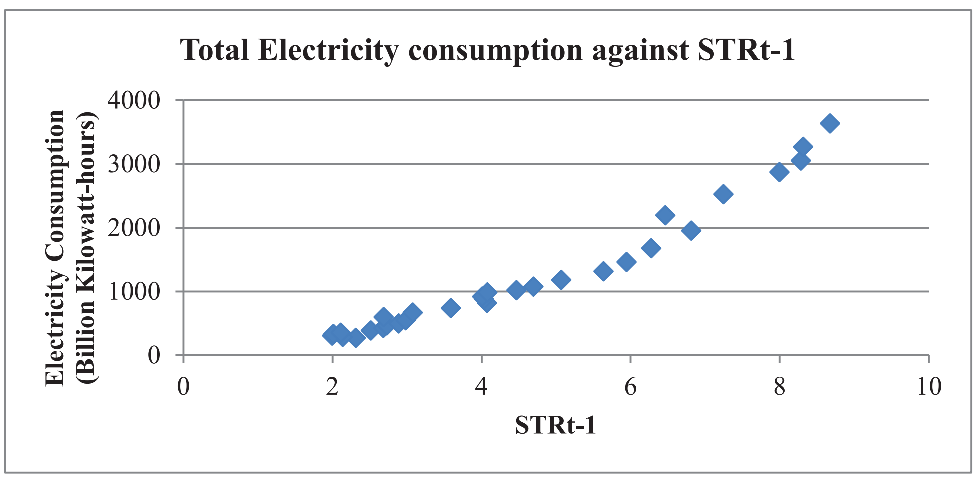

Figure 5.2.2 Total Electricity Consumption against STR_{t-1}[37]

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[36] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed June 12, 2013).

[37] Ibid

From the figures above, it is very hard to say which function form is more appropriate. Considering the original model in Chapter 3, the linear form regression and the double-log form regression are made.

Linear Form: (5.2)

$$Q_t = -260.349 + 0.336 * GDP_t + 227.172 * STR_{t-1}$$

	(0.029)	(20.543)	
t stat	11.669	11.059	
n=30	R^2= 0.991	$\overline{R^2}$=0.990	F= 1567.421

Double Log Form: (5.3)

$$Ln(Q_t) = 3.055 + 0.389 * Ln(GDP_t) + 0.819 * Ln(STR_{t-1})$$

	(0.075)	(0.163)	
t stat	5.168	5.019	
n=30	R^2= 0.989	$\overline{R^2}$=0.988	F= 1217.627

The function 5.2 and function 5.3 show that the R and $\overline{R^2}$ scores in these two functions are very close. Since these two regressions use different functional forms, the R values are not comparable. Hence, plotting graphs are helpful for deciding which one fit to the original data.

After comparing Figures 5.2.3 and 5.2.4, the Double-Log functional form looks a slightly better fit than the linear functional form. However, when the difference is not very obvious, a quantification comparison is necessary.

The mean of the linear Residuals Square is 7980.365 and the mean of the double log Residuals Square is 6373.064. So, the double log functional form is more appropriate in this mode.

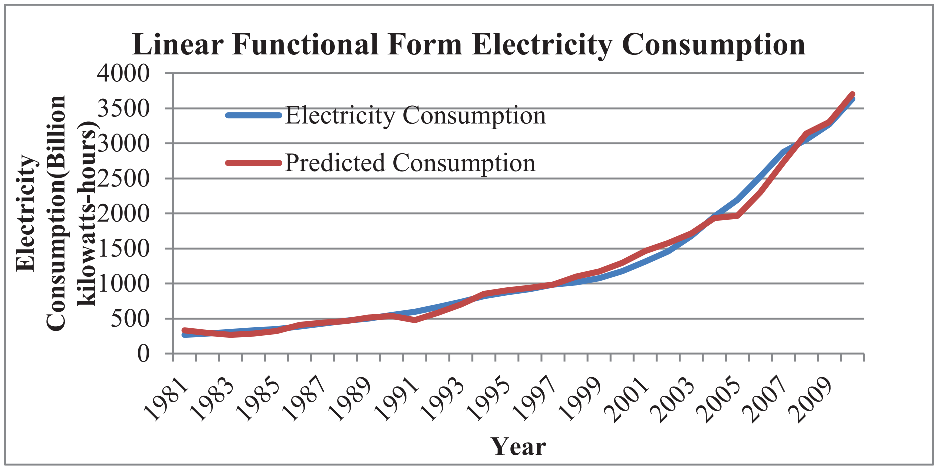

Figure 5.2.3 Linear Functional Form Electricity Consumption[38]

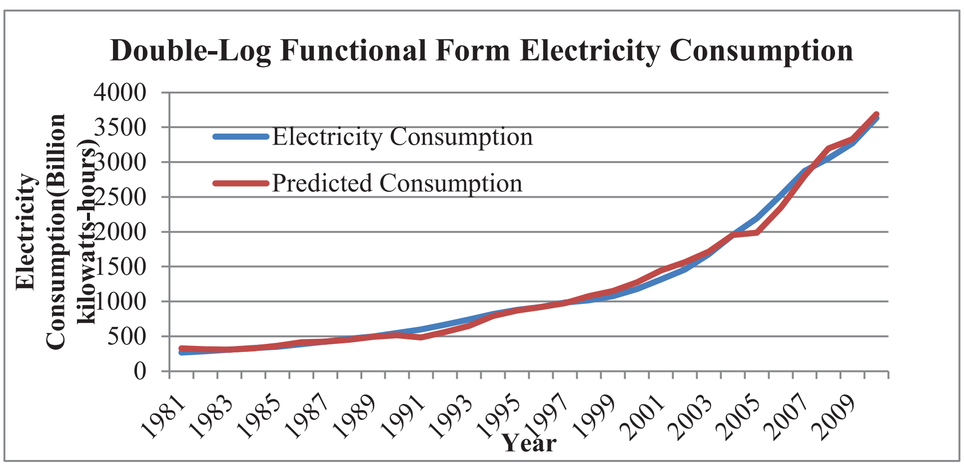

Figure 5.2.4 Double-Log Function Form Electricity Consumption[39]

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[38] Source: Appendix 1.

[39] Ibid.

5.3 Hypothesis Tests

In Chapter 5.2, the double functional form is decided for this model. For the hypothesis testing, the T-test needs to be done for each independent variable and the F-test needs to be done for the whole equation.

$$Ln(Q_t) = 3.055 + 0.389 * Ln(GDP_t) + 0.819 * Ln(STR_{t-1}) \quad (5.3)$$

	(0.075)	(0.163)		
t stat	5.168	5.019		
n=30	R^2= 0.989	$\overline{R^2}$=0.988	F= 1217.627	

GDP, as the most important determinant for economic activity, when it increases, the electricity consumption should increase as well, so the expected sign for GDP is positive. STR is a ratio represents China's economy structure, which is calculated by the sum of value-added Industry GDP plus value-added Services GDP divided by value-added Agriculture GDP. Figure 4.1 shows the structure change from 1980 to 2010. The high ratio of STR means the economy structure is more focused on the Industry and Services territory. Since Industry and Services are the major electricity consumers and Agriculture is a minor consumer of electricity, the expected sign of STR is positive.

T test Hypothesis:

GDP_t: The expected sign is positive

H_0: $\beta_1<0$; H_a: $\beta_1>0$

STR_{t-1}: The expected sign is positive

H_0: $\beta_2<0$; H_a: $\beta_2>0$

(β_1 is the coefficient of GDP_t, β_2 is the coefficient of STR_{t-1})

In the hypothesis test, if the absolute value of the t-statistic of the variable is greater than the critical statistic value from the t-table, and the expected sign for this variable is also the same as H_a, then H_0 can be rejected. Otherwise, H_0 is not rejected.

The degrees of freedom (df) is equal the number of observations (n) minus the number of independent variables (k) minus one. In the equation 5.3, the df is equal to 27. Using a five percent level of significance with a one tail test and 27 degrees of freedom, the critical statistic value from the t-table is 1.703. Table 5.3 shows the hypothesis test results for each variable.

Table 5.3.1 Hypothesis Test Table

	t_c	t_k	expected sign	Observed sign	Hypothesis test Results
GDP_t	1.703	5.168	+	+	H_0 rejected
STR_{t-1}	1.703	5.019	+	+	H_0 rejected

As Table 5.3 reflects, the coefficients of GDP_t and STR_{t-1} have the expected signs and the absolute value of t_k is greater than the value of t_c. So, the null hypothesis H_0 is rejected for these coefficients, which mean these variables are significant in this model.

To examine the entire equation for all the variable's coefficients, an F-test is needed.

F test Hypothesis:

H_0: $\beta_1 = \beta_2 = 0$

H_a: H_0 is not true

The equation for calculate F score:

$$F = \frac{R^2/k}{(1-R^2)/_{n-k-1}} \qquad (5.4)$$

Where, R^2 is the coefficient determinant.

k is the number variables.

n is the number of observations.

If the F score is greater than the critical value F_c, which is found in the F-statistics table at a certain level of significance, then H_0 is rejected. Otherwise, H_0 is not rejected. From Equation 5.3 and Equation 5.4, the F-score can be calculated. F equals 1217.627. From the F-statistics table, the F_c is 2.533 at the five percent probability level. Therefore, H_0 is rejected, which means this model is significant.

5.4 Multicollinearity

Multicollinearity or (collinearity) is the undesirable situation where the correlations among the independent variables are strong. It violates the sixth classical assumptions of OLS in Table 5.1 if there is a perfect linear relationship between independent variables. Generally speaking, a perfect multicollinearity is very rare in any case, but an imperfect multicollinearity is quite usual in many cases. Multicollinearity increases the standard errors of the coefficients, and lowers the t-scores of the related independent variables. There are several ways to detect multicollinearity, such as a test of simple correlation coefficients and a Variance Inflation Factors (VIF) test.

Table 5.4.1 Simple Correlation Table.

	Ln(GDPt)	*Ln(STRt-1)*
Ln(GDPt)	1	
Ln(STRt-1)	0.9787	1

The correlation numbers between the two independent variables are very high and that indicates the possibility of collinearity. Hence, the t-tests between pairs of the variables are necessary. For each pair, there is a t_r. If the absolute value of t_r is greater than the critical t (t_c), then there is significant collinearity. The function of t_r is below:

$$t_r = \frac{r_{1,2} * \sqrt{n-2}}{\sqrt{1-r_{1,2}^2}} \qquad (5.5)$$

Where, $r_{1,2}$ is the simple correlation coefficient between variable 1 and 2.

n is the number of observations.

Table 5.4.2 T Test Table for Collinearity Test

	r12	tr	tc
GDP_t vs STR_{t-1}	0.9787	25.21766	2.048

In table 5.5, the t_r values is greater than the t_c values, which means the pair of variables has significant collinearity. To measure how much the differentiation of the estimated coefficients are increased over the situation of no correlation among the independent variables, a VIF test needs be carry out. The function of the VIF test is:

$$VIF = 1/(1-R_i^2) \quad (5.6)$$

Where, R_i^2 is the coefficient of determination of a regression of explanatory i on all the other explicators.

To implement the VIF test, auxiliary regressions need to be done. The auxiliary regressions are established by using one of the independent variables as the dependent variable and using other independent variables as explanatory variables. The outputs of the auxiliary regressions are listed in Appendix 4.

Table 5.4.3 VIF Test

Dependent Variable	Independent Variable	R2	VIF
GDP_t	STR_{t-1}	0.957827	23.7118

In table 5.6, it shows the VIF value is greater than the tolerant value 10. So this model has some multicollinearity. However, GDP and STR have strong theoretical relationships to the consumption of electricity. So the best thing to manage multicollinearity in this case is simply to realize it in the model and to do nothing.

5.5 Autocorrelation

Generally, when using a regression model using time series data, the errors are often correlated over time. It can be represented using the following equations:

$$Y_t = \beta_0 + \beta_1 * X_t + \varepsilon_t \quad (5.7)$$

$$\varepsilon_t = \varepsilon_{t-1} + \mu_t \quad (5.8)$$

Where, Y is dependent variable, X is independent variable.

ε is the variance between observe Y and predict Y.

μ is the period error between ε.

There are two kinds of autocorrelations: pure and impure. When μ is a constant number, it is a pure autocorrelation; otherwise, it is an impure autocorrelations. According to the fourth classical assumption of OLS, "Observations of the error term are uncorrelated with each other," we need to exam the autocorrelation.

To exam the autocorrelations more quantificational, the Durbin-Watson test (d-test) can be used. The equation can be found below:

$$d = \frac{\sum_{t=2}^{T}(e_t - e_{t-1})^2}{\sum_{t=1}^{T} e_t^2} \quad (5.9)$$

Where, d is Durbin-Watson statistics.

e is residual.

t is time period.

T is the total number of observations.

Using equation 5.9, the Durbin-Watson statistics (d) for this model is 1.57. The output for the calculations is shown in Appendix 5. Since d is less than 2, a test for positive autocorrelation is needed. In this case, the test statistic d is compared to lower critical values (d_L) and upper critical values (d_U).

If $d < d_L$, which means there is statistical evidence for positive autocorrelation.

If $d > d_U$, which means there is no statistical evidence for positive autocorrelation.

If $d_L < d < d_U$, then the test is inconclusive.

From the Durbin-Watson Significant Table, the d_L is 1.284 and the d_U is 1.567. According to the decision rule, this model has no statistical evidence for positive autocorrelation.

5.6 Heteroscedasticity

In regression analysis, Heteroscedasticity (HS) means a situation in which the variance of the dependent variable varies across the data. So it violates the fifth classical Assumption of OLS which is "The error term has a constant variance." There are several methods to exam HS. Park test is the most wildly used method.

The equation of Park test is below:

$$Ln\ (e_t^2) = \alpha_0 + \alpha_1 * Ln\ (X_i) + \mu \qquad (5.10)$$

Where, e_t is the regression residual from equation 5.2.

α_0 and α_1 are the coefficients.

Xi is the suspect independent variable in equation 5.2.

μ is the error term.

Equation 5.10 shows that the Park test establishes a new double log function using the squire of regression residuals from the original model as the dependent variable and the suspect individual explanatory variable in the original model as the independent variable. After that, a regression needs to be done for the new function. Next is doing t-test for the

α_1. If H_0, which means α_1 is equal to zero, can be rejected, then there is evidence of HS in the residuals. Otherwise, H_0 cannot be rejected, and then there is no evidence of HS in the residuals. Since it is very hard to find which explanatory variable in Equation 5.2 should be implemented into Equation 5.10 from the figures above, all variables are calculated. The regression outputs can be found in Appendix 6.

Table 5.6.1 t_k for Park test

	t_k	t_c (two-tailed and 5% of significant)
Ln(Ln(GDPt))	-1.242876079	2.204
Ln(Ln(STRt-1))	-1.261287726	2.204

In Table 5.8, all the absolute values of t_k are less than t_c, so H_0 cannot be rejected. Hence there is no evidence of HS in the residuals.

5.7 Stationary

To make sure the OLS is the best linear unbiased estimator, the model has to be stationary. The Dickey-Fuller test is a widely used way to examine if a model is stationary or not. The Dickey-Fuller test equation is as follows:

$$\Delta e_t = \gamma_0 + \gamma_1 * e_{t-1} + \mu \qquad (5.11)$$

Where, Δe_t is the difference between e_t and e_{t-1}.

γ_0 and γ_1 are the coefficients.

e_{t-1} is the residual at the period of t-1.

μ is the error term.

A t-test for γ_1 needs be done. If the H_0 is rejected, that implies that the residuals are stationary. Otherwise, the residuals are nonstationary. The regression result of Equation 5.11 can be found in Appendix 7. The t_k of the residual e_{t-1} is -4.4 and the asymptotic critical statistic t_k is 2.79. Since the absolute value of t_k is greater than the absolute value of t_c, the H_0 is rejected. So the residuals are stationary.

5.8 Final Model

After a series of tests, the equation 5.3 can be used to estimate the electricity consumption of China.

From the equation 5.3:

$$Ln(Q_t) = 3.055 + 0.389 * Ln(GDP_t) + 0.819 * Ln(STR_{t-1}) \qquad (5.3)$$

	(0.075)	(0.163)	
t stat	5.168	5.019	
n=30	R^2= 0.989	$\overline{R^2}$=0.988	F= 1217.627

The final exponential form can be rewritten as follows:

$$Q = 20.168 * GDP_t^{0.389} * STR_{t-1}^{0.819} \qquad (5.11)$$

5.9 Analysis

In order to calculate the total electricity consumption of China in 2030, the value of GDP and STR must be known. In the Berkeley National Laboratory's (BNL) report[40], China's energy and emissions are analyzed under two scenarios: reference and max tech. For the answer to the topic question more intensively, this paper also separates the analysis as two scenarios. However, as it shows in table 5.9.1, the GDP growth of China is the same in both scenario.

Table 5.9.1 Berkeley National Lab's Forecast

Macroeconomic Parameters			
		Reference Scenario	Max Tech Scenario
GDP Growth			
	2010-2020	7.70%	7.70%
	2020-2030	5.90%	5.90%

As it was mentioned in chapter 3 and 4, GDP is gross domestic product; STR is a ratio calculated by the sum of value-added Industry GDP plus value-added Services GDP divided by value-added Agriculture GDP. From table 6.2.1, GDP is easy to calculate. According to the World Bank's data, the GDP of China in 2010 was 5930.53 (current U.S. Billion $). So the predicted GDP in 2030 is 22090.73 (current U.S. Billion $). According to the figure 5.9.1, the STR in 2030 will be 15.95.

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[40] David Fridley, Nina Zheng, Nan Zhou, Jing Ke, Ali Hasanbeigi, Bill Morrow and Lynn Price, *China Energy and Emissions Paths to 2030* (Lawrence Berkeley National Laboratory, 2012).

Indicator	1995-2010	2011-15	2016-20	2021-25	2026-30
GDP growth (percent per year)	9.9	8.6	7.0	5.9	5.0
Labor growth	0.9	0.3	-0.2	-0.2	-0.4
Labor productivitiy growth	8.9	8.3	7.1	6.2	5.5
Structure of economy (end of period, %)					
Investment/GDP ratio	49	42	38	36	34
Consumption/GDP ratio	47	56	60	63	66
Industry/GDP ratio	46.7	43.8	41.0	38.0	34.6
Services/GDP ratio	43.1	47.6	51.6	56.1	61.1
Share of employment in agriculture	36.7	30.0	23.7	18.2	12.5
Share of employment in services	34.6	42.0	47.6	52.9	59.0

Figure 5.9.1 China: Projected Growth Pattern Summing Steady Reforms and No Major Shock[41]

To summarize the analyses, Table 5.9.2 has been established after the calculations. Therefore, the answer for the first questions is: by 2030, the total electricity consumption of China is around 9500 billion kilowatt-hours.

Table 5.9.2 Conclusion Table

Year 2030		Reference	Max Tech
Total Electricity Consumption (Billion Kilowatt-hours)		9541.608	9541.608
	GDP_t	22090.73	22090.73
	STR_{t-1}	15.95	15.95

41 Source: Development Research Center of the State Council, *China 2030 – Building a Modern, Harmonious, and Creative Society* (The World Bank, 2013).

Chapter 6: Possible Alternative Energy sources

In this chapter the question of how much electricity can alternative energies provide in China by 2030 will be split to five parts. Each part will investigate the different energy sources in the electricity generation industry. After the five parts, a summary table will be build. By combining the electricity generated from all these alternative energies, the question above can be answered.

6.1 Hydro power

The development of hydroelectricity in China is quite impressive. Figure 6.1.1 shows the installed capacity of hydroelectricity grew 720 times from 1949 to 2005. The annual growth rate is 12.5% which means the capacity doubles almost every 7 years. Now, China has already become the largest hydroelectricity producer on the world.

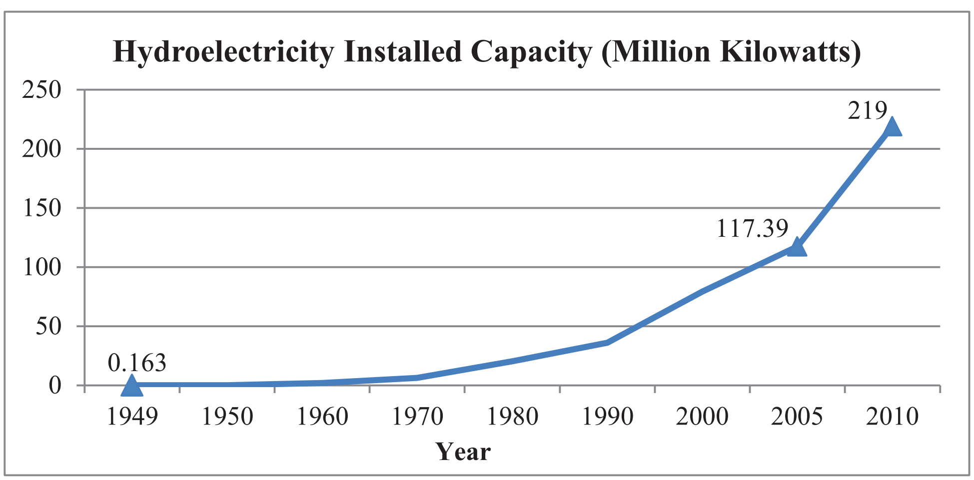

Figure 6.1.1 Hydroelectricity Installed Capacity[42]

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[42] Source: National Bureau of Statistics of China, 2011, http://www.stats.gov.cn/english/ (accessed June 22, 2013).

However, the usage level of hydro power in China is relatively low. In 2005, China implemented a country-wide hydro resource survey. The data shows the potential total reserves capacity is 694 MK, the technologically-feasible capacity is 541 MK, the economy developable capacity is 402 MK and the installed capacity in 2005 is 117 MK.[43] Compared to the 219 MK of the hydroelectricity installed capacity data in 2010, we can see that the high speed of development keeps going on. If China keeps this rapid growth, the hydroelectricity supply roof of 697 MK will arrive around year 2021 regardless of the economy and technology conditions.

Since hydroelectricity in China will be completely developed before 2030, in the reference scenario, the developable capacity (402 MK) will be used to measure the electricity amount provided by hydro power; in the max tech scenario, the technologically-feasible capacity (541 MK) will be used.

Usually, the annual electricity generation can be calculated by the capacity times the operation hours. The total hours of a year are 8760 using 356 days. However, because of the required inspection and maintenance electricity plants, there is no way to reach this number. The figure below shows the annual operation hours in hydro power stations and

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[43] XiaoLin Chang, XingHong Liu and Wei Zhou, *Hydropower in China at present and its further development* (Energy, 2009), pages 4400-4406.

nuclear power stations from 1980 to 2010. The nuclear power data starts from 1992 because China didn't have any nuclear plants before that time.

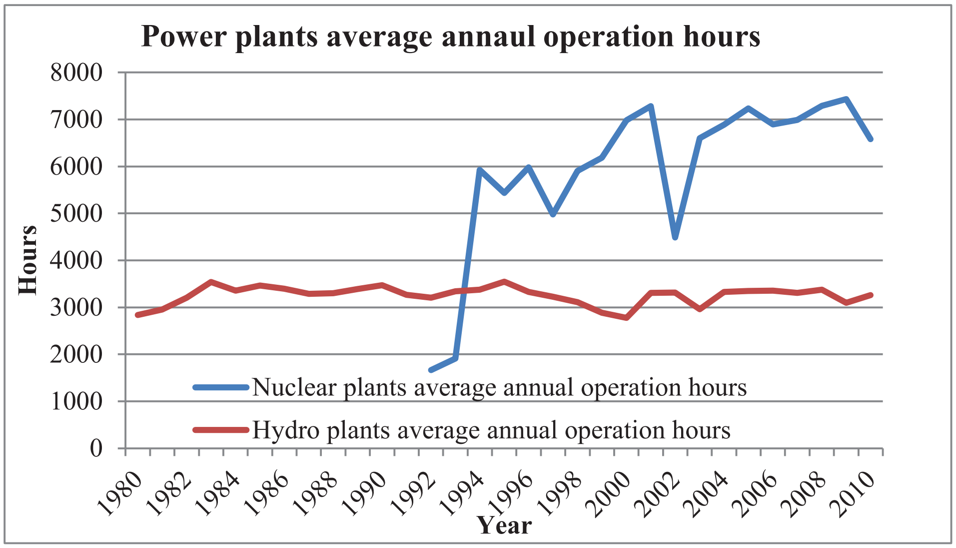

Figure 6.1.2 Power Plants Average Annual Operation Hours[44]

In figure 6.1.2, the hydro plant's average annual operation hours are quite stable around 3500. Therefore, the forecast value of the electricity amount provided by hydro power will be 1407 billion kilowatt-hours under the reference scenario, and it will be 1914.5 billion kilowatt-hours under the max tech scenario.

6.2 Nuclear power

The nuclear electric industry started vey late in China. The first nuclear electric power station is the Qinshan Phase I nuclear station where the first grid connection was December 1991. A nuclear station construction is a high tech, high cost and much more sensitive project compared to coal thermal stations, and the construction cycle usually takes around

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[44] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed June 28, 2013).

five years. In some extreme cases, an accident at a nuclear power plant may even bring unthinkable disaster. However, the advantages of nuclear power are every attractive. It is the most effective energy in electricity generating industry and the nuclear plants have a very long lifetime. What is more important is it can be built in the coastal area where the economy is developing very fast and the energy needs are most. Thus, the government is encouraging the nuclear electricity industry. In the newest Five-year Report – the 12th Five-year plan, the Chinese nuclear electricity industry will step into a period of great development. More information about the operating, under construction and further nuclear reactors can be found in appendix 2.[45]

After the Fukushima accident in 2011, the government temporarily suspended its approval of processing nuclear station projects for security inspections, but it never deviated from the goal of developing the nuclear electric industry. According to the data from IAEA[46] of the electricity production shares in 2012 in China, nuclear power occupies 1.99% of total. There are 18 operational and 28 under construction nuclear power stations in China.

With the development of nuclear electricity, how to deal with the growing amount of radioactive waste is on the agenda. Generally speaking, a 1 million kilowatts capacity

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[45] *Nuclear Power in China*, World Nuclear Association, 2013, http://www.world-nuclear.org/info/Country-Profiles/Countries-A-F/China--Nuclear-Power/#.UehrEYe1EQl (accessed June 29, 2013).

[46] Mao XiaoLong, *Overview of Nuclear Power Development in China*, International Atomic Energy Agency, 2013, http://www.iaea.org/NuclearPower/Downloadable/Meetings/2013/2013-03-18-03-21-TM-NPE/6.long.pdf (accessed July 2, 2013).

nuclear power station will produce tons of radioactive waste every year, and these wastes will consist of approximately 4 cubic meters of high-level waste, 20 cubic meters of intermediate-level waste and 140 cubic meters of low-level waste after the waste disposal processes.[47]

According to the requirement of the IAEA, all the intermediate and low level wastes are stored in the temporary nuclear waste repository after the solidification process. So far, there are two intermediate-low nuclear waste repositories (Gansu Yumen northwest repository and Guangdong Beilong repository) in China and another two are planned. Internationally, there are two treatments for high-level wastes. One is burying them deep underground after the solidification process. Many countries use this way, such as the United States, Russia, Canada, Australia and China. Another way is to throw them into the deep sea in a selected area after the solidification process. The internationally-accepted safest way to deal with the radioactive waste is to put them into a permanent disposal site, but it is not an easy thing to find such a place not only because of the geologic restrictions but also the opposition from environmentalists.

So far, there is only one permanent nuclear waste repository under construction in Finland. This site is as deep as 457 meters underground to make sure the waste inside will not affect

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[47] *Radioactive Waste Management,* World Nuclear Association, 2012, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/#.UehwFoe1EQk (accessed July 5, 2013)

the surface. Since year 2005, China has planned to build a permanent nuclear waste repository.[48] The designed life for this place is 10000 years and it is capable of storing 100 to 200 years of nuclear waste. According to the development of nuclear electricity, the project place will be confirmed between 2015 and 2020. Right now, the top site is Beishan. It is a desert area ideal great geologic conditions.

According to the forecast by the World Nuclear Association, the nuclear capacity of China will reach to 0.2 Billion Kilowatt by 2030. As it shows in figure 6.1.1, the average annual operation hours of nuclear plants fluctuate a lot at the beginning. The data from 1992 and 1993 are less than 2000 hours due to the test operation period. After that, the data shows that 7000 operation hours for nuclear plants are capable. Since the nuclear development relies more on policy compare to technology in the middle term future, the forecast value of the electricity amount provide by nuclear power will be 1400 Billion Kilowatt-hours in both scenario.

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[48] *Radioactive Waste Management,* World Nuclear Association, 2012, http://www.world-nuclear.org/info/Nuclear-Fuel-Cycle/Nuclear-Wastes/Radioactive-Waste-Management/#.UehwFoe1EQk (accessed July 5, 2013)

6.3 Natural Gas

Natural gas, as the cleanest burning fossil fuel, is being rapidly developed in China in recent years. More and more liquefied natural gas terminals are being built; thousands of pipelines are under construction; and billions of natural gas import contracts are being signed.[49]

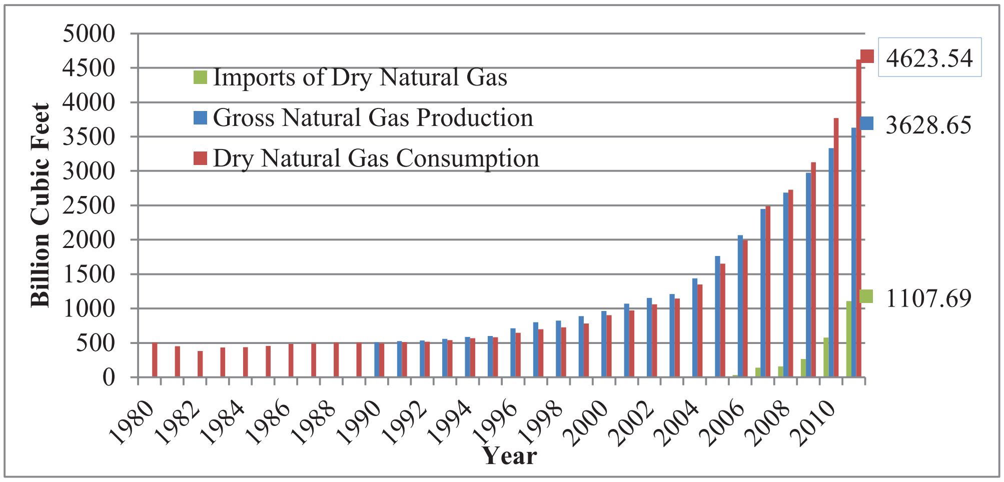

Figure 6.3.1 China Natural Gas from 1980 to 2011[50]

The graph above shows the development of natural gas industry in China from 1980 to 2012 according to the data from IEA. The progression will be even faster after a couple years due to many signed contracts starting to be implemented. The growth of natural gas will largely filled up the energy gap in many industries. However, in electricity generation, the impacts are much less.

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[49] Development Research Center of the State Council, *China 2030 – Building a Modern, Harmonious, and Creative Society* (The World Bank, 2013).

[50] Source: U.S. Energy Information Administration, 2011, http://www.eia.gov/ (accessed April 22, 2013)

In fact, natural gas power stations have many advantages compared to coal power stations. The gas power stations have less construction investment, less water consumption, less pollution emanation, and it has no external expenses. What's more, gas power stations have better flexibility to match the peak load regulation.[51] Because of all these advantages, the gas power stations can be the best choice in massive electricity consumption areas. However, there is one critical problem, the price of natural gas.[52]

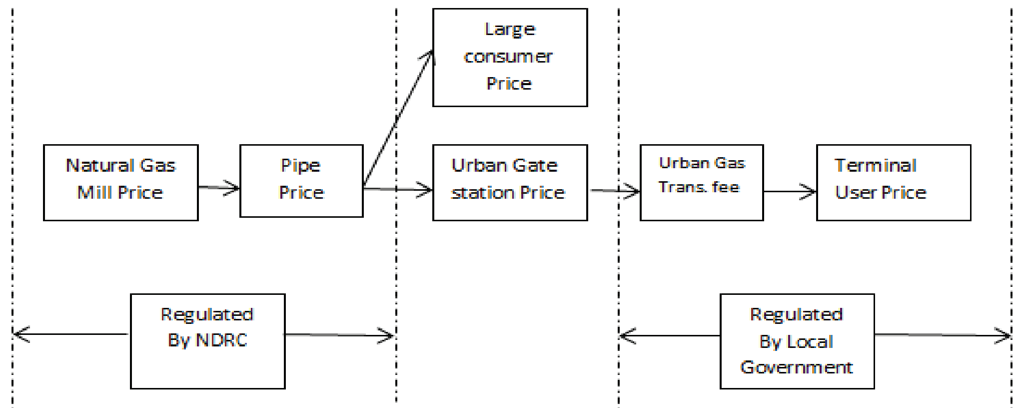

Figure 6.3.2 Chinese Current Natural Gas Pricing System

In China, the pricing system of natural gas is currently fixed or capped by the NDRC (National Development and Reform Commission) and local governments. Imported gas can provide abundant energy, but the side effect is that the natural gas price would increase.

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[51] April Lee, Owen Zinaman, and Jeffer Logan, *Opportunities for Synergy between Natural Gas and Renewable Energy in Electric Power and Transportation Sectors* (National Renewable Energy Laboratory, 2012).

[52] *Natural Gas Investment Opportunities in China*, The Parthenon Group, 2013, http://www.parthenon.com/IndustrialBriefGas/ParthenonPerspectives_NaturalGasInvestment_vWeb_May2013.pdf (accessed August 2, 2013).

The Central Asia pipe gas price is much higher than the native gas price. Right now, to ensure a stable, lower natural gas price in the domestic market, CNPC (China National Petroleum Corporation) is losing money as long as they import huge amounts of natural gas. According to the CNPC semi-yearly report which was published in August 2012, CNPC lost 19.6 billion Yuan in the first half of the year. This number is very close to the CNPC total loss in the year 2011, which was 21.4 billion Yuan.[53] Therefore, a natural gas pricing reform is quite necessary. In fact, in 2011, the government piloted pricing reforms in the provinces, Guang Dong and Guang Xi. The process of the reform was abstruse but the result was obvious: the natural gas price increased.

Even with the current lower natural gas pricing system regulated by NDRC, the fuel cost of using natural gas is about 0.27 to 0.33 Yuan per kilowatt-hour and the fuel cost of using coal is only about 0.2 to 0.23 Yuan per kilowatt-hour.[54] Since the construction cost and the depreciation value of natural gas power stations are relatively low, the fuel cost becomes the most important part of total cost and usually occupies more than 70 percent of the total. This means natural gas power stations are very fuel price sensitive. The

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[53] *2012 Annual Report*, PetroChina Company Limited, 2013, http://www.petrochina.com.cn/Resource/pdf/xwygg/2012ANNUALREPORT(e).pdf (accessed August 3, 2013).

[54] *Ibid*

upcoming natural gas pricing reforms will drive the price up and there will definitely be a huge resistance against the increase of natural gas power stations.

In some areas in China many other factors can influence the way reforms take place. Since Beijing is the capital of China, there are more aspects to be considered in addition to economic factors such as political, public opinion and international factors. Under the international and local pressures to regulate the environment, Beijing is implementing "Gas Replace Coal"[55] projects through policy requirement in recently years. According to the plan, all of the power plants and the heating plants in Beijing will use natural gas instead of coal before the year 2015. Although this is a specific case happening in Beijing, the director of the Energy Economy and the Development Strategy Research Center Office, Zhang Yousheng, believes that the economic efficiency is a complex topic.[56] For example, coal can produce an abundance of energy but has a great environmental impact, and so coal is not a viable choice. That is, when trying to provide more energy, there needs to a balance between the gain of energy and impact on the environment. When people cannot bear the serious environmental consequence of using coal, the regulations of letting coal users pay

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[55] Xinhua, *Beijing to replace coal-burning power plants,* 2013, http://www.china.org.cn/environment/2013-10/05/content_30210220.htm (accessed October 6, 2013).

[56] Nobuyuki Higashi, *Natural Gas in China, Market evolution and strategy* (International Energy Agency, 2009).

much more external cost will be put in place, and will bring the development of the natural gas power industry.

6.4 Wind power

Wind power, as another politically supported green energy industry, also has had great growth in recent years. From 2005 to 2010, the wind power capacity almost doubled annually. At the end of 2010, the total wind power capacity was 44 million kilowatts and the improved yearly capacity was 18 million kilowatts.[57] According to the 2012 Chinese Renewable Energy Society annual report, the wind power capacity in 2012 was 60.83 million kilowatts, the generation was 100.4 billion kilowatt-hours and the wind power replaced nuclear power as the third largest electricity power supply source.[58]

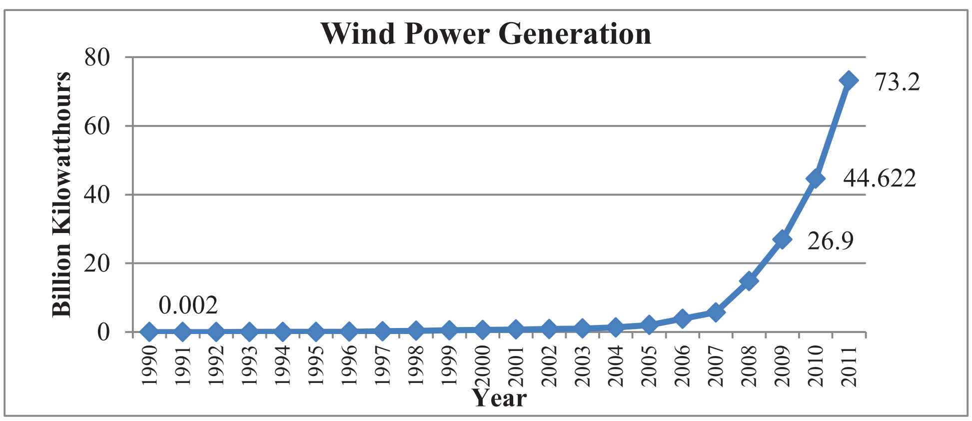

Figure 6.4.1 China Wind Power from 1990 to 2011

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[57] Rasmus Lema, Axel Berger, and Hubert Schmitz, *China's Impact on the Global Wind Power Industry* (German Development Institute, 2012).

[58] Li Junfeng, *2012 annual wind power report,* Chinese Renewable Energy Society, 2012, http://www.greenpeace.org/china/Global/china/publications/campaigns/climate-energy/2012/windpower-2012.pdf (accessed October 5, 2013).

The great progression of the wind power depends on several reasons. First is the political support. After 2005, a series of laws and regulations including, “The Chinese renewable energy law”[59], were issued. All of these rules have indicated the development direction, standardized the financial incentive and supervisory system, and promoted green energy usage. Second, the government improved the investment in the wind power industry. The press spokesman of the SGCC (State Grid Corporation of China), Zhang ZhengLing says there was 45.8 billion Yuan invested in the wind power constructions from 2006 to 2012. Third, many international exchange programs about wind power were organized in recent years. The progress of science and technology quickened the pace of the wind power industry. In 2012, the government issued the 12th Five-Year Plan. It specified the goal of installed wind power capacity, in 2015 it will be 100 million kilowatts and it will be 200 million kilowatts in 2020.

Wind power can be a really good alternative electricity generation power source in the future, except hydro and nuclear, because China has decent wind energy resources. According to the report from China Meteorological Administration in 2009, the total potential technological developable wind energy on the mainland is about 2.38 billion

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[59] *The People’s Republic of China renewable energy law*, The national People’s Congress of the People’s Republic of China, 2010, http://www.npc.gov.cn/huiyi/cwh/1112/2009-12/26/content_1533216.htm (accessed October 5, 2013).

kilowatts and the number offshore is 0.2 billion kilowatts.[60] Since the annual average wind generator working hours is 2000 hours per year, the total potential wind power can be 5160 billion kilowatt-hours. As calculated in Chapter 5, the total predicted electricity consumption in China in 2030 is 9541billion kilowatt-hours. Therefore, wind power can provide more than half of the electricity consumption in the future in the extreme optimal situation. Although there is no way this optimal case can be true because there are all kind of geographic and economic restrictions, the huge potential energy is still very attractive.

As it mentioned in Chapter 3, the paper "The predictive study of the China's wind power" predicted the wind power capacity in the future by associating the gross wind energy volume, the political goal and the wind power industry's current situation.[61]

Table 6.4.1 Development Goals of China's Wind Power

Development goals of China's Wind Power Total Installed Capacity			
		Units:	Million Kilowatts
Year	Lower Scenario	Middle Scenario	Higher Scenario
2020	150	180	220
2030	300	360	440
2050	420	580	780

[60] Research Center of the solar power, *China's wind energy resource assessment report* (The China Meteorological Administration, 2009).

[61] Jianling Gao, Hui Gao, and Rende Han, *The predictive study of the China's wind power* (Huaneng Energy Investment Institute, 2009).

Table 6.4.2 Wind Power Percentage in 2030

Wind Power Percentage in 2030			
	Lower Scenario	Middle Scenario	Higher Scenario
Capacity (Mkw)	300	360	440
Working Hours (h)	2000	2000	2000
Generation Volume(Bkwh)	600	720	880
Total Electricity Consumption (Bkwh)	9541.608	9542.608	9543.608
Percentage (%)	6.29	7.55	9.22

From the table 6.4.1, there are three different scenarios and three different years. In this paper, the data in year 2030 will be used. Still using 2000 as the average annual wind generator working hours, the results are shown below. The wind power can contribute about 6 to 9 percent of the total electricity consumption.

6.5 Solar power.

Solar power as a booming renewable energy resource also has a great development worldwide in recent years. There are two applications for solar power, the solar photovoltaic (PV) power system and the solar thermal system. Since the PV power system has many advantages such as easy installation, simple maintenance and flexible usage, it is more popular on markets. In the past 10 years, the total annual production of the PV cell increased 10 times and the average annual increase rate is above 50 percent. In 2010, the global total production of the PV cell was 16 million kilowatts and China contributed 10 million kilowatts.[62]

$$\text{Cost of PV Power} = \frac{Module\ System\ Price/Depreciation\ Cycle}{Sunlight\ Time/1000} + Maintain\ Price$$

According to the cost equation[63], the module system price (PV cell price) is the most important part because the sunlight time is fixed depending on the different areas, the depreciation cycle is relevantly stable restricted by technology and the maintenance price is relevantly low in the PV power system. Therefore, the price of PV cells determines the future of this industry. The good news is as long as the development of the PV power industry continues, the technological level is increasing, and the production cost is decreasing. So the PV cell's power conversion efficiency is growing and the price of PV cell is dropping. In 2000, the price of PV cells was about 4.5 U.S. dollars per watt and it dropped to under 1.5 U.S. dollars per watt in 2010. The power conversion efficiency also has greatly improved. According to the new research by clean-tech market research firm, the costs of PV cells are expected to drop to 0.36 U.S. dollar per watt by 2017.

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[62] Wang Ye, *The predictive study of the China's solar power* (National Energy Information Institute, 2012).
[63] Ibid

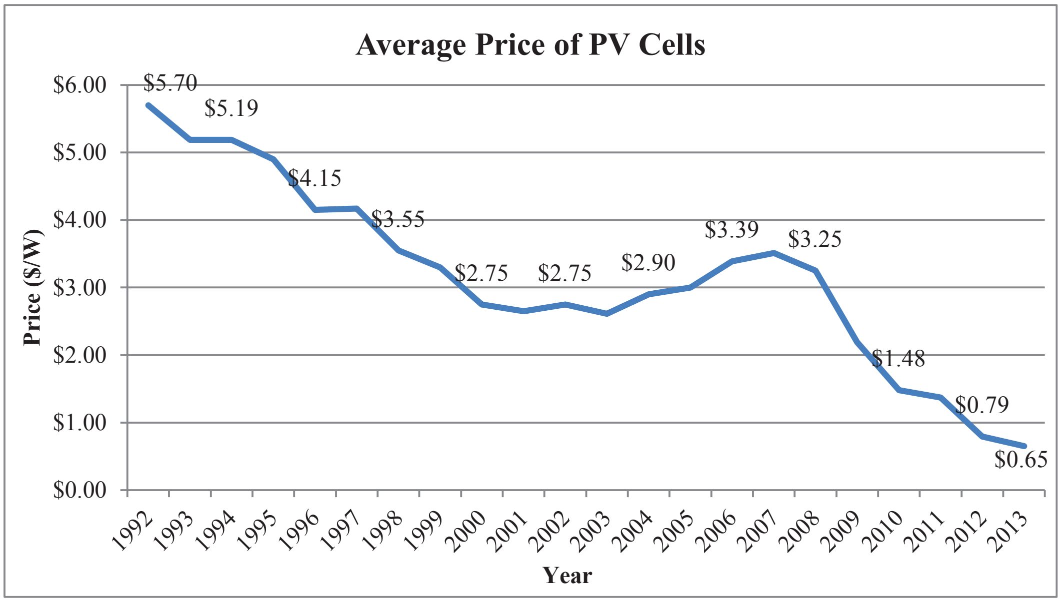

Figure 6.5.1 Average Price of PV Cells[64]

In 2010, the newly installed solar power capacity surpassed the wind power capacity in the EU (European Union) for the first time.[65] This indicates that solar power became the third largest renewable energy source after hydro power and wind power. In China, the government also encourages the development of the solar power industry. The goals in the 12th Five-Year Plan[66] in regards to solar power are: at the end of the 2015, the total solar power installed capacity should arrive at 21 million kilowatts and the annual generation ability should arrive at 25 billion kilowatt-hours. The long-term goal of the plan is to

[64] Source: Wang Ye, *The predictive study of the China's solar power* (National Energy Information Institute, 2012).

[65] Source: Wang Ye, *The predictive study of the China's solar power* (National Energy Information Institute, 2012).

[66] *The 12th Five-Year plan,* National Energy Administration, 2011, http://www.nea.gov.cn/131398352_11n.pdf (accessed October 20, 2013).

achieve a total installed solar power capacity of 50 million kilowatts. According to the research report from CPNN (China Power News Network) which is charged by NEA (National Energy Administration), in 2013 the installed PV power capacity occupied about 0.5% of the total electricity capacity and the expected percentage in 2030 will achieve up to 12% to 15%. The research report shows several reasons for this tremendous progress. The most important one is the decline cost of the PV power system. The author believes the PV module average price will keep declining due to the increases of the technology level and the power conversion efficiency. Another reason is the reform of the distributed PV power system. In the recent past, the distributed PV power systems in China could only support the electricity supply in the attached building, but right now, after rapid development of the national grid, many distributed PV power systems can connect to the grid. The author predicts that the distributed PV power systems will have an economic return around 2019, which means the cost of PV power will be lower than other major fossil powers, and that will be no doubt a huge stimulant to investors.

6.6 Conclusion table

After the analysis of the possible alternative energies, a conclusion table is established. As the result shows in this table, China has a chance to provide more electricity using a larger percentage of alternative energy, as compared to coal, in 2030.

Table 6.6.1 Conclusion Table

Year 2030	Reference	Max Tech
Total Electricity Consumption (Billion Kilowatt-hours)	9541.61	9541.61
Electricity from Hydro %	14.75	20.06
Electricity from Nuclear%	14.67	14.67
Electricity from Wind %	6.29	9.22
Electricity from Solar %	12.00	15.00
Combination %	47.71	58.96

This result is very existing not only because it implies the government's long term goal may achieve but also indicate the natural environment could be much better than now in future. As the second largest electricity consumption country on the world, China can use more balanced energy sources to provide electricity is also a good news in energy security aspect.

Chapter 7: Summary and Conclusions

In the past 30 years, China has made a remarkable economic progression. The GDP in China grew from 176 billion USD in 1979 to 8.36 trillion USD in 2012.[67] China became the second largest economy, the biggest manufacturer and the biggest energy consumer in the world. Due to the economic growth, more and more energy is needed in China. Electricity as the most important energy form is very crucial not only in industrial production but also in people's daily lives. Since China has abundant coal reserves, which is much cheaper than other energy sources, coal has been the major supply of energy. Burning coal leads to a lot of environmental problems and these problems eventually harm people. Especially in recent years, the increasingly serious air pollution in many areas in China has overshadowed its economic achievements.

Although the environmental problem has been noticed by the Chinese government about 20 years ago, the restrictions of the energy shortage, technological level and the pursuit of economic development made coal still be the major electric generation energy source. However, in response to the priority of the government's central development concept being changed to building a harmonious society, and with the progression of technological development, the energy structure of the electric generation will have a great change.

[67] Liu Zhen, *A Study on China's Economy Development*, (IEEE, 2010).

Therefore, the focus of this thesis is whether or not China can use alternative energies instead of coal to provide more electricity by 2030.

To elaborate on the topic more comprehensively, the development of China’s economy, China’s electricity industry and environmental problems are introduced as background knowledge. Relevant literature is introduced. The literature provides basic knowledge, the original model and abundant raw data for this paper. Based on this literature, an OLS model has been built to predict the total electricity consumption in China by 2030. After a series of tests and modifications, the final model has been settled on and analyses were carried out. The analyses show that the total electricity consumption in China by 2030 will be about 9500 billion kilowatt-hours under both the reference scenario and the max tech scenario.

After that, the development and expectations of the hydro power, nuclear power, natural gas, wind power and solar power in China are described. Using the predicted electricity generation capacities of the alternative energies times the corresponding average annual operation hours and sum them up, the combination of the alternative energies can provide 47.71% of the total electricity consumption under reference scenario and 58.96% under max tech scenario.

After the study of the Chinese economy, energy and electricity history, investigation of the environmental problems, research of the different literature, analysis of the political plan and demonstration of the model, the conclusion of this paper is that China has a chance to use alternative energies instead of coal to provide more electricity by 2030.

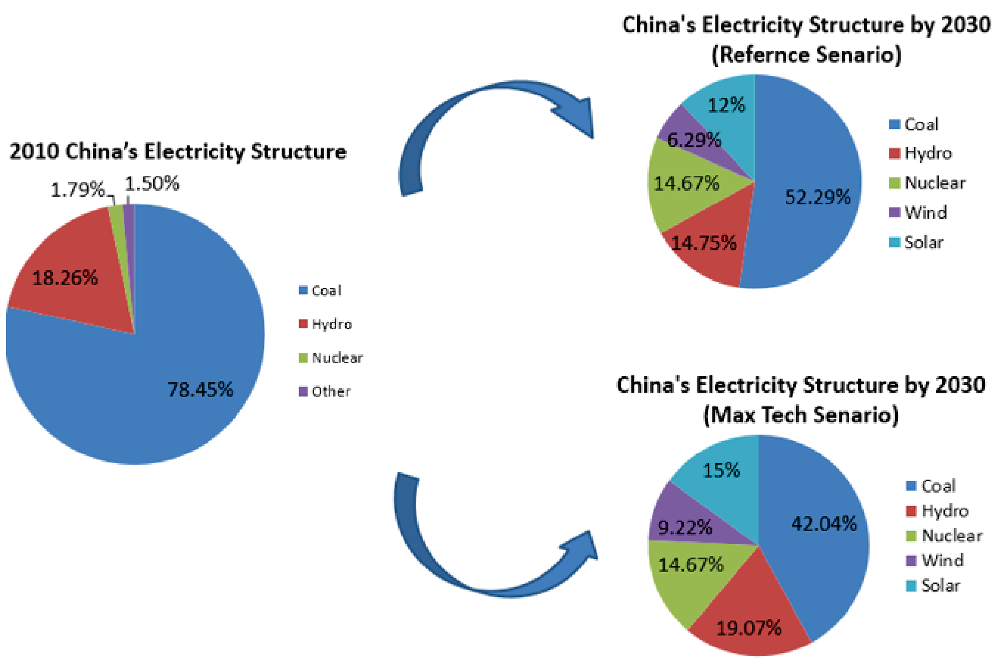

Figure 7.1 China's Electricity Structure Change

This outcome is very heartening because it indicates that the government's core progression principle, the harmonious development of society, could be implemented and a much better natural environment could exist in China in the future.

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Appendix

Appendix 1. Raw Data

Table A.1.1 Raw Data for China (1981-2010)

Year	Q_t	GDP_t	STR t-1
1981	294.017	194.1111	2.314086
1982	311.758	203.1832	2.136646
1983	334.636	228.4559	1.995049
1984	358.72	257.4321	2.0139
1985	390.678	306.6667	2.112171
1986	427.349	297.8319	2.515832
1987	472.472	270.3722	2.684584
1988	517.849	309.5226	2.729848
1989	555.538	343.9737	2.891654
1990	590.346	356.9369	2.983286
1991	643.116	379.4687	2.687831
1992	716.04	422.6609	3.077253
1993	795.733	440.5009	3.589285
1994	880.411	559.2247	4.07394
1995	956.307	728.0072	4.034933
1996	1005.499	856.0847	4.009451
1997	1070.225	952.6527	4.078457
1998	1103.697	1019.459	4.468325
1999	1172.261	1083.278	4.696064
2000	1280.613	1198.475	5.071564
2001	1426.677	1324.807	5.638779
2002	1584.671	1453.828	5.948424
2003	1810.261	1640.959	6.276573
2004	2103.526	1931.644	6.814124
2005	2370.145	2256.903	6.466519
2006	2717.811	2712.951	7.248768
2007	3090.551	3494.056	7.998104
2008	3280.668	4521.827	8.285301
2009	3508.391	4991.256	8.318302
2010	3904.124	5930.529	8.677591

Appendix 2. Operating, under construction and further nuclear reactors

Table A.2.1 Operating Nuclear Reactors in China

Units	**Province**	**Net capacity (each)**	**Type**	**Operator**	**Commercial operation**
Daya Bay 1&2	Guangdong	944 MWe	PWR (French M310)	CGN	1994
Qinshan Phase I	Zhejiang	298 MWe	PWR (CNP-300)	CNNC	Apr-94
Qinshan Phase II, 1-4	Zhejiang	610 MWe	PWR (CNP-600)	CNNC	2002, 2004, 2010, 2012
Qinshan Phase III, 1&2	Zhejiang	650 MWe	PHWR (Candu 6)	CNNC	2002, 2003
Ling Ao Phase I, 1&2	Guangdong	938 MWe	PWR (French M310)	CGN	2002, 2003
Tianwan 1&2	Jiangsu	990 MWe	PWR (VVER-1000)	CNNC	2007, 2007
Ling Ao Phase II, 1&2	Guangdong	1020 MWe	PWR (CPR-1000)	CGN	Sept 2010, Aug 2011
Ningde 1	Fujian	1020 MWe	PWR (CPR-1000)	CGN	Apr-13
Hongyanhe 1	Liaoning	1000 MWe	PWR (CPR-1000)	CGN-CPI	Jun-13
Total: 17		**13,842 MWe**			

Table A.2.2 Nuclear Reactors under Construction and Planned in China

Plant	Province	MWe gross	Reactor model	Project control	Construction start	Operation
Hongyanhe units 2-4	Liaoning	3x1119	CPR-1000	CGN, with CPI	**4/08**, **3/09**, **8/09**	2013, 2014
Ningde units 2-4	Fujian	3x1089	CPR-1000	CGN, with Datang	**1/08**, **1/10**, **9/10**	2013, 2014, 2015
Fuqing units 1&2	Fujian	2x1087	CPR-1000	CNNC	**11/08**, **6/09**	11/13, 9/14
Yangjiang units 1-4	Guangdong	4x1086	CPR-1000	CGN	**12/08**, **8/09**, **11/10**, **11/12**	8/13, 2014, 2015, 2017
Fangjiashan/ Wanjianshan units 1&2	Zhejiang	2x1087	CPR-1000	CNNC	**12/08**, **7/09**	12/13, 10/14
Sanmen units 1&2	Zhejiang	2x1250	AP1000	CNNC	**3/09**, **12/09**	3/14, 8/14 or 9/15
Haiyang units 1&2	Shandong	2x1250	AP1000	CPI	**9/09**, **6/10**	5/14, 3/15
Taishan units 1&2	Guangdong	2x1750	EPR	CGN	**10/09**, **4/10**	2014, 2015
Shandong Shidaowan	Shandong	210	HTR-PM	Huaneng	**12-Dec**	2016
Fangchenggang units 1&2	Guangxi	2x1080	CPR-1000	CGN	**7/10**, **2011**	2015, 2016
Fuqing units 3&4	Fujian	2x1080	CPR-1000	CNNC	**7/10**, 2011*	7/15, 5/16
Tianwan units 3&4	Jiangsu	2x1060	VVER-1000	CNNC	**12/12**, 10/13	2017, 2018
Fuqing units 5&6	Fujian	2x1100	ACP1000	CNNC	2014	
Changjiang units 1&2	Hainan	2x650	CNP-600	CNNC & Huaneng	**4/10**, **11/10**	2014, 2015
Hongyanhe	Liaoning	2x1080	ACPR1000		2013?	2016-

units 5&6				CGN, with CPI		
Yangjiang units 5&6	Guangdong	2x1080	CPR1000+	CGN	2013*	2017
Fangchenggang units 3-6	Guangxi	4x1080	ACPR1000	CGN	late 2014?	
Ningde units 5&6	Fujian	2x1080	ACPR1000	CGN	?	
Xudabao / Xudapu units 1&2	Liaoning	2x1250	AP1000	CPI, with Datang	delayed	
Sanmen units 3&4	Zhejiang	2x1250	AP1000	CNNC	?	
Haiyang units 3&4	Shandong	2x1250	AP1000	CPI	2010?	
Sanming units 1&2	Fujian	2x880	BN-800	CNNC	2013	2019, 2020
Zhangzhou units 1&2	Fujian	2x100	ACP100	CNNC & Guodian	2015	
Tianwan units 5&6	Jiangsu	2x1080	CPR-1000	CNNC	12/12, 8/13	
Lufeng (Shanwei) units 1&2	Guangdong	2x1250	AP1000	CGN	2014?	
Shidaowan units 1-2	Shandong	2x 1400	CAP1400	Huaneng	Apr-14	2018
28 under construction						
29 Planned (coastal)						
	Inland units planned but deferred					
Wuhu units 1&2	Anhui	2x1250	AP1000	CGN	2012	
Xianning (Dafan) units 1&2	Hubei	2x1250	AP1000	CGN	2015	
Taohuajiang units 1-4	Hunan	4x1250	AP1000	CNNC	2015	

Pengze units 1&2	Jiangxi	2x1250	AP1000	CPI	2015	
Xiaomoshan units 1&2	Hunan	2x1250	AP1000	CPI	2015	
Longyou (Zhexi) units 1&2	Zhejiang	2x1250	AP1000	CNNC	2015	
Yanjiashan/Wanan/Ji'an	Jiangxi	2x1250	AP1000	CNNC	2015	
Shaoguan units 1-4	Guangdong (inland)	4x1250	AP1000	CGN	2015	
20 planned (inland)		25,000MWe				
Total: 77		**86,570 MWe**				

Table A.2.3 Further Nuclear Power Units Proposed in China

Plant	Province	MWe gross	Expected model	Project control	Construction	Start up
Taishan units 3&4	Guangdong	2x1770	EPR	CGN	by 2015	
Nanchong (Nanchun, Sanba)	Sichuan	4x1080	ACPR1000	CGN		
Shidaowan units 3&4	Shandong	2x1400	CAP1400	Huaneng		
Tianwan units 7&8	Jiangsu	2x1200	VVER-1200 (AES-2006)	CNNC		
Xianning (Dafan) units 3&4	Hubei	2x1250	AP1000	CGN		
Shidaowan units 5&6	Shandong	2x1400	CAP1400	Huaneng	2013?	
Shandong Shidaowan	Shandong	18x210	HTR-PM	Huaneng		
Changjiang units 3 & 4	Hainan	2x650	CNP-600 or ACP-600	CNNC & Huaneng		
Haiyang units 5&6	Shandong	2x1250	AP1000	CPI		
Hongshiding (Rushan) units 1&2	Shandong	2x1100	ACP1000?	CNNC		
Xiaomoshan units 3-6	Hunan	4x1250	AP1000	CPI		
Xudabao / Xudapu units 3-6	Liaoning	4x1250	AP1000	CNNC with Datang		
Lufeng (Shanwei) units 3-6	Guangdong	4x1250	AP1000	CGN		
Fangchenggang units 3-6	Guangxi	4x1080	ACPR1000	CGN	late 2014?	
Yingtan	Jiangxi	2?		Huaneng		

Nanyang units 1-6	Henan	6x1250?	AP1000 (if CPI)	CNNC or CPI		
Xinyang units 1-4	Henan	4x1080	ACPR1000	CGN		
Changde (Chenzhou, Hengyang)	Hunan	4x1000?		CNNC & Guodian?, CGNPC		
Zhangzhou 1-4	Fujian	4x1250	AP1000	CNNC & Guodian		
Zhangzhou 5-6	Fujian	2x1250	AP1000	CNNC & Guodian		
Subtotal: 74 units		**70,000+ MWe**				
Jiyang	Anhui	4x?		CNNC		
Sanmen units 5&6	Zhejiang	2x1250	AP1000	CNNC		
Cangnan	Zheijiang	6x1000		CGN/Huaneng		
Zhexi /Longyou units 3&4	Zhejiang	2x1250	AP1000	CNNC		
Haijia /Haifeng units 1&2	Guangdong	2x1000?		CGN		
Jinzhouwan units 1&2	Liaoning	2x1000				
Fuling units 1-4	Chongqing	4x1250	AP1000	CPI		
Jingyu units 1-4	Jilin	4x1250	AP1000	CPI & Guodian	2013?	
Liangjiashan	Jilin	2x1250?	AP1000	CGN & Guodian		
Changchun Jiutai	Jilin	2x1250?	AP1000	CGN & Guodian		
Songjiang	Shanghai	2x1250?	AP1000	CGN & Guodian		
Wuhu units 3-4	Anhui	2x1250	AP1000	CGN		
Pengze	Jiangxi	2x1100	AP1000	CPI		

units 3&4						
Heyuan /Jieyang **units 1-4**	Guangdong	4x1000		CNNC?		
Haiyang **units 7&8**	Shandong	2x1250	AP1000	CPI		
Pingnan/Baisha **units 1-4**	Guangxi	4x1250	AP1000	CPI		
Hengren **units 1-4**	Liaoning	4x1250	AP1000	CPI		
Lanzhou	Gansu	2?		CNNC		
Xiangtan	Hunan	4x1250	AP1000	Huadian		
Donggang	Liaoning	4x1000		Huadian		
Haixing	Hubei	4x1250 (of 6)	AP1000	Huadian		
Shizu	Chongqing			CNNC		
Qiaofushan	Hebai			CNNC		
Songzi/Xianning 5&6	Hubei		AP1000	CGN		
Guangshui	Hubei	4x1250	AP1000	CGN		
Zhingxiang	Hubei	5000 MWe	AP1000	CNNC, Datang		
Hebaodao	Guangdong			CNNC		
Yibin	Sichuan			CNNC		
Sanming 3&4	Fujian	2x880?	BN-800?	CNNC	2015	
Site to be decided	Heilongjiang	4x1000		Huaneng		
Subtotal: about 82 units		46x1250 2x1400 14x1000 2x880 c.18x210 **Approx. 89,000 MWe**				

Total: about 152		**158,000+ MWe**	

Appendix 3. Summary Output of the Functional Form Regression

Table A.3.1 Linear Form Regression Results

Regression Statistics	
Multiple R	0.995721
R Square	0.991461
Adjusted R Square	0.990828
Standard Error	94.16513
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	27796717	13898358	1567.412	1.19E-28
Residual	27	239411	8867.072		
Total	29	28036128			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-260.349	61.73198	-4.21742	0.000248	-387.013	-133.686
GDPt	0.335721	0.028771	11.66871	4.7E-12	0.276688	0.394754
STRt-1	227.1719	20.54272	11.05851	1.57E-11	185.0218	269.3221

Table A.3.2 Double Log Form Regression Results

Regression Statistics	
Multiple R	0.994502
R Square	0.989034
Adjusted R Square	0.988222
Standard Error	0.086065
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	18.03841	9.019206	1217.627	3.47E-27
Residual	27	0.199994	0.007407		
Total	29	18.23841			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.055267	0.284255	10.74832	2.95E-11	2.472024	3.638511
Ln(GDPt)	0.389733	0.075401	5.168805	1.94E-05	0.235023	0.544443
Ln(STRt-1)	0.819772	0.163307	5.019826	2.89E-05	0.484694	1.15485

Appendix 4. Summary Output of the Auxiliary Regressions

Table A.4.1 Auxiliary Regressions Results

Regression Statistics	
Multiple R	0.978686314
R Square	0.957826901
Adjusted R Square	0.956320719
Standard Error	0.215710593
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	29.59051	29.59051289	635.9303	8.58E-21
Residual	28	1.30287	0.04653106		
Total	29	30.89338			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	3.712175781	0.124218	29.88435682	8.73E-23	3.457727	3.966625
Ln(STRt-1)	2.119685307	0.084056	25.2176594	8.58E-21	1.947505	2.291865

Appendix 5. Durbin-Watson statistics Calculation Results.

Table A.5.1 Durbin-Watson Statistics Results

Year	et	e t-1	(et-et-1)^2	et^2
1981	-0.20255			0.041027
1982	-0.09326	-0.20255	0.011945591	0.008697
1983	-0.94103	-0.09326	0.718720239	0.885536
1984	0.007008	-0.94103	0.898773735	4.91E-05
1985	-0.03805	0.007008	0.002030096	0.001448
1986	-0.0777	-0.03805	0.001571885	0.006037
1987	0.005303	-0.0777	0.006888741	2.81E-05
1988	0.031564	0.005303	0.00068965	0.000996
1989	0.010037	0.031564	0.000463408	0.000101
1990	0.066745	0.010037	0.00321586	0.004455
1991	0.211921	0.066745	0.021075964	0.044911
1992	0.168235	0.211921	0.001908451	0.028303
1993	0.129481	0.168235	0.001501906	0.016765
1994	0.035125	0.129481	0.008903084	0.001234
1995	0.008724	0.035125	0.000696981	7.61E-05
1996	0.000157	0.008724	7.34014E-05	2.46E-08
1997	0.010202	0.000157	0.000100915	0.000104
1998	-0.0571	0.010202	0.004530191	0.003261
1999	-0.06486	-0.0571	6.02128E-05	0.004207
2000	-0.07743	-0.06486	0.000157834	0.005995
2001	-0.09357	-0.07743	0.000260598	0.008755
2002	-0.06924	-0.09357	0.000591971	0.004794
2003	-0.02159	-0.06924	0.002270537	0.000466
2004	0.00117	-0.02159	0.000518011	1.37E-06
2005	0.098267	0.00117	0.009427718	0.009656
2006	0.073772	0.098267	0.000600017	0.005442
2007	0.023984	0.073772	0.002478844	0.000575
2008	-0.04468	0.023984	0.004714694	0.001996
2009	-0.01776	-0.04468	0.000724822	0.000315
2010	-0.0145	-0.01776	1.06075E-05	0.00021
		Sum	1.704905964	1.085441
		d=	1.570702815	

Appendix 6. Regression Outputs for Park Test.

Table A.6.1 Park Test Results ($Ln(GDP_t)$)

Regression Statistics	
Multiple R	0.228659
R Square	0.052285
Adjusted R Square	0.018438
Standard Error	3.317063
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	16.99664	16.99664	1.544741	0.224221
Residual	28	308.0814	11.00291		
Total	29	325.078			

	Coefficients	Standard Error	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	2.725848	7.65853	0.355923	0.724566	-12.9619	18.41364
Ln(Ln(GDPt))	-5.02515	4.04316	-1.24288	0.224221	-13.3072	3.256891

Table A.6.2 Park Test Results ($Ln(STRt_{-1})$)

Regression Statistics	
Multiple R	0.231865
R Square	0.053761
Adjusted R Square	0.019967
Standard Error	3.314478
Observations	30

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	17.47667	17.47667	1.590847	0.217613
Residual	28	307.6014	10.98576		
Total	29	325.078			

	Coefficients	Standard Error	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-6.17138	0.765616	-8.06067	8.9E-09	-7.73968	-4.60309
Ln(Ln(STRt-1))	-2.13713	1.694401	-1.26129	0.217613	-5.60795	1.333696

Appendix 7. Regression Outputs for Dickey-Fuller test

Table A.7.1 Dickey-Fuller Test Results

Regression Statistics	
Multiple R	0.646253
R Square	0.417643
Adjusted R Square	0.396074
Standard Error	0.191694
Observations	29

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.711533	0.711533	19.36331	0.000152
Residual	27	0.992154	0.036746		
Total	28	1.703687			

	Coefficients	Standard Error	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*
Intercept	-0.01947	0.036082	-0.53966	0.593856	-0.09351	0.054562
et-1	-0.82076	0.186521	-4.40038	0.000152	-1.20348	-0.43805