MEETING CHINA'S ELECTRICITY NEEDS THROUGH CLEAN ENERGY SOURCES: A 2030 LOW-CARBON ENERGY ROADMAP

by

Zheng Hu

A dissertation submitted to the Faculty of the University of Delaware in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Energy and Environmental Policy

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After defending this Ph.D. dissertation, it is time for me to return to my home country.

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ABSTRACT

China is undergoing rapid economic development that generates significant increase in energy demand, primarily for electricity. Energy supply in China is heavily relying on coal, which leads to high carbon emissions. This dissertation explores opportunities for meeting China's growing power demand through clean energy sources. The utilization of China's clean energy sources as well as demand-side management is still at the initial phase. Therefore, development of clean energy sources would require substantial government support in order to be competitive in the market. One of the widely used means to consider clean energy in power sector supplying is Integrated Resource Strategic Planning, which aims to minimize the long term electricity costs while screening various power supply options for the power supply and demand analysis. The IRSP tool tackles the energy problem from the perspective of power sector regulators, and provides different policy scenarios to quantify the impacts of combined incentives. Through three scenario studies, Business as Usual, High Renewable, and Renewable and Demand Side Management, this dissertation identifies the optimized scenario for China to achieve the clean energy target of 2030. The scenarios are assessed through energy, economics, environment, and equity dimensions.

Chapter 1

INTRODUCTION

1.1 Carbon Emissions

There is growing evidence that massive release of carbon dioxide and other greenhouse gases have led to global climate change. According to the 4th International Panel on Climate Change (IPCC) Assessment Report, the climate change can present a significant challenge for the human society to sustain socioeconomic development on a long-term basis (Sathaye and et al, 2007). De-carbonization solutions can be approached by using innovative technologies (Bazilian and Hobbs, 2011).

In 1980, the worldwide carbon dioxide concentration was 338.8 parts per million (ppm) and increased to 395.33 ppm by 2014, an increase of 16.69% for only 34 years. According to Flavin (2008), it took our society approximately 160 years to increase carbon dioxide (CO_2) concentration by 20 ppm before the process of industrialization, whereas increasing industrial activities raised carbon dioxide intensity by another 50 ppm in only 30 years. Without effective restriction, carbon dioxide concentration will continue to set new records. Therefore, actions on tackling climate change are needed.

It is generally agreed that industrialization has enabled rapid growth of the economy (Agerup and et al, 2004; Baumert and Winkler, 2005). At the global scale,

increase in energy consumption created demand for fossil fuels leading to significant release of greenhouse gases (GHG). Flavin (2008, p75) emphasizes that:

> "Humanity is at risk of creating a climate unlike any seen before, unfolding at an unnatural, accelerated pace—more dramatic than any changes in the climate since Earth was last struck by a large asteroid nearly a million years ago."

In order to reduce carbon emissions caused by industrial activities, building a low-carbon economy is now the most commonly agreed development strategy (Bown and Crowley, 2010; Lund and Mathiesen, 2009; Sathaye and et al, 2007). Addressing climate change requires inclusion of environmental, economic, energy and equity dimensions, and it cannot be solved by focusing merely on one dimension of the problem while excluding others. As argued by the IPCC (Sathaye and et al, 2007), the global energy industry should re-structure through technological, economic, and policy innovations.

1.2 Selection of Research Topic

For any country, reducing GHG emissions is a long term process which requires visionary planning for several decades into the future. A clear and feasible energy target is required, and supportive policies can play a key role in setting such an energy target (Adger and et al, 2003). This dissertation conducts scenario analysis for achieving a proposed GHG emission reduction targets.

1.2.1 Electricity Industry

De-carbonization should start from the electricity sector, which is the core sector for low-carbon transition in all industrialized countries. According to Stern (2012), it is crucial to transform the current structure of energy supply in the electricity generation sector in order to better adopt a low-carbon economy. The regulators must make stronger commitments to encourage supportive entrepreneurships utilizing power generated from clean energy. Fankhauser (2012) seconds Stern (2012) that traditional process of power generation contributes heavily to carbon emissions; on the other hand, technologies that enable clean energy power supply are increasingly becoming economically feasible.

As shown in Figure 1.1 in 2009, global carbon emission was 5,800 million metric tons. Electricity generation contributed to 41.2% (2,389.6 million metric tons) of total global carbon emissions, and 33% of overall greenhouse gas emissions. Power generation is the biggest CO_2 emitter in the world, and the sector has twice the amount of emissions compared to the second biggest CO_2 emitting sector - transportation. IEA (2010) also indicates that electricity industries in developing countries like India and China have even higher contributions in carbon emissions due to great percentage of industrial activities in economic outputs.

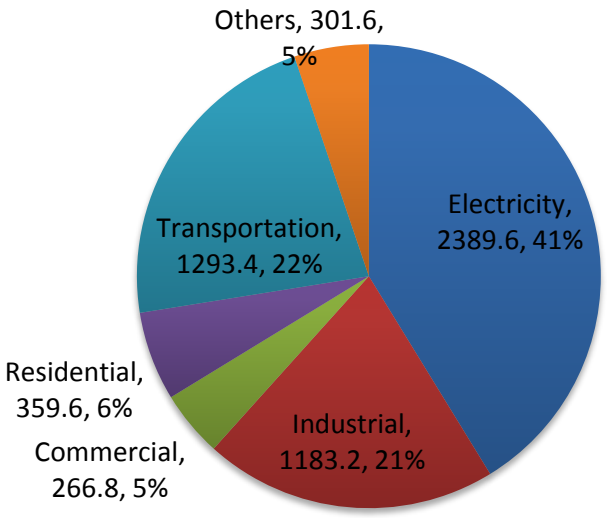

Figure 1.1 Global CO_2 Emissions by Sectors in 2009 (unit: million metric tons; International Energy Agency, 2010)

1.2.2 Country Selection

Figure 1.2 shows carbon emissions from several major countries in the world in 2011 (Energy Information Agency, 2014). China is commonly agreed to be the biggest industrial country in the world in terms of the value of its industrial output (Deloitte Research, 2003; Mattoo and Subramaniam, 2011; Cooper and Vargas, 2004). As illustrated in the figure, carbon emission is heavily accelerated with industrial activities. In order to understand the potential of reducing global carbon emission, it is essential to investigate the emission reduction opportunities in China.

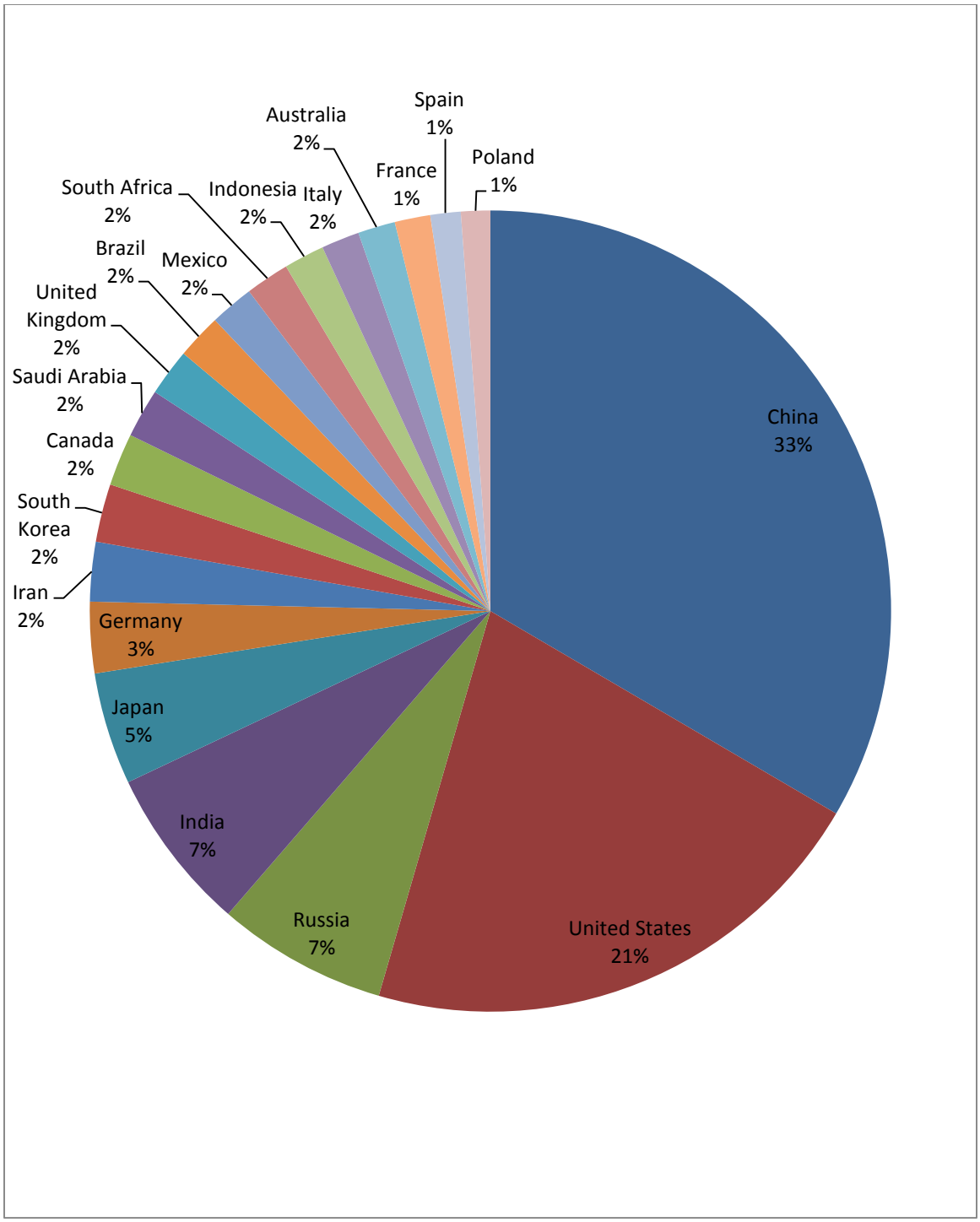

Figure 1.2 Contribution of Carbon Emission from Major Countries in 2011
Data Source: EIA, 2014

According to the China Academy of Science (2012), 40% of China's carbon emissions were from power generation (it matches with Figure 1.2). Coal power generation represents 80% of total emissions in the electricity sector (China Academy of Science, 2012). Thus, it is important to tackle the major carbon emitters via providing feasible planning strategies in China's electricity industry.

1.2.3 Target Selection

The International Panel on Climate Change (IPCC) asserts that it is still feasible for the world to limit global temperature increase within 2 degree Celsius above the pre-industrial level with a combined global effort; as a result, the International Energy Agency (2015) developed the scenario analysis to achieve the 2 degree target of the IPCC. According to the study from the IEA (2015), decarburization of the electricity sector needs to be a global effort, shared by all countries and regions. Figure 1.3 summarizes the result from the IEA (2015) study for China. In order to achieve the 2 degree scenario, clean energy sources need to provide 50% of China's total electricity generation by 2030.

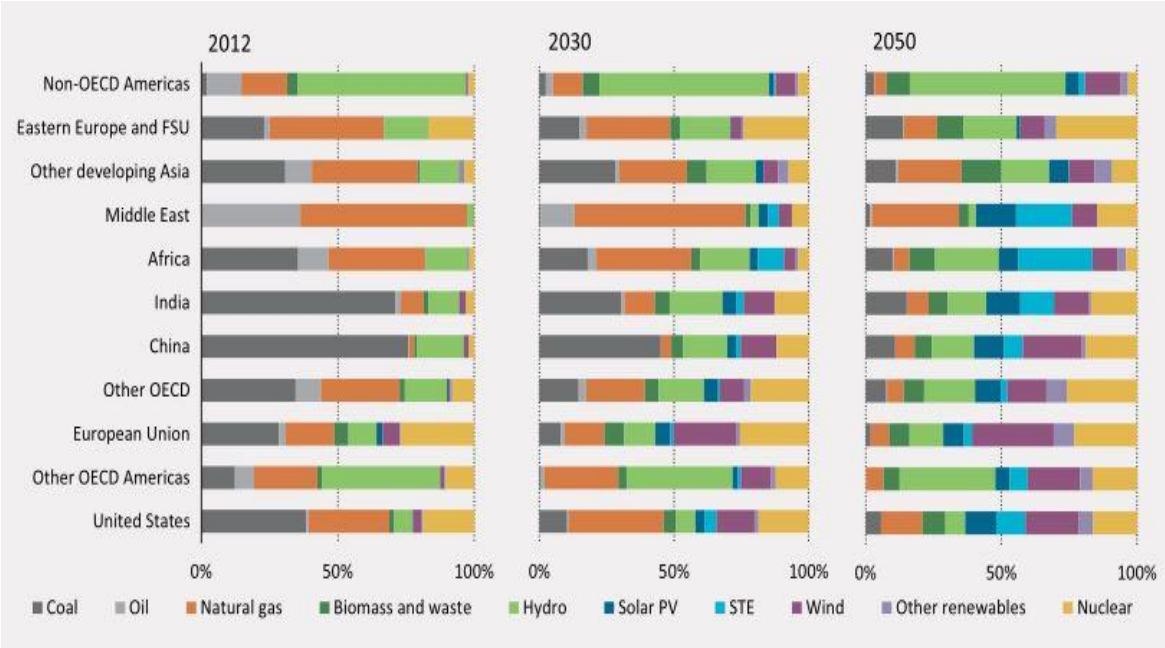

Figure 1.3 Summary of achievement of major countries for the 2 degree scenario
Source: IEA, 2015

This dissertation looks for a realistic and desirable pathway for China to achieve the 2 degree scenario through clean energy sources. For this purpose, it is essential to define the term 'clean energy' used in this dissertation. In this dissertation, clean energy sources refer to renewable energy, nuclear, and hydropower. Renewable energy shall inclusively consider wind power and solar power. Clean coal, natural gas and other sources of combustible energy are not considered in the category of clean energy sources. Many countries have 2030 clean energy pathways. The following sub sections review these targets for the major economies.

1.2.3.1 Status quo and Future Targets in the U.S.

According to the IEA (2012), US had 286 TWh hydropower in 2010, which was 8.1% of global hydropower generation and 6.5% of America's total electricity generation. IEA (2012) also pointed out that the U.S. is the biggest nuclear power provider in the world. It produced 839TWh of nuclear power in 2010, which accounted for 30.4% of total global nuclear electricity generation, and 19.3% of U.S. domestic power generation.

In 2009, the U.S. Department of Energy has released the national targets for Greenhouse Gas emission reductions at 17% in 2020 from 2005 levels, and 42% emission reduction by 2030 from the 2005 level (D.O.E., 2009). Furthermore, the White House has claimed the most aggressive energy reduction goal in the world by calling for 80% of U.S. cleaner energy power generation by 2035. However, the definition of clean energy sources in the White House announcement was very broad, it included clean coal and natural gas in the clean energy portfolio (EIA, 2011).

The projections from Caperton, et al (2011), Brown (2011) and the IEA (2015) are in an agreement that the share of clean energy will reach 55% of total U.S. electricity supply by 2030. Furthermore, according to the EIA (2012), renewable energy will provide approximately 15% of total electricity supply (0.68 trillion kWh), hydropower is expected at 14% (0.63 trillion kWh), and nuclear power at 19% (0.91 trillion kWh) in 2030. By 2030, U.S. would remain the biggest nuclear power generating country in the world; renewable energy is estimated to be the second biggest contributor in U.S. clean energy after nuclear (EIA, 2012).

1.2.3.2 Status quo and Future Targets in Europe

In 2010, Europe[1] generated 9% of its electricity from renewable energy (Eurostat, 2013). There was 553 TWh electricity generated from hydropower in 2010, accounting for 12% of total electricity generation in EU27. According to Renewable Action Plan (2011), the 2020 European energy target of achieving 20% clean energy in final energy consumption does not include hydropower.

Since nuclear power in the EU27 has publically suffered from heavy political pressures, share of electricity from nuclear power plants has been minimized in electricity supply since 2005. In 2010, only 14 European countries had nuclear power plants, and power generated from nuclear power was restricted due to safety concerns that was raised from the Fukushima accident in 2010. In 2010, nuclear power provided 27.1% of total electricity generation (European Commission Eurostat, 2013). Share of nuclear in electricity supply was declining (e.g., the share of nuclear power was by 2.7% lower in 2011 than in 2010).

The 2030 European energy roadmap requires much higher renewable energy penetration, which is projected to be 75% in power generation in order to achieve the 2degree scenario (IEA, 2015). Meanwhile, the European Renewable Energy Council (Muth and Smith, 2011) proposed that renewable energy should achieve 45% clean energy in total power generation by 2030 without the contribution of hydropower.

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[1] In this dissertation the term Europe refers to the European Union (EU) 27 member countries.

In addition to the general EU targets, the German electricity regulator has its own 2030 clean energy target published in its Renewable Energy Resource Act. Germany will have at least 45% clean energy (including nuclear and hydropower) in 2030 under this official target (Keles, Most, Fichtner, 2011). In Denmark, a 2030 clean energy projection of having 50% renewable energy power generation (including nuclear and hydropower) was proposed as the intermediate goal for reaching its 100% clean energy goal by 2050 (Lund and Mathiesen, 2009).

1.2.3.3 Status quo and Future Targets in China

The definition of clean energy in China's energy industry includes renewable energy, nuclear power and hydropower (Li and et al, 2013). Based in China's officially released data clean energy share in power generation was 21.3% in 2011, which included 2% of nuclear power and 17.4% hydropower (Zhang and et al, 2013). In comparison with the U.S. and Europe, China's current clean energy penetration is low.

During the 2009 Copenhagen Conference, China declared two 2020 energy commitments: 1) reducing carbon emissions per unit of GDP by 40% to 45% with respect to the 2005 baseline, and 2) achieving at least 15% non-fossil energy in its primary energy sources (Mastny, 2010). On June 30th, 2015, China submitted its Intended Nationally Determined Contribution (INDC), including the target to peak CO2 emissions by 2030 and lower the carbon intensity per unit of GDP by 60% to 65%, below 2005 levels by 2030 (International Center for Climate Governance, 2015). Regarding the 2030

carbon emission target, the 18th Communist Party of China's National Congress has promised to reach the peak of CO2 emission by 2030, which is expected to be 10-11 billion tons of CO2. This target means the future growth of energy consumption of China is limited within 2.2-2.8%, in comparison with the past growth rate of 6.2% from 1990 to 2012 (Zhang and et al, 2013).

Since the national reform and opening-up policy was initiated in 1978, China's economy has grown rapidly in the past 35 years. Per capita GDP was less than 400 USD in 1978 and it reached 4,000 USD in 2010 (Li, 2009). Growing economy is associated with higher energy consumption: By 2020, in order to support its fast economy development, China will consume approximately 4.46 billion ton-coal equivalent (tce) energy (3.10 billion tce in 2010) and 7,653TWh of electricity (4,085TWh in 2010), which indicates a great challenge for China's CO2 emission reduction goals in the near future (Zhang and et al, 2013).

China actively participates in international cooperation effects on environmental issues (Wang, 2013). During the 12th Five-Year-Plan (FYP), China's energy policy focused on developing low-carbon economy (IEA, 2011). It includes two 2020 targets: reducing 40-45% CO_2 emissions per unit of GDP, and having 15% non-fossil energy in its primary energy supply.

As demonstrated in Figure 1.4, China's energy structure for power generation in 2010 was heavily dominated by coal (IEA, 2011). China's coal power capacity was 687.5 GW in 2010, which was 65% of 1,073 GW total capacity, and double from 2005's 519 GW. In terms of consumption, IEA (2011) pointed out that coal consumption in China

was 2350 Mtoe in 2010, shared 47% of global coal consumption, which was more than the next 16 largets coal consuming countries combined. Hydro, wind, nuclear and solar power are major clean energy contributors to China's electricity industry.

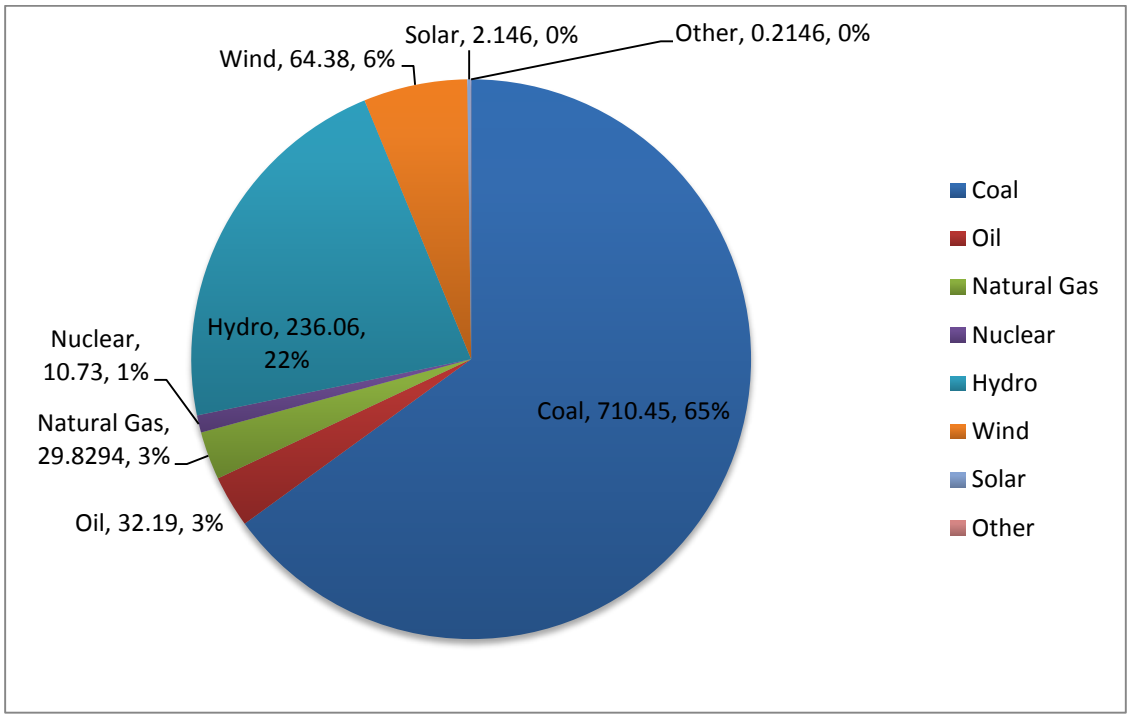


Figure 1.4 China's installed capacity in 2010 (unit: GW)
Data Source: IEA, 2011

China's 2002 Power Deregulation Act restructure of the State Power Corporation, by removing regulatory responsibilities and separating the power generation companies from the grid services (IEA, 2011). The State Electricity Regulatory Commission (SERC, sub-authorized under the National Development and Reform Council, NDRC) became the regulatory entity of China's electricity industry since the 2002 deregulation.

After the deregulation, electricity industry in China has two major segments (Winkler and et al, 2007): 1) power generation is separated into five giant electricity generation companies; and 2) power transmission and distribution were combined, which

were shared by two grid companies, State Grid China Corporation [2] (SGCC) and the China Southern Power Grid (CSG).

The SGCC is the biggest electric grid corporation not only in China but also in the world. Its business covers 26 out of 31 provinces, 88% of China's land surface, and has 1.5 million employees (CSG covers the other 5 provinces in southernmost China). Notably, SGCC is the only player in China which integrates all smaller-scale grid segments into the big nationwide transmission network. It has adopted three phases of grid developing (SGCC, 2010): 1) the planning period 2009-2010; 2) the construction period 2010-2015; 3) the fully upgrade period 2015-2020. When the entire plan is completed, China's electricity industry can reduce 0.47 billion tce (ton of coal equivalent) energy and avoid 1.38 billion tons of CO_2 emissions each year.

Furthermore, the SGCC is actively investing and operating a number of pilot studies on the demand side management (DSM): eco-buildings, smart communities, energy saving campaign, World Expo demonstrations, DSM exhibitions, and etc (Liu, 2012). These pilot research projects provide a foundation for the implementation of China's DSM in the future electricity planning periods. Given China's current status of initiating DSM project, it is without a doubt that DSM will greatly contribute to China's electricity sector in the near future.

The electricity sector in China relies heavily on coal power plants. In order to predict the potential for clean energy development, it is vital to understand the composition of coal power plant stock. Table 1.1 demonstrates the capacity, generation and operating hours of China's coal power plants by categories in 2010. By the end of the

[2] The SGCC has always been recognized as a very competitive corporation in the world. It was ranked as top 20 of the top 500 corporations since 2003. And again in 2010, it was ranked as No. 8, comparing with No. 15 in 2009. The net profit of the SGCC in 2009 was 0.67 billion USD (globally ranked No. 12), and its return on assets (ROA) of that year was 0.4% (globally ranked No. 14).

11th Five Year Plan (2005-2010), China has closed 77 GW small units of coal power plants. According to the State Council (2012), it is mandatory for all small coal units (capacity lower than 50 MW) to be closed by 2015. Due to the restriction policies on coal power together with encouraging policies on renewable energy sources, it is easy to predict that additional percentage of coal power can be replaced by alternative energy sources.

Table 1.1 Breakdown of Coal-based Power Generation in 2010 by Power Plant Type

	Capacity		Generation		Operation Hours
	GW	% in GW	TWh	% in TWh	Per year
<100 MW	68	9.5%	300	8.7%	4430
100-300 MW	138	19.5%	622	18.1%	4500
300 MW	210	29.6%	1029	29.9%	4900
600 MW	245	34.5%	1237	36%	5050
1000 MW	49	6.9%	250	7.3%	5100
Total	710	100%	3438	100%	

Data Source: IEA, 2012

In November 2014, President Xi Jinping announced the China's 2030 energy target during the *Asia-Pacific Economic Cooperation* (*APEC*). The two major energy targets were, 1) to achieve 20% clean energy target in China's total energy consumption, and 2) to cap carbon emissions. Since the 20% clean energy penetration is referring to the total energy consumption in China, and electricity sector is the major contributor to carbon emission, it is reasonable to have 10-15% higher penetration of clean energy in China's electricity sector than the total energy consumption (Liu, 2014).

As summarized in Table 1.2, China had 21% clean energy in 2010. Given the significant reduction potential for coal power plants, as well as considering the high growth potential for clean energy, it is reasonable to consider the IEA (2015) 2 degree

roadmap in the case of China. This dissertation shall quantitatively study the feasibilities of having 50% clean energy power generation for China in 2030.

Table 1.2 Summary of clean energy generation for U.S., E.U., and China

	U.S.	E.U. 27	China
2010 Status	Renewable (4%), Hydro (6%), Nuclear (19.3%) **Total 29%**	Renewable (9%), Hydro (12%), Nuclear (27%) **Total 48%**	Renewable (2%), Hydro (17.4%), Nuclear (2%) **Total 21%**
2030 Projection	**Total 55%**	**Total 75%**	**Total 50%**

Data source: DOE (2014), IEA (2015), Liu (2014).

After setting the 50% clean energy generation target by 2030, an equally important question is how to reach the target through policy incentives. The most commonly used policy incentives in China are: adjustments of energy incentive levels and changes in energy taxation policies. This dissertation will also address how these policies influence the development of renewable energy, and to what degree do they restrict the consumption of coal and other types of combustible energy sources.

1.3 Research Questions

This dissertation will investigate the feasibility of achieving the 2030 clean energy target of 50% in China's electricity industry. A core research question that needs to be addressed is: how can clean energy be effectively integrated in China's future electricity planning?

Detailed analysis supplement this question will rest on the following set of propositions:

- Is China's 2030 clean energy target of achieving 50% from clean energy power generation feasible?
- How can China effectively allocate each type of clean energy resource in order to reach this target?
- What are the associated economic, environmental, and social impacts of reaching this 2030 clean energy target?

1.4 Organization of Other Chapters

The dissertation demonstrates opportunities for boosting the growth of sustainable power penetration in China through policy incentives. Chapter two provides reviews of available literature on: low-carbon economy/electricity, China's energy structure and clean energy development, the model of Integrated Resource Strategic Planning (IRSP), Demand Side Management (DSM) and its application for China. Chapter three describes the methodology, which includes relevant mathematic theories, and further explains the details of data input requirements. In chapter four, the details of scenario design are introduced. It is also important to explain utilized data sources for each scenario. In chapter five, results are analyzed for each individual scenario and then they are compared. Chapter six in the first half underlies policy recommendations in detail and the second half of this chapter follows with conclusions.

Chapter 2

LITERATURE REVIEW

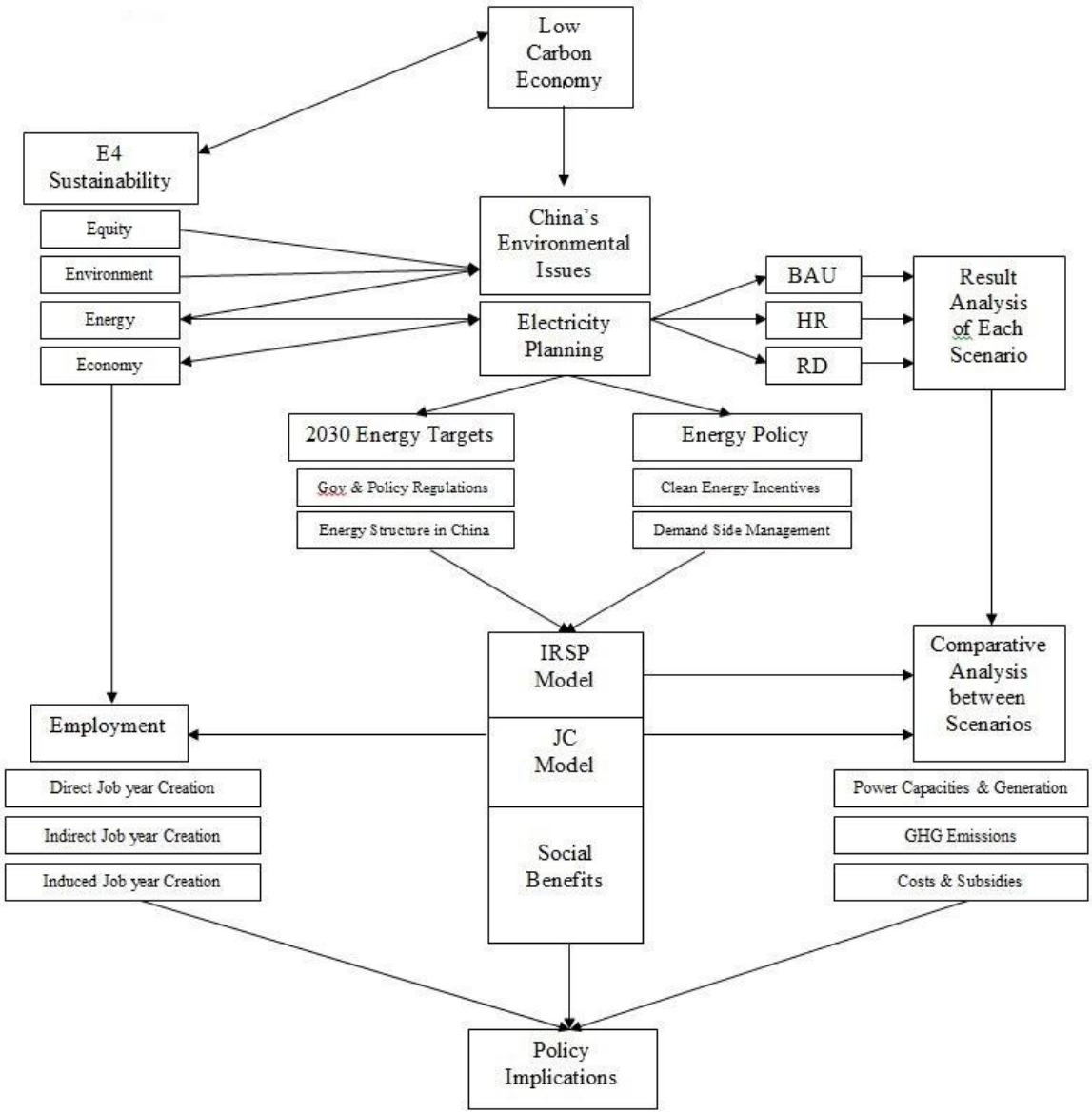
2.1 Dissertation Flowchart

The flowchart presented in this section describes the relationship between the topics covered in this chapter. Low-carbon economy is the conceptual ideology of this dissertation research. Meanwhile, the core framework of the low-carbon economy is the E4 principle. The four elements of the E4 principle are: equity, environment, energy and economy (Wang, 2000). For elaborating the four elements and fitting them into the situation of China, the following major topics are described: China's current environmental issues, China's clean energy policy regulations, changes in employments in China's energy sector, and social benefits that are related to electricity planning.

China's environmental issues are mainly caused by fossil fuel power supply (State Council of China, 2012). In order to change the energy structure, it is essential to study the details of China's energy policy framework. Based on the regulatory functions and the energy structure in China, the research aims to meet China's 2030 energy targets with feasible energy policy adjustments. During the analysis, three scenarios are examined: Business as Usual (BAU) scenario, High Renewables (HR) scenario, and Renewable and Demand Side Management (RD) scenario. The electricity process has two associated

economic objectives, minimizing costs and maximizing high quality job creation. The Integrated Resource Strategic Planning (IRSP) model optimizes the costs structure of electricity planning, and the Job Creation (JC) model provides the comprehensive analysis on associated employment increase of different scenarios.

Furthermore, electricity planning is not merely meeting the power demand with clean energy generation, Demand Side Management (DSM) technologies could effectively contribute to the reduction of power demand and hence reduce pressure on clean energy generation. China has a large area of land, around 9.6 million square kilometers. Most of the clean energy sources, for instance, wind, solar and hydropower, are located in the west and midland China; however, more than 80% of the load centers are located near the east coast (State Council of China, 2012). On the other hand, most of the transmission lines in China's current national grid networks were built by the Japanese contractors during the Second World War in the 1930s (Liu, 2013). In order to meet the high economic growth in China and the associated energy demand, it is required to replace the current grid network with larger capacity, more reliable and higher voltage and ultra-high-voltage (UHV) transmission lines, aside with other technologies which includes smart grid.



2.2 Low-carbon Economy and E4 concept

Low-carbon economy (LCE), according to Delay (2007), refers to a development model that cuts CO_2 emissions without reducing the pace of economic growth. Srinivasan et al (2011) argue that transiting from 'carbon-intensive climate-sensitive' development paradigm to 'low carbon climate resilient' economy requires a restructuring of economic

activities, while the total economic outcome is not necessarily being influenced (Daly, 1990). In other words, tackling climate change issues does not necessarily require sacrifice of economic opportunities (Rong, 2010; Ye and et al, 2007). Srinivasan and et al (2011) point out that the achievement of low-carbon economy could be realized through a combined effort of technology and policy solutions.

According to Wang (2000) and Beg (2002), building a future energy system of reduced carbon emission does not entail simple changes in fuels or technology types. It is rather relying on transformation of an institutional regime of political, social and economic implementations. Energy planning is an instrument of sustainable development, which is a process of protecting the environment, as well as an access of enhancing social equity and providing opportunities to the public for appropriate level of economic gain. This argument is supported by Srinivasan, Ling and Mori (2011), who points out that the influence of global climate change is not only limited as an environmental problem but also contains great socio-economic and geopolitical impacts.

2.2.1 Low-carbon Economy

Adopting the model of low-carbon economy can help forward-thinking economic units to achieve an objective of long sustainable and environmental sound growth with low risk (Daly, 1996; Srinivasan and et al, 2011). The planning procedure of having a proactive approach to the design of climate responsible road map is becoming extremely important. It is argued that in order to attain the real outcome of LCE, it is essential to integrate the GHG reduction target into the planning procedure of industrial development (Srinivasan and et al, 2011). The previous chapter has illustrated the importance of power sector in carbon emission, thus, this dissertation argues that low-carbon electricity supply

as well as energy efficiency should be introduced in China in order to enter low-carbon economy.

Delay (2007) points out the two most effective methods for realizing low-carbon electricity, which are the: 1) increase of energy efficiency in industrial activities, resulting in reduced energy costs and reduced carbon emissions; and 2) identification of the area where carbon footprint of the manufacturing production line or tertiary service is at high level. After that, changes can be made to address the issue of carbon emission. Externally, innovation solutions are required, new technologies and clean energy sources should be integrated by supportive policies and fiscal incentives (Delay, 2007).

Relating the concept of low-carbon electricity to the case of China, as emphasized by the IEA (2012), the increasing CO_2 emission of China is a direct result of the dynamics of economic development, which accelerates ever increasing energy use, mainly for the purpose of electricity consumption.

China's annual economic growth rate was approximately 10% from 1990 to 2010; however, its CO_2 emission growth rate was at least doubled during the same period (Dechezlepretre and et al, 2009). In 2010, CO_2 emission in China's power sector was 7 billion tons (IEA, 2012). In consideration of China's long term economic activities, it is important for this country to realize a sustainable development for the long run as strong and effective policy incentives are urgent to be applied in China's electricity sector.

Pacala and Socolow (2004; in Srinivasan, Ling and Mori, 2011) indicates the three 'must-have' procedures of transition to LCE scenario are: finance, technology and policy instruments. China has long been emphasized financial investments for clean energy development. It has the largest total amount of financial investments in carbon reductions globally, and the volume of investment in this area is still increasing each year in the 12th FYP (Liu, 2012). Clean energy development and energy efficiency are the two

major areas of financial support in China. Details of China's supportive financial policies are demonstrated in this chapter.

From the technology perspective, Srinivasan, Ling and Mori (2011) place emphasis on the improvement of end-use energy efficiency, which represents a set of technologies, for instance, lighting appliances, heating appliances, cooling appliances and other types of electric appliances. Thus, during the power planning process, it is also important for this dissertation to explore the technical development of potential of China's energy efficiency implementations.

Having a suitable and sustainable energy target is also important for a sound GHG reduction. China's 12th five year plan has adopted several energy intensity and carbon intensity targets; however, China is required to provide a detailed objective of tackling its carbon reduction from the electricity sector, which is the biggest carbon contributor of China due to the mass utilization of coal power plants.

2.2.2 The E4 Concept

As stated by Wang (2000), growth refers to quantitative growth yet it is not sustainable in the long run, e.g. economic growth and the growth of electricity consumption; however, electricity planning seeks a long-term sustainable balance between the economy, environment, energy and social equity. Since energy and society are closely integrated, human welfare on all aspects should be inclusively considered for a balanced energy planning (Wang, 2000).

Figure 2.1 demonstrates a framework of sustainable development with the integration of time and the conformed E4 interlocking nature, which are energy, environment, economy and equity. The accumulation of wealth has experienced rapid

growth in the last several decades, finding the balance for energy, environment, economy and equity is becoming more important in order to achieve a sustainable growing social wealth in present and especially in a future energy regime (Wang, 2000).

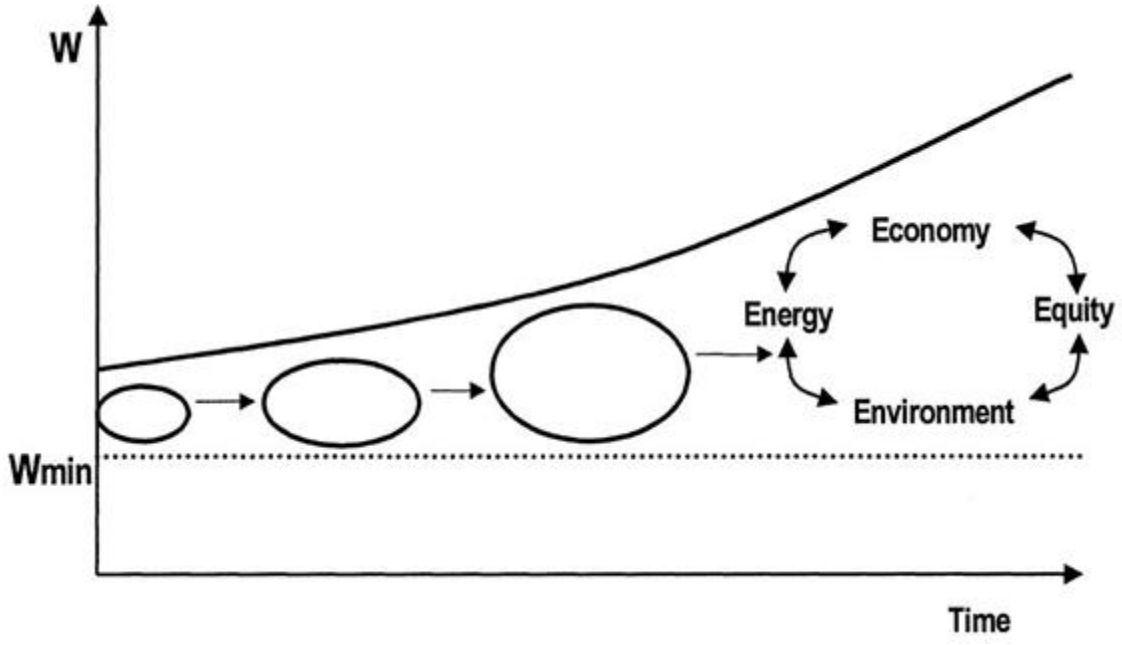


Figure 2.1 The E4 framework of sustainable development
Source: Wang, 2000

Electricity planning in this dissertation aims to achieve the stability between social-economic elements. Thus, the objective of 2030 China's electricity planning is not merely aiming to achieve the conventional energy system of least economic cost, but most importantly, to encourage the potential of China's environmental responsibility and to investigate the associated social benefits.

A core focus in this dissertation is to study the reduction of carbon emissions, as well as avoided major air pollutants impacting public health, such as: nitrogen, sulfur,

and nitrogen dioxides. Furthermore, in the methodology section, the job creation estimation model from Rutovitz and Atherton (2009) is introduced. The model quantifies potential jobs created in the electricity sector by implementing different energy policies.

2.3 Review of Existing Roadmaps in Literature

Lawrence Berkeley National Laboratory (LBNL) has been developing comprehensive energy roadmaps for China since 2001 (Fridley, 2013). Instead of studying for a least-cost scenario, their investigation studied the best available technologies to help China theoretically reduce maximum amount of carbon emissions. The LBNL used the 'end-use' models to study the energy plans from 2012 to 2030, including electricity, petroleum, natural gas, and coal. For the demand patterns, LBNL had three major focus areas: power generation, residential efficiency, and transportation. In addition, LBNL in their model also considered population growth, urbanization, and a number of macro-economic indicators (Fridley, 2013).

The model used in LBNL's report was developed by the China Energy Group under the NDRC, and the software platform used was the Long Range Energy Alternatives Planning (LEAP) which was developed by the Stockholm Environmental Institute. The LEAP model enables the LBNL to capture diffusion of end use technologies and macroeconomic drivers, such as population, GDP growth, and etc. According to Fridley (2013), the two most important factors in the LBNL 'end-use' model are quantity of energy consumption and technical efficiency.

There were two scenarios in the LBNL's study, the reference scenario and the Max Tech scenario. The reference scenario followed China's current economic growth and the Max Tech scenario assumed adoption of the best available technologies without concern for the economic costs. The major difference between these two scenarios, according to Fridley (2013), lies in the level of efficiency improvements. The study evaluated final energy consumption in residential, commercial, industrial and transportation sectors; hence, the standardized unit of energy in the research is tons of coal equivalent (tce). A number of other factors were also being considered: industrial production, equipment efficiency, residential appliance usage, vehicle ownership, and power sector efficiency (Fridley, 2013).

Figures 2.2 and **2.3** demonstrate two scenario comparisons for power capacity and power demand predictions. According to obtained results, power consumption will achieve 7,091 TWh under the reference scenario, and 5,500 TWh for the Tech Max scenario. For power capacity, it would be 2,000 GW for the reference scenario and 2,250 GW for the Max Tech scenario. In 2030, under the Max Tech scenario the share of fossil fuels in power generation would be 34%. Non-fossil fuels would provide 66%, including 23% hydropower, 16% wind power, 23% nuclear power, 3% solar power and 1% biomass; and the distribution of power capacity would be 55% for fossil fuels and 45% for non-fossil fuels, including 17% hydropower, 15% wind power, 7% nuclear power, 2% solar power and 4% biomass.

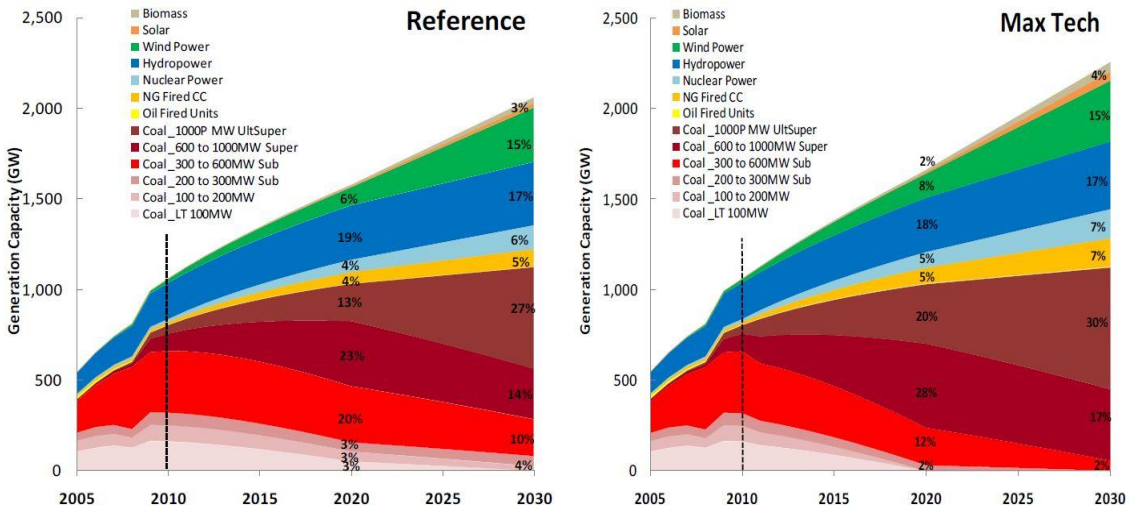


Figure 2.2 Power capacity under the Reference and Max Tech scenarios
Source: Fridley, 2013

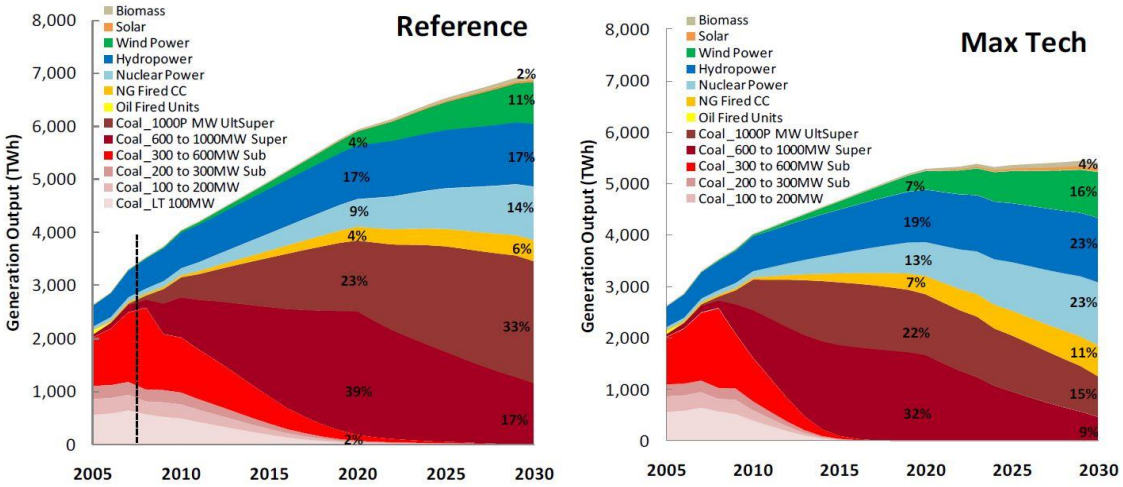


Figure 2.3 Power generation under the Reference and Max Tech scenarios
Source: Fridley, 2013

The LBNL research also evaluated the saving potential of energy under the Max Tech scenario at 1 billion tce beyond the reference scenario (Fridley, 2013). Meanwhile, the primary source of savings is from electricity sector, which benefits from

increased renewable energy in the power sector and also increasing coal power efficiency. Carbon emission will peak by 2020 under the Max Tech scenario. From 2020 to 2030, carbon emission generally shows declining curves for the reference and the Max Tech scenarios. By 2030, the total amount of CO_2 emissions was projected at 7,190 Million Metric Tons (Mt) under the Max Tech scenario and 10,126 Mt under the reference scenario.

IEA's World Energy Outlook developed China's 2030 energy roadmap. Same as LBNL, IEA also predicted that China's energy structure would shift towards less energy-intensive activities and more energy-efficient technologies. There are two scenarios in IEA's analysis, the Reference scenario and the Alternative Policy scenario. The forecasting method of IEA (2007) was based on the economic model, including a number of key variables such as economic growth, energy price, technology innovation, energy intensity, and domestic consumption.

Economic growth is assumed to average 6% per year during the entire projection period (IEA, 2007). The coastal region's economy is expected to continue to grow more rapidly, averaging 6.1% per year to 2030. Moreover, due to government policies aimed at structural adjustments to economic growth, the share of the services sector in China's total GDP is assumed to increase steadily from 40% in 2005 to 47% in 2030. The IEA (2007) assumes that the Chinese government will gradually phase out all energy subsidies over the projection period, and fuel price will be in line with international prices. However, since the primary input for electricity is coal, the impacts of coal price are mainly determined by the regulatory restrictions. Furthermore, it is

assumed that energy efficiency would grow steadily since the technology improvements and innovation development.

According to IEA's (2007) Reference scenario, China's electricity demand would be 8,472 TWh in 2030, growing at the average annual rate of 4.9%, driven mainly by heavy industry (see Table 2.1). In the longer term, energy demand will slow down as the economy matures. In 2030, coal power would share 78% of total energy demand, hydropower would share 12%, nuclear power would share 3%, and wind power would share 2%. In terms of power capacity in 2030, the total capacity is expected to be 1,775 GW at an annual growth rate of 5.1%. Coal power would share 71%, hydropower would share 17%, nuclear would share 2% and wind power would share 3%. The total CO_2 emission from China's power sector in 2030 is predicted to be 6,202 Mt, in which 5,997 Mt (97%) would come from coal power (details see Appendix 1, Tables A.1.1 and A. 1.2).

In the Alternative Policy scenario, China's electricity demand in 2030 is predicted to be 7,435 TWh, which is 12% less compared with the Reference scenario (IEA, 2007). There would be 64% fossil fuel energy generation, and the share of renewable energy in power generation would reach 24% of the total electricity generation in 2030, in which 17% will come from hydropower, 6% from nuclear power, 3% from wind power and 1% from solar power generation. On the other hand, the total installed capacity is predicted to be 1,627 GW in 2030. Overall, fossil fuel capacity share would be 64%, and non-fossil fuel capacity share would be 36%, including 23% hydropower capacity, 3% nuclear power capacity, 5% wind power capacity and 2% solar power

capacity. Furthermore, carbon emission in the electricity sector would be 4,726 Mt in 2030 according to the Alternative Policy scenario, in which 4,465 Mt (94%) would come from coal power generation.

Green Peace also studied the global energy roadmap from 2009 to 2050, with a concentration on electricity sector and a number of heavy industrialized countries including China. Same as the IEA's methodology, Green Peace also utilized the economic model with a number of additional variables, including the best available technologies, consumer behavior changes, economic structural changes, and the characteristics of major industrial sectors.

Green Peace (2012) built two scenarios, which are the Reference scenario and the Energy [R]evolution scenario. Under the Reference scenario, total primary energy demand in China increases by 89% from 96,000 Peta Joules (PJ) in 2009 to around 181,300 PJ in 2050. In the Energy [R]evolution scenario, energy demand increases by 9% compared to the consumption in 2009 and it is expected to reach 104,500 PJ by 2050. For the electricity sector, under the Energy [R]evolution scenario, power demand in the industrial, residential, and service sectors is expected to increase at slower rates, and even higher increases can be avoided. With the utilization of efficiency measures, total electricity demand would be 10,040 TWh per annual in 2050. Meanwhile, according to the Energy [R]evolution scenario, efficiency measures in the electricity industry could avoid power generation of 3,320 TWh per year (equivalent to 29% of the total power generation).

Table 2.2 and table 2.3 illustrate the details of power generation and power capacity distribution for the reference scenario and for the [R]evolution scenario (Green Peace, 2012). Under the reference scenario, fossil fuels share in in the total power generation would be 71.5% in 2030, and non-fossil fuels would provide 28.5%. In terms of power capacity, share of fossil fuels would be 59% of the total capacity and share of non-fossil fuels would be 41%. On the other hand, under the [R]evolution scenario, fossil fuels would share 52% and non-fossil fuels would share 48% of the power generation; meanwhile, in terms of power capacity, fossil fuel would share 38% of the total capacity and non-fossil fuel would share 62%. Share of non-fossil fuels in the [R]evolution scenario would be by 7% higher than that in the reference scenario. Furthermore, according to the Green Peace (2012), China's total CO_2 emissions from power generation in 2030 would be 12,007 Mt under the reference scenario and it would be 7,531 Mt under the [R]evolution scenario, which is a 37% reduction of carbon emissions (Appendix 1).

NDRC (2011) studies China's 2030 energy roadmap from the perspective of official regulators. Under the study, China's energy supply would mainly depend on fossil fuels, however, with the maturity of renewable energy technologies, the contribution of renewable energy sources in China' electricity industry will grow fast. Since the study was conducted by China's energy regulatory agency, the two key concerns of the NDRC were focused on: potential for renewable energy that could be utilized for power generation, and the pace of electricity demand growth under China's economic development trends. Other factors, for instance, technological maturity, economic structure, carbon reduction, were also have been considered by the NDRC.

Accordingly, the economic potential of China's renewable energy capacity was estimated at 5.9 billion kW by 2030, and the annual energy production was projected between 4-4.6 billion tce per year (see Table 2.4). NDRC (2011) pointed out that wind and solar power would have the highest economic potentials for power capacities in China in the nearest future. For wind power, the economic potential was estimated between 0.7-1.2 billion kW, and annual energy production was projected between 0.5-0.8 billion tce. The economic potential for solar power was expected to be 2.2 billion kW, and its annual energy production was projected between 1.1-1.4 billion tce.

Table 2.1 China's renewable energy potential

	Theoretical potential (hundred GW)	Economic potential (hundred GW)	Annual energy production (hundred million tce/year)
Wind	43	7-12	5-8
Solar	1700 billion tce	22	11-14
Biomass	-	-	8.9
Hydro	6	5	8.6
Geothermal	462.65 billion tce	0.2	0.5
Ocean	6100	9.9	5.5
Total		59	40-46

Source: National Development and Reform Commission, 2011

There are three scenarios that were designed by NDRC (2011), namely high scenario, middle scenario, and low scenario (in figure 2.4). The high scenario refers to the maximum amount of investment to be invested and strong policy to be applied for new energy technologies; hence, renewable energy could be consumed at the greatest possible

level. The low scenario is a reference scenario, which simulates the conservative development of renewable energy following China's current economic development pace under the 11th FYP. The middle scenario studies the development trend between the high scenario and the low scenario, in which the major uncertainty is the total capability of China's renewable energy contribution during the projected period.

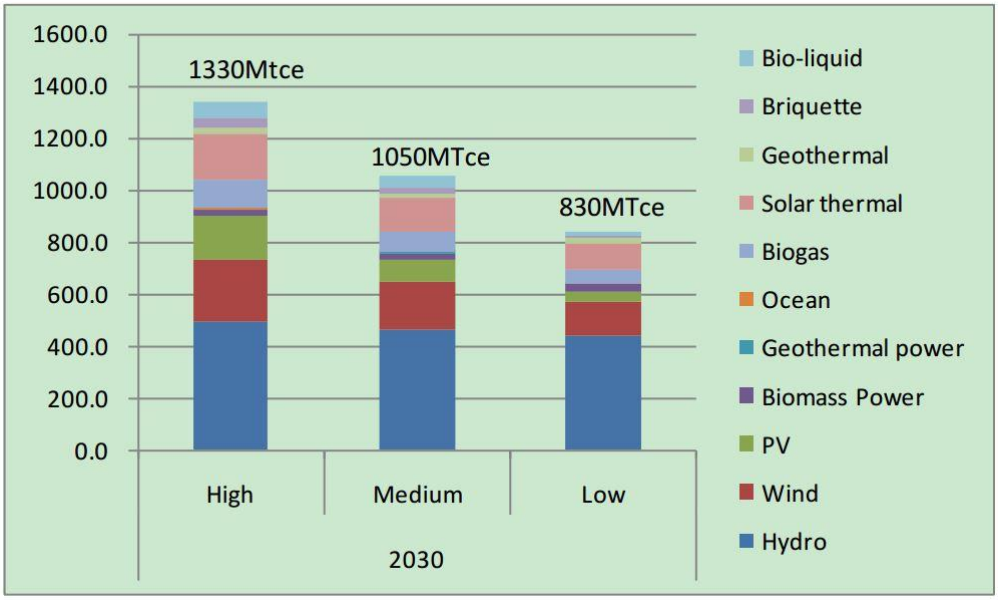


Figure 2.4 Scenarios for China's 2030 renewable energy development
Source: NDRC, 2011

As demonstrated by NDRC (2011), the assumption for renewable energy utilizations in these three scenarios are: 13.3 billion tce for high scenario, 10.5 billion tce for middle scenario, and 8.3 billion tce for low scenario. After converting values from tce units into electricity units, these values are 10,827 TWh for high scenario, 8,548 TWh for middle scenario, and 7,657 TWh for low scenario.

Wind and solar power are the two forms of renewable energy that receive high attention since they have the utmost potential for development (NDRC, 2011). For the

development of wind power, NDRC (2011) indicates that on-shore wind power would continue to be the major technology, and more efforts would be made to promote the on-gird wind power technologies. For the development of solar power, high efficiency, high stability, and low cost crystalline silicon technology would be largely used in China. Meanwhile, the generation costs of large scale PV is expected to drop to 1 RMB per kWh by 2015, 0.6 RMB per kWh by 2020, and then 0.4-0.5 RMB per kWh by 2030.

The REmap 2030 is an energy roadmap prepared by the International Renewable Energy Agency (IRENA), which assesses how different countries could effectively work together to significantly increase the share of renewable energy in the global energy mix by 2030 under the application of innovative technologies. The IRENA (2014) sees China as a global leader in renewable energy development, with massive potential to accelerate a diverse range of renewable sources and innovative technologies, both for power generation and for power consumption.

IRENA's methodology is to optimize the balance for China's 2010, 2020 and 2030 energy allocation, and to assess renewable energy technology options that could be deployed in China. The model includes two major categories: cost and technology. Cost is referred as capital cost, operation cost and maintenance cost; and technical performance considers reference capacity of installation, capacity factor and conversion efficiency of both renewable and conventional energy types. The analysis studies a number of sectors: industry, buildings, transport, and power and district heat; while this dissertation only focuses on the power sector.

There are two scenarios in the IRENA report, the reference scenario and the REmap scenario. The reference scenario follows the current trend of renewable energy development until 2030, and the REmap scenario illustrates the feasibility of a scenario that has higher penetration of optional technologies. IRENA collects national-level data on end-users and the power sector, and use the 2010 as the base year as a starting point. Data are collected from the historic trend as well as from China National Renewable Energy Centre (CNREC), which is a sub-division of the NDRC.

Table 2.5 demonstrates the findings of the IRENA analysis. For the REmap scenario, total energy demand in the electricity sector in 2030 would be 9,150 TWh, and renewable energy would contribute to 40% of the total energy demand (IRENA, 2014). For the reference scenario, total energy demand would be 9,113 TWh in 2030, which is very similar with that of the REmap scenario. Renewable energy would also play a major role in power capacity development. For the reference scenario, renewable energy capacity would be 1,005 GW in 2030, and for the REmap scenario, it would be 1,467 GW, which is approximately by 50% (462 GW) higher.

For both reference and REmap scenarios, the development of hydropower is expected to be 500 GW (including both power generation and pump storage) and 1,600 TWh. However, the biggest differences are the development of wind power and solar power. In 2030, wind power generation would be 647 TWh for the reference scenario and 1,263 TWh for the REmap scenario, and solar power generation would be 197 TWh for the reference scenario and 1,263 TWh for the REmap scenario. In terms of power capacity, wind power would be 355 GW and solar power would be 139 GW for the

reference scenario, and then 561 GW (wind power) and 308 GW (solar power) respectively for the REmap scenario in 2030 (for details see Appendix 1).

The reduction of carbon emission is also being demonstrated by the IRENA (2014) report, and the results show that projected reduction of 2030 China's carbon emission in the REmap scenario is significant, compared to the reference scenario (See Table 2.6). Carbon emission in 2030 is expected to be 5,762 Mt for the reference scenario and 4,544 Mt for the REmap scenario in the electricity sector, and the gap between these two scenarios is 1,218 Mt. Accordingly, carbon emission in China's electricity sector is proven to be the highest among other industrial emitting sectors. According to the study, China's electricity sector shares 57% of the total emission under the reference scenario and 54% under the REmap scenario (IRENA, 2014) (see Apendix 1).

Summary of the findings from the LBNL (2012), IEA (2007), Green Peace (2012), NDRC (2011), and IRENA (2014) are presented in the Table 2.2 below. As illustrated in the table, the projection of 2030 China's electricity demand falls in the range of 7,091 TWh and 10,500 TWh. On the other hand, the projection of 2030 power capacity is expected to be between 1,005 GW and 2,250 GW. Meanwhile, 2030 carbon emission is projected to fall in the scale between 7,190 million tons to 8,877 million tons. Renewable energy penetration is expected to share approximately 36% to 66% in terms of total power generation, and would share approximately 36% to 45% in terms of total power capacity in China's 2030 energy roadmap planning.

Table 2.2 Summary of 2030 China energy roadmap

	Lawrence Berkeley National Laboratory (LBNL, 2012)	International Energy Agency (IEA, 2007)	Green Peace (2012)	National Development & Reform Council (NDRC, 2011)	International Renewable Agency (IRENA, 2014)
Prediction of 2030 China's Electricity Demand & Scenarios	• Reference 7,091 TWh 2,000 GW • Max Tech 5,500 TWh 2,250 GW	• Reference 8,472 TWh 1,775 GW • Alternative Policy 7,435 TWh 1,627 GW	• Reference 10,040 TWh 2,195 GW • Energy Revolution 8,966 TWh 2,099 GW	• High scenario 10,827 TWh • Middle scenario 8,548 TWh • Low scenario 7,657 TWh	• Reference 10,500 TWh 1,005 GW • RE Map 9,800 TWh 1,467 GW
Methodology & Indicators	End Use Model, Population, Urbanization, GDP & growth, Efficiency improvements, Industrial sectors	Economic growth, Energy price, Technology innovation, Energy intensity, Domestic consumption	Best practice technologies, Behavior changes, Economic structural changes, Industrial sectors	Social & economic indicators, Policy supports, Carbon reduction, Technology maturities	Predictions from historic trend, China National Renewable Energy Centre (CNREC), and other official data sources.
Power Generation %	Fossil fuel: 34% Non-fossil fuel: 66%	Fossil fuel: 64% Non-fossil fuel: 36%	Fossil fuel: 55% Non-fossil fuel: 45%	Fossil fuel: 58% Non-fossil fuel: 42%	Fossil fuel: 61% Non-fossil fuel: 39%
Power Capacity %	Fossil fuel: 55% Non-fossil fuel: 45%	Fossil fuel: 64% Non-fossil fuel: 36%	Fossil fuel: 60% Non-fossil fuel: 40%	Fossil fuel: 63% Non-fossil fuel: 37%	Fossil fuel: 60% Non-fossil fuel: 40%

2.4 Uniqueness of the Dissertation

As indicated by Yuan (2014), the electricity sector is responsible for 40% of China's carbon emission, making it the largest emitting sector in China. According to Yuan (2014), there is a demand for developing China's 2030 roadmap for electricity industry. Hence, this dissertation concentrates on developing China's electricity roadmap.

This dissertation focus on the finding the optimal pathways for China's electricity industry through 2030, which will address climate change problem. However, in comparison with the research done by others: LBNL (2012), IEA (2007), Green Peace (2012), NDRC (2011), and IRENA (2014), this dissertation has its own uniqueness by focusing on the below six areas.

First, since the research only focuses on the electricity sector, there is no need to coordinate the consumption of electricity in other sectors, e.g. transportation sector, heat generation, and the accuracy of energy allocation would be largely increased. A number of studies reviewed in the previous section (LBNL, 2012; IEA, 2007; IRENA, 2014) consider electricity consumption in multiple industrial sectors. The analysis would become more complicated and more difficult to simulate when there is a combination of electricity generation, transportation, and heat generation. Uncertainties would be increased and the total amount of variables from 2015 to 2030 would also be increased.

In the reviewed studies, researchers tried to simulate the pattern of electricity consumption in a number of other sectors, e.g., the development of electric vehicle, trying

to study the possibility of utilizing power heating sources, and etc. This dissertation would argue that it is very hard to quantify the effect of these innovative technologies, and it is even harder to track the ratio of mass implementations of these new methods in the market. In order to provide a more practical analysis of China's 2030 energy system, this dissertation only studies the electricity sector, instead of focusing on the other sectors. Focusing only on the electricity sector helps to move toward a deeper and more feasible analytical research, and the results could be better applied for China's real life situation.

Second, this dissertation evaluates technical feasibilities of proposed scenarios. In most of the other reviewed research, a stronger focus is to utilize the socio-economical inputs and design a theoretically achievable model for China's 2030 energy roadmap. For instance, a typical technical constrain in the electricity sector, is the utilization hours of wind power and solar power. These two types of power plants are the mainstream renewable energy sources in China's non-fossil fuel energy development; however, it is important to understand that peak load demand are usually happening during the noon hours of a typical day, where solar power could hardly meet the electricity demand due to its low capacity factor, and wind power usually generate electricity at nights when there are more wind resources.

Third, the other researches are mainly focusing on energy planning at a much longer time-scale. Many of their models are developed to conduct results beyond 2030, even going into China's 2050 projection (Green Peace, 2012). Under such circumstance, salvage value of power capacities and consideration of remediation after power plant is

closed would not be applied at the end of 2030. For electricity roadmap that ends in a certain year, it is vital to realize that salvage value should be subtracted after the ending year of power planning. Among the five reports, LBNL (Fridley, 2013) is the only study that touch based on discussing salvage value at the end of the planning period in terms of power capacities that are still performing by 2030. Hence, my dissertation would like to apply the accounting rule of 'straight line depreciation' to calculate the salvage value of power plants.

Fourth, despite that the LBNL (Fridley, 2013) and Green Peace (2012) also facilitated energy efficiency in its research, but their scenarios were trying to achieve maximum technical efficiency without concerning the costs and commercial barriers of implementing the efficiency tools. However, this dissertation introduces DSM to reduce energy demand first and then aims to practically utilizing power supply to meet the rest of the power demand, which would be helpful for non-fossil fuel power supply to share a higher percentage in the total electricity demand.

This dissertation focuses on the power generation as well as power demand side. Since this dissertation already has the estimated amount of electricity demand in each year, it is important to deduct the energy consumption that could be saved via DSM, and then utilize clean energy sources to meet the remaining amount of energy demand. As a result, result of the power planning could reduce the electricity generated from fossil fuels, and as a consequence also reduce carbon emissions.

Fifth, the IRENA (2014) and NDRC (2011) illustrate the carbon emission in the primary energy consumption, but this dissertation aims to illustrate the reduction of not

only carbon emission but also pollutions in the electricity sector, including CO_2, SO_2 and NO_x. This dissertation argues that evaluating the potential of reducing other types of pollutants, for instance, SO_2, NO_x, are important in terms of planning for the electricity roadmap.

Sixth, since the other five studies generally have a broader research scale (electricity, transportation, industries, etc.), most of their studies are lacking of economic analysis from the perspective of associated job creation (the study from Green Peace was the only research touch based job creation). As an industry with the characteristic of natural monopoly, electricity sector is generally seen as an important social component for the government to increase social welfare by adding job opportunities in the market (Liu, 2013). When optimization models are looking to achieve the lowest total cost during the entire planning period, it would be meaningful for policymakers to read how many jobs in the electricity sector could be created that is associated with each planning scenario.

As a result, the readers could have a general understanding of how many jobs can be created not merely because of the power plant constructions and operations, as well as a series of in-direct jobs plus a larger scale of induced jobs. This dissertation would argue that increasing job opportunities for a region could directly bring impacts to the local community, which is equally important as reducing total cost of electricity planning. Hence, this dissertation investigates the total number of job opportunities that could be increased according to the optimized 2030 electricity roadmap for China.

2.5 China's Air Quality and Environmental Issues

China is facing rapid economic development, which would continue driving increase in electricity demand in the near future. As a result of the current electricity structure, massive coal power generation is a key barrier for China to build a low-carbon economy (IEA, 2012; Jiang and Zhuang, 2012). Inclusion of low-carbon electricity in China's development strategy is vital for addressing country's environmental problems, and thus it could be helpful for China to follow a sustainable social-economic development (Ladislaw and Nakano, 2011).

Since the 2000s, China has experienced significant environmental challenges associated with coal smog and its interaction with transportation exhausts (Akimoto and et al, 2006; Dincer, 1999; Dorf, 2001). Combination of these pollutants induces chemical reactions which result in particulate matters (Roffo, 2012). Particulate matter could be categorized into two types, PM_{10} and $PM_{2.5}$, which are both harmful for human health (Li, 2011). PM_{10} consisting of particles with aerodynamic diameters smaller than 10 nanometers and $PM_{2.5}$ consisting of particles with aerodynamic diameters smaller than 2.5 nanometers (Wang and et al, 2013; Jayasinghe, 2008). According to the Inter-governmental Panel on Climate Change (IPCC) 5th Assessment Report (Cubasch and Wuebbles, 2013), electricity generation through coal power plants is a major contribution to PM_{10} and $PM_{2.5}$. There are currently no data available on $PM_{2.5}$ created from the electricity sector; hence, the environment section of the E4 theoretical concept of this dissertation shall focus only on illustrating the concerns and impacts of $PM_{2.5}$, and data analysis on $PM_{2.5}$ is absent for the scope of this dissertation.

Figure 2.5 compares the top 10 most polluted cities in China and in the U.S. As illustrated, the pollution in China is much higher than that in the U.S. According to the World Health Organization (American Lung Association, 2014), the intensity of $PM_{2.5}$ over 10 g/m3 will start to damage people's health through increasing lung cancers and heart diseases. The current air qualities in China are key concerns since a large number of cities in China are having severe air pollution issues by greatly exceeding the WHO standard of $PM_{2.5}$ index. Among the top ten most polluted cities in China, the range of $PM_{2.5}$ intensities is 102-156 g/m3, in comparison, the range of $PM_{2.5}$ intensities for top U.S. cities is 13-19 g/m3. The result indicates an urgent and severe issue for public health due to the environmental damages affecting the local communities.

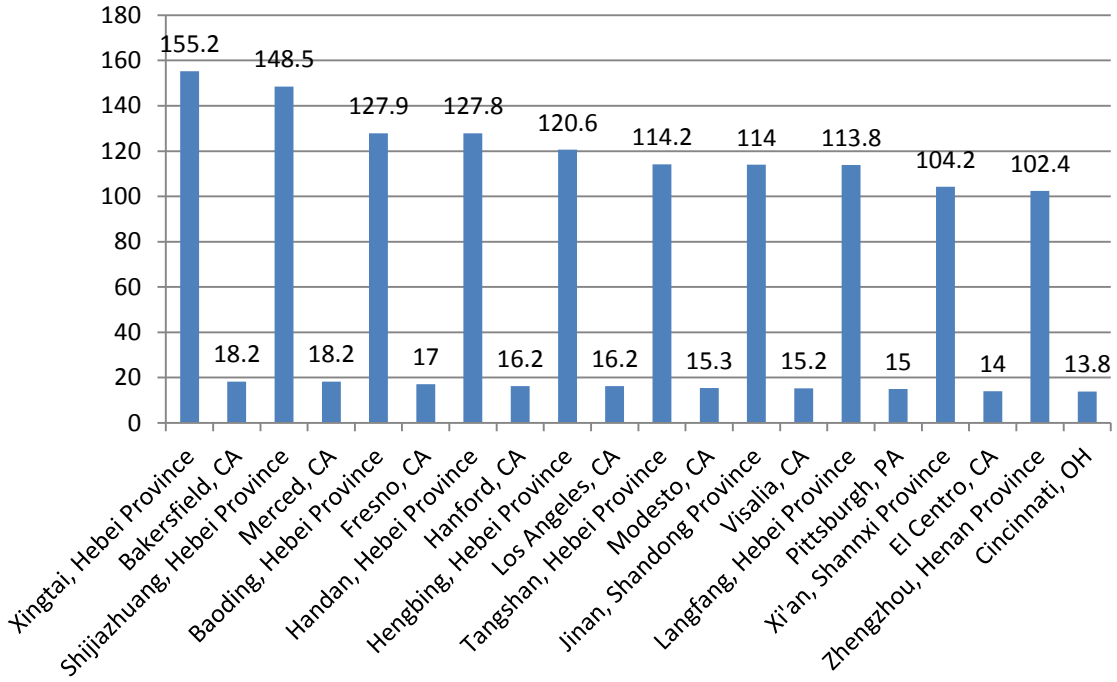


Figure 2.5 Top 10 most polluted cities in China and the U.S. (Unit: g/m3)
Source: American Lung Association, 2014

Air pollution is a nation-wide concern for China; nonetheless, the region of Beijing-Tianjin-Tangshan (BTT) and its nearby Hebei province are among the most severely exposed regions due to high intensity of heavy industries located in these regions (Yang and et al, 2005; Smith and et al, 1994; Wang and et al 2006). Most of the electricity supply in BTT region is produced by coal power plants (Roffo, 2012; CNEMC, 2013; Sokolov and et al, 2009; Tu, 1998). Due to this, average density level for $PM_{2.5}$ in Beijing was 89.5g/m3 in 2013, exceed 9 times of the World Health Organization (WHO) standard (Nielsen and Ho, 2013). Meanwhile, the indexes for SO_2, NO_x and PM_{10} for Beijing in 2013 were 26.5 g/m3, 56 g/m3, and 108 g/m3 respectively (Deng, 2013). In 2012, the ratio of lung cancer was 49.70 per 10 thousand patients, which caused 44.15 deaths per 10 thousand patients (Cong, 2012). In this regard, it is generally agreed by many scholars that Beijing should address environmental problems created by the coal power generation as a top priority (Chan and Yao, 2007; Li and et al, 1994; Sun and et al, 2004).

2.6 China's Clean Energy Policies

Energy policies in China are developed by the central government. The involved governmental bodies are mainly: State Council of China (SCC), NDRC, SERC, National Energy Agency (NEA), and China Electricity Council (CEC). However, due to the monopoly characteristic of China's electricity industry, the detailed policies are agreed

between the SERC and the SGCC before they are officially released. Strong evidence of this situation is that the president of the SGCC, Mr. Liu Zhenya, is also the president of the CEC, and he has senior positions in other government sectors. Hence, leadership of the SGCC is also controlling the leadership of the CEC. The main executive branch of China's electricity sector is monitoring itself in terms of power regulation and planning.

Major policies, supporting clean energy sources, implemented in China's electricity sector can be grouped in two categories: 1) requirements of clean energy utilization in future plans, and 2) tariff incentives for clean energy development. In order to understand the potential of China's clean energy development, it is necessary to review the current policy framework of China's clean energy incentives. National plans related to China's clean energy development, as well as major types of clean energy policies are presented in the following section. Since the major types of clean energy resources in China are hydropower, wind power, solar power, and also nuclear power. Studies on policies and incentives of these forms of power are concentrated in this section.

2.6.1 The 12th Five Year Plan for Renewable Energy

Under the clean energy targets set by the NDRC for the 12th FYP (i.e., 2011-2015) were to achieve 0.478 billion ton-coal-equivalents (tce) for renewable energy by 2015, which was projected to represent 9.5% of total primary energy consumption in 2015 (Li and et al, 2013). During the 13th FYP, renewable energy capacity is required to grow by 160 million kW, including 70 million kW of wind power capacity, 20 million kW of solar

power capacity, and 7.5 million kW of biomass (Liu, 2013). These targets were consistent with the 2020 targets set by the Chinese government. The targets were set based on discussions with the SGCC, since the SGCC is the implementer and its involvement is crucial for effectively achieving the targets (Winkler and et al, 2008).

Calling upon the request from the State Council of China, in 2012, the Financial Ministry of China released an additional financial support in responding to the NDRC adjustment of clean energy tariff incentives (Development Research Council of the State Council of China, 2007). As a result, the total adjusted amount of funding was 8.598 billion RMB, including 5.851 billion RMB for wind power (68.1%), and 0.723 billion RMB[3] for solar power (8.4%).

2.6.2 The 2012 Renewable Energy Act

The 2012 Renewable Energy Act is an additional policy instrument based on the 11th FPY energy regulation framework. Several policy modifications are made for renewable energy types. According to the State Council of China (2013), key policy details are summarized as:

2.6.2.1 Hydropower

- Speed up the approval and verification process of small and medium size (capacity

[3] The currency exchange ratio between USD and RMB is 1:6.23 in 2013. Thus, 1 RMB = 0.16 USD. This exchange ratio applies to the rest of this dissertation.

under 500 MW) hydropower projects.

- Speed up the construction of bump-storage hydropower stations.
- Establish a national institution to manage resident migrations incurred by hydropower projects.
- Increase the wholesale price of hydropower to compensate migration, ecology recovery and other substantial costs.
- Improve developmental pattern of hydropower and switch to multistage low dams.
- Address issues of ecological recovery and environmental protection during development.

2.6.2.2 Wind Power

- Establish national wind resource research institute and compile national wind resource.
- Accelerate the process of detailed planning for overall national power grid development.
- Implement policy rules in the *Renewable Energy Act* and work out supportive measurements.
- Establish national technology research platform. Reinforce R&D and speed up the standardization of wind turbines.
- Enhance the research on grid-access technologies for wind power.

2.6.2.3 Solar Power

- Develop national long-term industrial policy scheme for solar power, and work out clear policy rules on technical supports.
- Establish funds to provide fiscal subsidies and tax credit for solar power industries. Encourage commercialized solar power development.
- Incorporate solar-heat products, e.g. solar heat water system, into the national fiscal subsidy program. Integrate the development of solar water heater with building designs.

2.6.2.4 Nuclear Power

- Increase R&D investment on nuclear power. Based on the third generation of nuclear technology, increase the construction speed of fast-reaction power plants.

- Reinforce the examination standards of evaluating nuclear power plant security. Enhance the acquisition of post-processing technology for nuclear waste.
- Revise the technology standards for nuclear power according to China's power grid adoptability.
- Establish a standard national education program for safety nuclear training. Enhance the ability of reactions in emergency situations.

2.6.3 Wind Power Subsidies

China has three financial sources for wind power subsidies: Clean Development Mechanism (CDM), governmental subsidies, and electricity sales revenue (Austin and et al, 1999; Castro, 2010; Karakosta and et al, 2009; Lloyd and Subbarao, 2009). CDM provides a large amount of international financial aid, with each kWh of wind power receiving 8 cents (in RMB) in subsidies but the CDM funding criteria exclude many domestic wind projects. In contrast, governmental subsidies are a major force in accelerating the development of wind power (Wang and et al, 2012). In 2010, China invested 103 billion RMB, at 32.72% annual growth, representing 26.14% of its total power sector investment (Cheng and et al, 2011). Figure 2.6 shows that Chinese wind power subsidies grew rapidly from 2002 (138 million RMB) to 2008 (2.38 billion RMB).

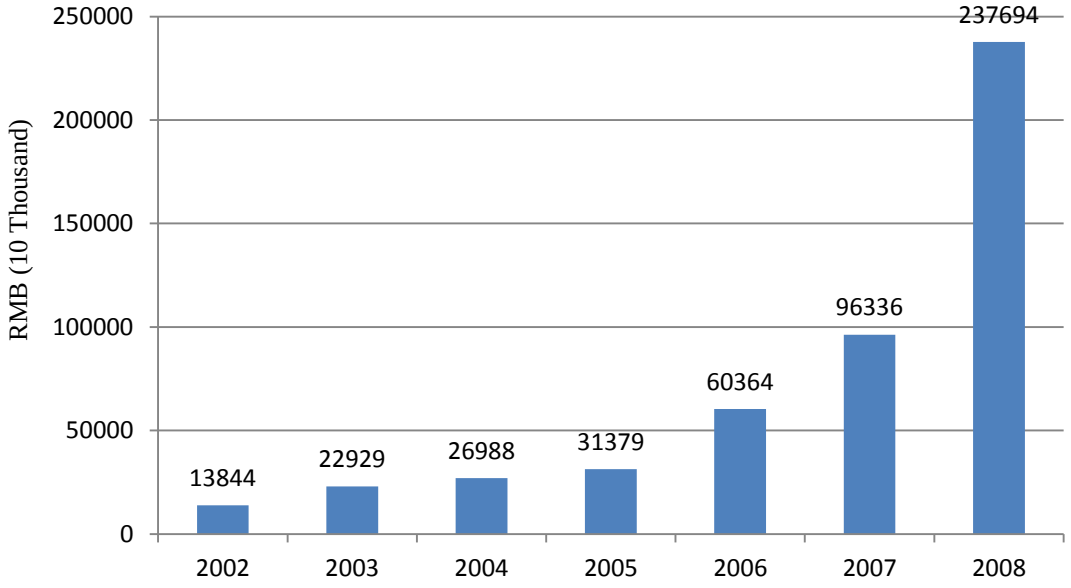


Figure 2.6 China's Wind Power Subsidy Growth
Data Source: Xia and Song, 2009

In China, part of the profit from coal power is used to subsidize wind power (Olsen and Fenhanm, 2008; Soker and et al, 2007). In 2009, such cross-subsidies for renewable energy, especially wind power, were raised from 0.2 cent/kWh (in RMB) to 0.4 cent/kWh, and in 2011, the coal power charge was increased by 0.6 cents/kWh (in RMB) to support another increase in the cross-subsidy. The annual growth of China's wind power market reached 60% in 2006, followed by three consecutive years (2007–2009) of more than 100% growth in installed capacity (GWEC, 2009).

In 2009, NDRC (Li et al., 2013) released *NDRC Pricing* Reg. (*2009)1906*, which divided China's onshore wind resource into four categories; each category has a different benchmark tariff. The government applied "price floor" method, which means the result of bidding is limited to a certain minimum price, to prevent the price from going below

the cost (China Renewable Energy Committee, 2009). As in Figure 2.7 and Table 2.3, floor prices vary from 0.51 to 0.61 RMB/kWh, according to the State Council (2013), the weighted average price of China's wind power is 0.57 RMB/kWh.

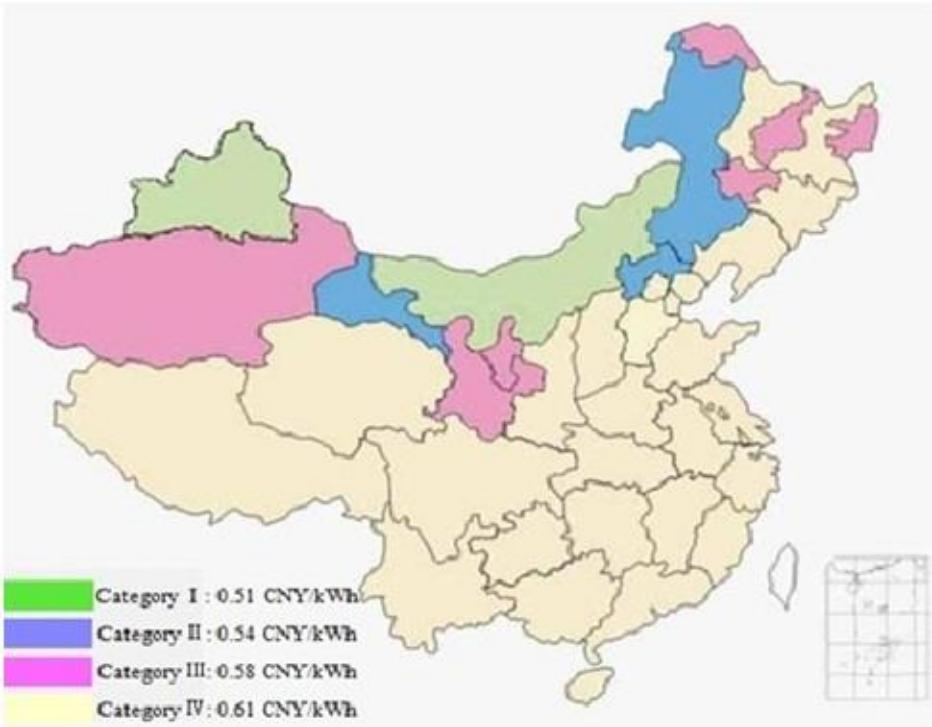


Figure 2.7 Tariff categories for Onshore Wind Power (Jiang et al., 2011)

Table 2.3 Floor prices in China's wind power, RMB/kWh (Jiang et al., 2011)

Resource Zone	Floor Prices (RMB/kWh)	Administrative Areas
Category I	0.51	**Inner Mongolia Region except:** Chifeng, Tongliao, Xing'anmeng, Hulumbeier; **Xinjiang Uygur Region:** Urumqi, Yili, Karamay, Shihezi
Category II	0.54	**Hebei:** Zhangjiakou, Chengde; **Inner Mongolia Region:** Chifeng, Tongliao, Xing'anmeng, Hulumbeier;

		Gansu: Zhangye, Jiayuguan, Jiuquan
Category III	0.58	**Jilin:** Baicheng, Songyuan; **Heilongjiang:** Jixi, Shuangyashan, Qitaihe, Suihua, Yichun, Daxinganling; **Gansu except:** Zhangye, Jiayuguan, Jiuquan; **Xinjiang Uygur Region except:** Urumqi, Yili, Karamay, Shihezi; Ningxia Hui Region
Category IV	0.61	Other parts of China not being mentioned above

2.6.4 Solar Power Subsidies

By the end of 2013, China had 19,720 MW of total solar power installed, which represented 0.6% of the domestic power capacity and 14% of the global solar power capacity, ranked number one in global solar market (IEA, 2014). On the other hand, there is also a large portion of China's solar power panels being exported to the international market, which shared more than 50% of the global solar market (Zhang and et al, 2013). A popular discussion is to increase share of domestic energy market for Chinese manufactured PV modules (Liu, 2013; Xu, 2009). This action could practically increase China's clean energy penetration with minimum impact to China's domestic economy.

However, applicable policy incentives on solar price should be placed to support such movement. According to the Price Bureau of the NDRC (Zhang and et al, 2013), on-grid solar power projects receive 1.15 RMB/kWh after subsidies. Without sufficient tariff subsidies, solar power can hardly compete with other energy resources during the power generation bidding process. In comparison with the price of wind power (0.57 RMB/kWh), an existing price restriction has been a key barrier for China's solar power.

Since 2009, China has invested more than 10 billion RMB into solar capacity subsidies through two major incentives, 'Solar Roof Plan' and 'Golden Solar Project'. These incentive programs are funded by Ministry of Finance (Ministry of Finance, 2009). The Housing and Urban Rural Development Ministry of China (HURD) limits the subsidy level at (HURD in China Ministry of Finance, 2009):

> "No more than 50% of total installation cost for non-rural regions, and no more than 70% of total installation cost for rural regions."

2.6.5 Hydropower in China

Hydropower is the major source of China's clean energy generation. China has 542 million kW of estimated technically hydropower potential, and it is ranked No.1 in the world. However, less than 30% of this potential is currently being utilized (State Council, 2013). In China, hydropower is being categorized as large-scale hydropower (capacity above 500MW) and medium-and-small-scale hydropower (capacity 500MW and below). The cost of power generation from hydropower is relatively low, thus, hydropower does not need to be financially subsidized (Zhang, 2004). However, massive developing of hydropower resource is limited by the geographic characteristics of the country. Most of China's hydro resources are allocated in the southwest region, whilst most of the load centers are located in the eastern China.

In the 2012 Energy Policy, the State Council of China (2013), placed a great focus on China's hydropower due to its low cost and environmental benefits. To sum up the hydropower section of the 2012 Renewable Energy Act, the government does not have

any plan to provide financial incentives to hydropower in the 12th FYP, tariffs of hydropower are set at the same level as in the 11th FYP. Restriction policies of approving hydropower generators are being enhanced; plans for large scale hydropower are being declined yet small-and-medium hydro power plants are encouraged to develop.

As discussed above, SGCC and SGC are the only two grid companies in China. The bulk of hydro resources is geographically located in the southernmost of China, thus, SCG has a greater concentration in hydropower resources than the SGCC. In China's 2012 Energy Policy (State Council, 2013), during the 12th FYP hydropower development, the State Council required SCG to: 'develop local resources, stimulate local economic development, improve the local environment and benefit local people'.

In order to effectively achieve China's 2020 targets, the SCG forecasts to have 290 GW of hydropower in 2015. Meanwhile, along with achieving the 2020 targets, the State Council also required the SCG to appropriately improve the detailed policies of residential resettlement support for the local communities that required to be relocated to other regions (State Council of China, 2013). It is agreed that satisfactory residential resettlement policy is important to China's social stability.

The development of large scale hydropower usually causes a large impact in the local community from various perspectives. It is evident that both the construction and operation of large scale hydropower plants are usually associated with significant environmental impacts to the local communities (Wang, 2004, Lu, 2009, and Pan, 2009). China had 13 large scale hydro power plants by the end of 11th FYP. Most of them are

located in western and southern China due to the large amount of water resources in provinces located in those regions.

China has the world's largest hydro dam, Three Gorges Dam, which has substantial impacts on the local environment in the Yangzi River. The State Council had approved the Three Gorges Dam project in 1993. The construction procedures were divided into three phases, which lasted for a total of 18 years. However, the discussion of whether to build the Three Gorges Dam lasted for 73 years since 1919 when President Sun Yit-sin stated the Three Gorges Dam plan as a part of the 'Founding China's Industrial Plan' (Tang, 2011). In 1992, the State Council held the 7th National People's Congress, which decided to initiate the construction of the Three Gorges Dam by a 67% affirmative vote (Tang, 2011).

After the construction of Three Gorges Dam, studies and research are still actively discussing the positive and negative impacts of the Three Gorges Dam on the local communities (Wang, 2004; Lu, 2009; Gu and et al, 2012; Humphery, 2006; and Pan, 2009). According to Wang (2004), the most significant impact to the local communities was the relocation of local residents. Lu (2009) pointed significant concern over sediment pollution and decreasing stream way water quality. Meanwhile, Pan (2009) paid more attention to the biodiversity factors of the local environment. Tang (2011) summarized the impacts of how hydropower could affect local communities (see Table 2.4).

Table 2.4 Categorized impacts of large scale hydro power plants

Categories	Perspectives	Impact	Recommendations

Land and the Nature	Land loss	Immigration land became a wet land on both sides of the stream ways	Adjustment of hydropower operational schemes
	Stream flow	The stream flow could be discontinued; and hydrological dynamics could be changed	Enhance dispatch policy of dam operation
	Sediment	Sedimentation fills up the dam; could be threatening during high water periods	Storing clean water and removing the mud
Biological Impacts	Biodiversity	1) Cut-off the freeway of migration fish; 2) Change of seasonal water temperature; 3) Adjustment of fish breeds	1) Divide several water layers in the free way 2) Increasing fall fish ladders 3) Artificial breeding and adjust fishery market demand
	Land biology	1) Less capable for land organisms to survive 2) Potential of plant disasters and insect pests 3) Soil salinization	1) Protecting rare species by various methods 2) Use chemical methods to prevent soil salinization
	Geological disaster	Earthquake, land sliding, land collapse	Tackle geological disasters
	Climate change	Climate change impacts the local area	N/A
Others	Civilization loss	Destroy and flood historic sites & cultural relics	Mitigation of these sites
	Virtual sights	Destroy the natural sights	Create new sights in the local area
	Constructions	Large scale impacts to other river streams	Prevent construction impacts
	Health	Blue algae disasters	Clean up the blue algae

Data Source: Tang, 2011

Table 2.9 shows eleven perspectives on impacts and associated possible recommendations made by other researchers who are in favor of large scale hydro power

plants. The eleven perspectives could be grouped into three general categories: land and nature, biological impacts, and others. Regarding the issues and suggested actions to prevent problems, Tang (2011) points out that these listed recommendations would not permanently resolve negative impacts on nature and society; these comments are only temporary suggestions and theoretical hypotheses. Tang (2011) also argues that the key action to prevent these potential problems is to stop utilizing large scale hydro power plants.

As summarized in table 2.9, large scale hydropower has three categories of impacts on local communities. By comparing the negative impacts and the recommended actions, it can be argued that the above arguments are not very convincing. For instance, chemical methods do not provide a perfect solution to soil salinization since chemical applications to the agricultural land usually cause side effects (Gu and et al, 2012).

Secondly, losses of historic sites cannot be completely replaced with mitigation solutions. Most historic sites with 2000 to 3000 years of history especially were not able to be protected and thus were destroyed during the construction of the Three Gorges Dam (Tang, 2011). Furthermore, Tang (2011) points out that temperature changes in the local area can be potentially caused by building large scale hydro power plants. Yet there is no positive solution to this issue. Avoiding building large scale hydro power plants is probably the best alternative until a feasible plan is developed.

2.6.6 Nuclear Policy

The development of China's nuclear power is heavily regulated by the National Development and Reform Council (NDRC). China National Nuclear Corporation operates all of China's nuclear power generation plants. Three policies affecting China's nuclear power development in China in the immediate future: 1) the re-approval of planning and construction of nuclear power plants, 2) increasing on-grid tariff for nuclear power, and 3) tax rebates from nuclear power revenues.

After 2011 Fukushima Daiichi nuclear disaster in Japan, most countries have either withdrawn or delayed their plans for constructing nuclear power plants. Likewise, China has postponed all of the planning and construction procedures of nuclear power plants after 2011 (NDRC, 2013). After the completion and enhancement of the *Nuclear Safety Planning*, approvals of new nuclear power plants in China started to grow at a high volume since 2013 (Haiyan Commercial Bureau, 2013).

A typical case is the approval of Haiyan Nuclear-powered City in Zhejiang province. The Haiyan county in Zhejiang province was approved by the NDRC to build a *Nuclear-powered City* in 2010, however it was put on hold due to the impact of 2011 Fukushima Daiichi nuclear disaster. This project was approved to continue by the NDRC in 2012. The construction of *Nuclear-powered City* was to start in 2013 and estimated to be finished in 2020 (Haiyan Commercial Bureau, 2013). The Haiyan County has the first domestic-designed nuclear power plant in China; Qinshan Nuclear Base, which is a Pressurized Water Reactor (PWR) nuclear power plant of 2.9 GW power capacity in Zhejiang Provence.

In 2013, NDRC up-dated the on-grid tariff rate for nuclear power to 0.43 RMB/kWh. This new released per kWh nuclear power tariff rate is by 0.04 RMB higher than that during the 11th FYP (NDRC, 2013). With the increased on-grid tariff in 2013, nuclear power in China is estimated to grow faster in the 12th FYP.

Taxation on China's nuclear power plants was started in 1998. However, in order to encourage the development of China's clean power generation, the NDRC persuaded other governmental departments to reduce taxation on nuclear power since the late 2000s. Thus, the *Announcement of Nuclear Industry Taxation Policy* (Financial Ministry, 2009) was co-developed by the Finance Ministry and National Taxation Bureau in 2008. This policy is summarized as (Financial Ministry of China, 2009):

> "75% of the tax from nuclear power revenues can be rebated in the first five years of operation, 70% of the tax from nuclear power revenues can be rebated from the sixth to the tenth year of operation, and 55% of the tax from nuclear power revenues can be rebated from the eleventh to the fifteenth year of operation, no more tax rebates after 15 years of operation."

2.7 Social Benefit: Job Creation

As introduced in the E4 model, job creation is an important element for representing social equity. According to Breslin (1996), Bruil (2008) and Byrne (1998), it is agreed that high growth of clean energy generation could create large number of green jobs. Direct jobs refer to jobs in the primary industry sector. Indirect jobs refer to the secondary industry sector, including fuel production, manufacturing, construction and maintenance. Induced jobs are other related job opportunities, e.g. catering, accommodation and etc. (Rutovitz and Atherton, 2009).

Figure 2.8 illustrates the direct employments in each type of energy source in China in 2008. Since coal power contributes significantly to China's electricity generation (65%, see above paragraphs), it is clear that 85% of China's energy related jobs are associated to coal. Renewable energy and hydropower shared 13% of China's energy job market in 2009. Rutovitz and Atherton (2009) introduced a comprehensive model that could be used to study China's 2030 energy job creation that is associated with electricity planning. Their functions are slightly modified in this dissertation in order to fit into China's situation. Details are introduced in the methodology section.

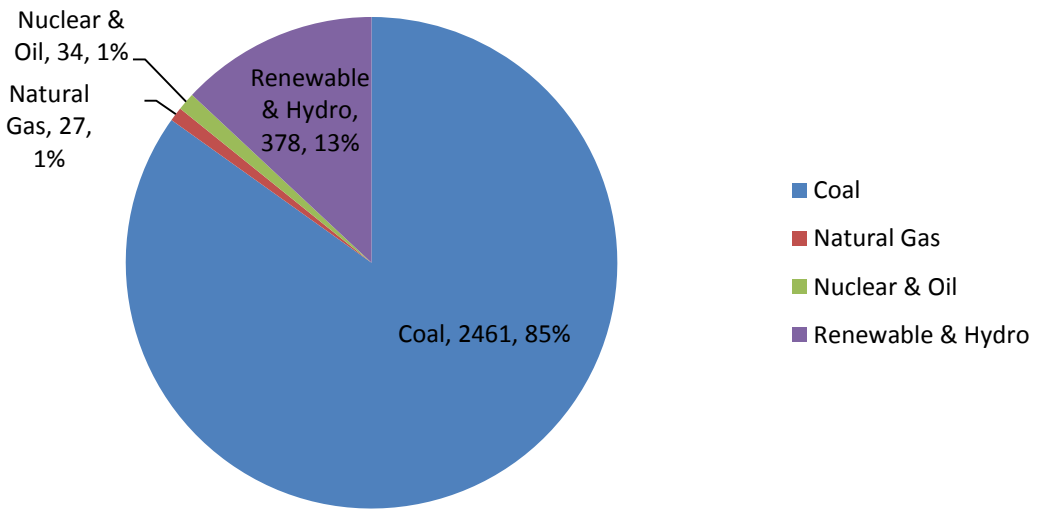


Figure 2.8 Employments of each energy type in China in 2008 (unit: thousand jobs)
Data Source: Rutovitz and Atherton, 2009

2.8 Review of Job Creation Literature

According to the E4 conceptual model, the potential of job creation is an important component of evaluating the economic impacts (Wang, 2000). This dissertation investigates the potentials for clean energy in China's future electricity supply associated job opportunities in the clean energy sectors.

In Table 2.5 presents summary data gathered from literature review on job creation in the electricity sector. Pembina (2004) oversees the 2020 job creation in the Canadian clean energy sector, the U.K. Department of Trade and Industry (DTI, 2005) evaluated the 2020 job market in the British power sector with a close focus on Scotland, and Lantz (2009) investigated the situation in the U.S. Nebraska's wind power industry through two scenarios in 2030. Meanwhile, there are also two studies that projected China's 2030 employment in the power industry. The Green Peace (2012) provided two job creation scenarios on China with different assumptions of energy demand outputs, and the IRENA (2014) also provided an estimation of China' s electricity sector job creation analysis with its own energy assumptions for 2030.

Table 2.5 Job creation for the electricity industry in different countries

	Canada (Pembina, 2004)	**U.K.* (Department of Trade & Industry, 2005)**	**Nebraska U.S. (Lantz, 2009)**	**China (Green Peace, 2012)**	**China (IRENA, 2014)**
Target Year	2020	2020	2030	2030	2030
Methodology	JEDI Employment Factor	Cost Based Supply Chain	Cost Based Input Output Model	JEDI Employment Factor	JEDI Employment Factor

Total Jobs	12,700 to 26,900	1,900 Scotland 5,830 UK(rest)	2,129 to 3,947	S1: 2.76 m S2: 3.24 m	2.89 million
Direct Jobs		1,300 Scotland 4,200 UK(rest)	1,600 to 2,925		
Indirect Jobs		200 Scotland 430 UK	345 to 659		
Induced Jobs		400 Scotland 1,200 UK(r)	184 to 363		
Uniqueness	Hydropower has the strongest potential	Wind power has the strongest potential	Two scenarios studies wind power	Two Scenarios	N/A

*Job creation in the U.K. separately evaluates the potential in Scotland and that in the rest of U.K.

Pembina (2004) conducted Canadian renewable energy sector's job opportunity analysis. The deployment of the innovative power generation technologies was analyzed through 2020. The methodology of Pembina (2004) was based on the JEDI model that was developed by Rutovitz and Atherton (2009).

In the JEDI model, the objective is to evaluate employment impacts of renewable energy deployment. Rutovitz and Atherton (2009) calculated and compared potential employment opportunities in the renewable energy sector and conventional electricity generation with a number of assumptions on electricity generation until 2050. According to Rutovitz and Atherton (2009), the concept of employment factor approach is to estimate the job impacts by multiplying the installed capacities of power plant facilities, capacity additions in MW; or multiplying the energy production in GWh by applying the employment factors, which is the amount of jobs that is associated with each unit of MW or GWh with technology-specific employment factors.

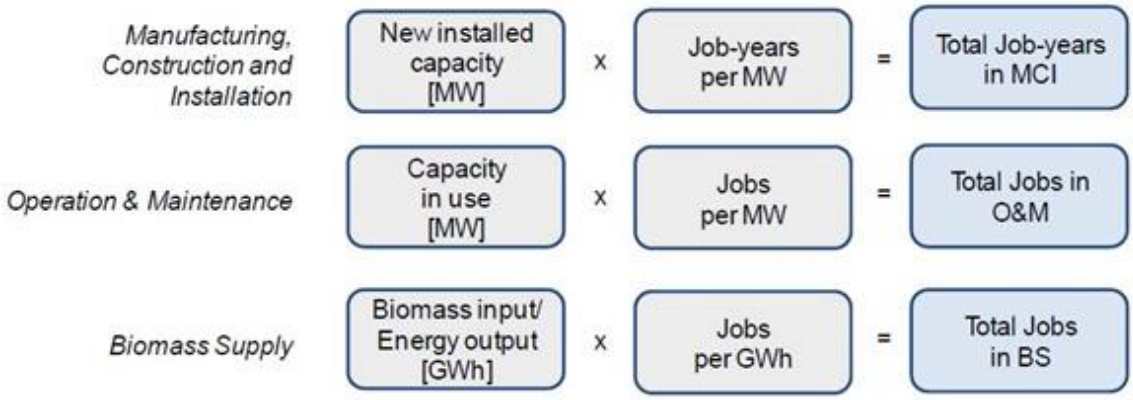


Figure 2.9 The employment factor approach (Rutovitz and Atherton, 2009)

As a result, it is concluded that renewable energy sources in Canada consists of 6 construction jobs per MW of power capacity (Pembina, 2004). Under the Clean Air Renewable Energy Coalition, the potential of Canadian clean energy market would bring in 12,700 to 26,900 jobs by 2020. Accordingly, hydropower creates the highest amount of jobs in Canada, and wind power creates the second highest amount of job creation over the period.

Second, the British Department of Trade and Industry (DTI, 2005) conducted a study on job creation in the electricity sector in the U.K., with a focus on Scotland. Hence, analysis of the U.K. energy sector job has been separated into two segments, Scotland and the rest of the U.K. The methodology of the DTI (2005) is cost-based supply chain analysis.

The DTI (2005) applied a detailed analysis of the supply chains that are connected to clean energy technology deployments. The supply chain approach is a measurement that considers the complexity of technologies and energy related supply

chains. In this model, the employment number is measured through the analysis of monetary value in the power industry. According to the DTI (2005), this study identified the companies' actives in this industry and their position in the energy related supply chains, as well as utilizing several connected technologies, such as energy storage technologies, fuel cells and hydrogen production.

As shown in DTI (2005), in the supply chain approach, there are templates for each type of power plant. The templates contain information including power plant capacity, fixed cost, variable cost, length of construction, and life span. For each type of power plant, a supply chain is constructed. The monetary value of each phase in the supply chain is determined and subdivided into material costs, labor costs and a profit margin (DTI, 2005). For each type of power plant, employment factors could be multiplied by the power capacities, construction length, O&M, and etc.

For the analysis of U.K. power sector, the total monetary value by 2020 is expected to be 290 million British Pounds, in which around 80 million British Pounds would be attributed to the Scottish power sector. There are totally 1,900 energy jobs in Scotland and 5,830 energy jobs in the rest of the U.K. The DTI (2005) also separately distinguish the direct jobs, indirect jobs, and induced jobs. Accordingly, there would be 5,500 direct jobs with 1,300 in the Scotland and 4,200 in the rest of the U.K., and there would be 630 indirect jobs with 200 in the Scotland and 430 in the rest of the U.K., furthermore, there would also have 1,600 induced jobs in total, 400 in the Scotland and 1,200 in the rest of the U.K.

In comparison, the DTI (2005) also calculates the per unit of construction job in the U.K., which is predicted to be 10 jobs per MW, which is much higher than the result of 6 jobs per MW in the Canadian power sector (Pembina, 2004). Furthermore, research finding shows that wind power could generate the largest amount of job opportunities in the U.K., which is also different from the result shown in Canada (DTI, 2005; Pembina, 2004).

Third, Lantz (2009) studied the 2030 projected job creation and economic impacts in Nebraska's wind power industry. Nebraska is planning to build 7,800 MW of wind power by 2030, and the first step is to estimate the effect of having 1,000 MW by 2020 as a pilot phase. The methodology used by Lantz (2009) is using the National Renewable Energy Laboratory's (NREL) JEDI model. Result of the studies includes direct, indirect, and induced job estimates under two scenarios, the reference scenario and the alternative scenario. The alternative scenario is supported by the Community Based Energy Development (C-BED) policy of the Nebraska state.

According to Lantz (2009), construction jobs are calculated using the job-year concept, and the total construction period under this concept is estimated to be 20 years, maintenance for the life span of wind power operations is also assumed to be 20 years (Table 2.11). Lantz (2009) investigates into the installation of new wind power capacities; there is no re-investment on facilities through O&M requirements. On the other hand, Lantz (2009) does not consider the impacts of manufacturing activities within the Nebraska state, but finished products being used outside Nebraska's wind power industry (see Appendix 1).

Lantz (2009) summarizes that the 2030 development and construction of 7,800 MW of wind energy in Nebraska is estimated to support 1,600 total jobs each year under the reference scenario, and 2,925 total jobs each year under the C-BED policy scenario. These estimates include 840 direct wind industry jobs each year under the reference scenario and 1,580 direct wind industry jobs each year under the C-BED policy scenario. For the 1,000 MW pilot project, it is estimated to create 345 total jobs in the reference scenario and 659 total jobs in the C-BED policy scenarios, which includes 184 and 363 direct wind industry jobs each year under these two scenarios.

Besides the above analysis, there are also a number of studies that focus on China's job creation in the electricity sector. The Green Peace (2012) studies the global energy development through 2050, in which China's job creation analysis is a concentration in its non-OECD chapter. The energy roadmap of Green Peace (2012) was reviewed, it is vital to focus on China's 2030 job prediction in this section. The methodology of Green Peace is based on the JEDI model. Employment factor is the key determinant of prediction, which is a multiplier that calculates how many jobs are associated with each unit of power capacity (Table 2.12). For China, since average productivity of coal production is 700 tons per person per year, which is lower than global average, hence, the Green Peace (2012) uses lower employment factors for China's situation (see Appendix 1).

Green Peace (2012) developed two scenarios for China's electricity roadmap, the reference scenario and the Energy [R] scenario. The reference scenario could enable 2.76 million jobs in China's electricity sector, and the Energy [R] scenario could enable

3.24 million jobs by 2030 under the job year concept. There are two kinds of categorizing jobs, by sector and by technology. In the sector category of the reference scenario, domestic fuel supply could generate the highest amount of jobs, 1.84 million, which is 67% of the total jobs; and 1.89 million which is 58% under the Energy [R] scenario. In the technology category, coal power is the biggest employer in both reference and Energy [R] scenarios, which is 1.89 million (68%) jobs for the reference scenario and 1.43 million (44%) for the Energy [R] scenario.

IRENA (2014) also predicts China's 2030 job creation in the electricity sector. As a result, China is expected to have 2.89 million total jobs in its electricity sector according to the 2030 REmap planning. The prediction is based on the 2030 Remap of IRENA. The REmap utilizes the bottom-up approach, which studies the key power plant types for achieving the 2030 energy target. The job prediction of the REmap methodology uses the JEDI model, developed by Rutovitz and Atherton (2009), which uses the same model as Green Peace (2012), but there are no adjustments in employment factors. IRENA (2014) did not have sufficient data for China's job predictions.

2.9 Major Demand Side Management Technologies in China

According to Liu (2013) The SGCC has been actively investing and operating a number of pilot studies on the demand side: eco-buildings, smart communities, energy saving campaign, World Expo demonstrations, DSM exhibitions, and etc. These pilot

researches provide solid foundation for the implementation of China's DSM in the future electricity planning periods.

This dissertation engages the planning of DSM technologies as part of the 2030 China's electricity planning, thus it is important to investigate the potentials of the most relevant DSM equipment in the next 15 years. China has been an industrialized country for more than 30 years (Institute of Development Studies, 2006); its economy is now experiencing an economic transition period from being a 'world factory' to an economy with stronger focus on tertiary industries. According to Figure 2.9, the National Bureau of Statistics (2012) pointed out that 73% of China's total end-use electricity in 2010 was consumed by the secondary industries. By monitoring data from 2008 to 2010, electricity consumption of the secondary industry, e.g. construction, was declining each year, and the share of tertiary industry, e.g. services, knowledge, etc., was growing. Percentage of the electricity consumption for primary industry and the residential sector was roughly staying the same during that period (National Bureau of Statistics, 2012).

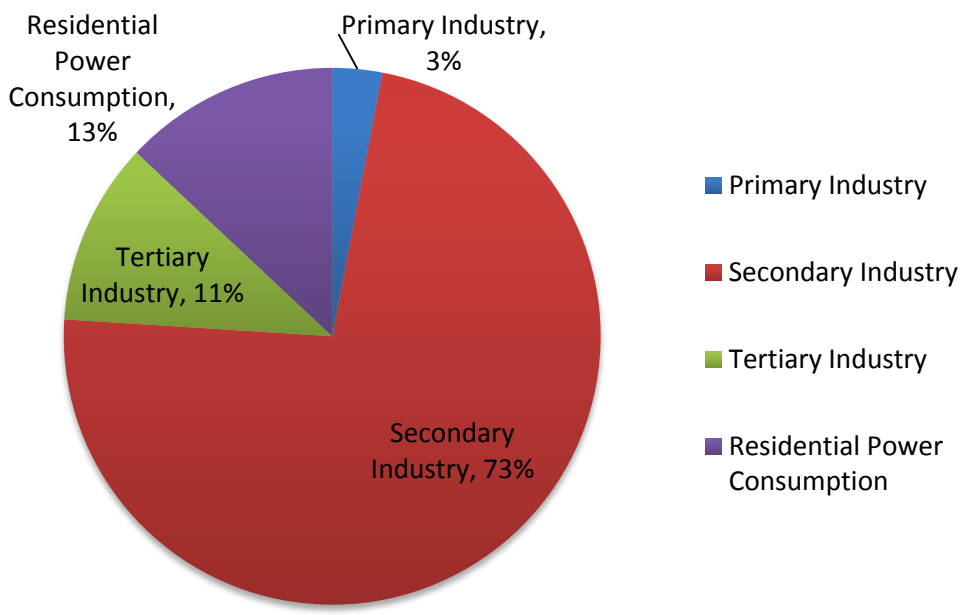


Figure 2.9 China's electricity consumption by end-uses
Data Source: National Bureau of Statistics, 2012

As a result, investigations of DSM equipment should be narrowed down to key representative industrial and commercial equipment, moreover, DSM technologies in the residential sector is worth studying. Instead of separately studying each type of home appliances, it is appropriate to create an inclusive category for broad efficient home appliances due to the small potential (compared with commercial and industrial potentials, reference from figure 2.11) of energy conservation in this sector. According to the study from Zhang and et al (2013) as well as Jenkins (2002), below are the major types of DSM equipment in China:

- Efficient lighting fixtures
- Efficient electric motors
- Variable Frequency Drives (VFD)

- Peak-load shifting devises
- Load interruptible devises
- Energy efficient transformers
- Energy efficiency home appliances

Efficient lighting fixtures are commonly used in all economic sectors (from primary to tertiary industry), and it is also commonly applied in the residential sector (Hammond, 2004). The standard of recognizing higher efficiency light fixture in China is, increasing the efficiency rate of light via improved technologies but the illumination standard should stay constant. For instance, an 8 watt high efficiency light reflector (e.g. LED light fixture) has the same outcome as 40 watt filament reflector, thus, the efficiency rate for one hour is (40-8)/8= 4.

Efficiency motors can realize the objective of energy conservation through replacing out-of-dated electric motors with higher efficiency motors. In China, the ministry of industry has published the national standard of GB18613-2002 of defining the levels of motor efficiency rate (Zhang and et al, 2013). Since 1978, China has participated the global economy for more than 35 years, it is expected that a lot of manufactories would need to replace their motors in the next 10-20 years.

China is still a heavy industrialized country, developing an appropriate scheme to subsidize efficiency motors can motivate industrialists to re-evaluate the cost-benefit cycle during production process by replacing motors before their life time, which can largely help to increase China’s energy efficiency level in the industrial sector.

Another common equipment to realize industrial efficiency level is the variable frequency drive (VFD). Industrial productions usually require different output capacities during different hours on motor operations depend on the nature of industries (Alanne and Saari, 2006). Motors in the factory would be constantly turned on and off under different capacity requirements, sometimes they are operated at full capacity and sometimes they have to stay standby.

However, without automatic controlling system, motors are usually operated uneconomically when they need to stay standby. Installing VFDs can automatically control the power capacity and changes while guarantee the output capacities meet the requirement of industrial productions. VFD is an automatic optimization system attached to the motors, which could effectively control the frequency of operating capacities, and thus to achieve more economic output and budget control during the production process. VFD has long been popular in the U.S.; however, this technology is still relatively new to many developing countries, including China (Zhang and et al, 2013).

Unlike the efficiency power plant (EPP) devises, peak-load shifting devices are not aiming at reducing electricity consumption. Instead, they shift a certain portion of electricity consumption from peak load hours to non-peak load hours (Herz, 2009). In China, electricity tariff for commercial buildings are charged separately from industrial rates, which creates an increasing demand of load shifting in many shopping malls and office buildings. The most reliable and economic method to shift load is ice storage technologies for air conditioning. Peak-load leveling machines create ice from water at

nights when power consumption and tariff rates are low, and release ice to water during the day time when tariff rates are high (Xiong and et al, 2010).

Energy efficient transformers can also reduce electricity losses in comparison with the traditional energy transformer. Power losses usually occur during delivery: when electricity is delivered from power plants to the grid network, when it is delivered between different voltages of grid lines, and when it is delivered from the transmission line to load centers. Energy efficient transformers are located at substations between the transmission and distribution lines to reduce losses during the process of power deliver.

When electricity is being delivered from the power plants to load centers through transmission lines (cross-country power delivery from western China to the east coast of China), the voltage on the transmission grid in China is alternating current (AC) for the purpose of reducing line losses, which is usually 800-1000 kV on the transmission grid. When the electricity arrives at the load centers, it has to be converted into lower voltages, for instance 220 Volts in the case of China, in order for the electricity to be consumed by end users. By applying new materials and new frequency control technologies, energy efficient transformer could smoothly transform electricity between different voltages at minimum power losses.

China's electricity industry is seen as a combination of a planned and market economy. Thus, load control can be realized via two methods: changes in tariff rates and direct load cuts. In this dissertation, the focus is on the function of the first method (changes through tariff rate) since the latter method (direct load cut) may cause direct influence on China's economic output.

There are various forms of energy efficiency home appliances, e.g. refrigerators, washing machines, dish washers, air conditioners, and etc. The report from Deloitte Research (2003), the consumption of electronics will be centered in Asian countries in the next 10-20 years. The NDRC introduced the U.S. 'energy star' regulatory standards into China's home appliance market. With the increasing purchase capacity of China's domestic consumers and the sufficient policy incentives, China is expected to have a large amount of energy efficiency home appliances that are being utilized in the residential sector in the near future (Redman and et al, 2008). Thus it is important to conduct research for home appliances.

As part of China's 12th FYP report, the 'National Fundamental Public Service Development Method' has developed a one-year incentive scheme of 26.5 billion RMB for energy efficiency home appliances (State Council of China, 2012). The incentive is expected to be able to renew after each year. The purpose of such incentive involves the 'home appliance in rural China' program. This program provides extra financial subsidies to the home appliance trade-in system in rural regions. Residents in the rural China are eligible to get higher values of their old electronics for purchasing energy efficiency home appliances. This program has created an economic boom of electronic market in rural China, which not merely aims to increase energy efficiency, but also targets to reduce the gap between urban and rural societies in China (Patel and et al, 2011).

Chapter 3

METHODOLOGY

This chapter describes the methodology used in the dissertation. Methodology presents the systematic analysis, which comprises the principles associated with the best method of practice; in a number of cases, it incorporates concepts such as paradigm, theoretical model, phases and quantitative or qualitative techniques (Berg, 2009; Creswell, 2003). In the following sections, first, it is essential to begin with the theoretical concept of Integrated Resource Planning (IRP), the principle of employment models; and second, it is important to present the options of a few practical models. Furthermore, after selecting the practical models for power planning and job creation, a rationale for using and adjusting the most feasible models for the dissertation research shall be provided.

3.1 Integrated Resource Planning Concept

According to Wilson and Biewald (2013), the Integrated Resource Planning is a utility planning strategy for meeting forecasted annual peak energy demand, plus established reserve margin, through a combination of supply-side and demand-side resources over a specified future period. The relationships between these elements are

illustrated in Figure 3.1. According to Wilson and Biewald (2013, p12), a successful utility's resource plan should include the details of the following steps:

- Load Forecast
- Potential Resource Options
- Determine Suitable Resource Mixes
- Public Participation
- Creating and Implementing the Resource Plan

As stated in Figure 3.1, the first step of the IRP is to forecast the load demand of future years. Second, it is important to assess share of by different sources in meeting the electricity demand. Composition of power supply sources can also influence transmission and distribution networks, and rate structure.

The objective of energy mix could be determined by the implementer of IRP, and uncertainties, environmental and social-economic factors shall be reflected during this process. After approval by the regulators, it is essential that IRP implementation is monitored by the regulators. The monitoring process may require adjustments in resource re-allocation (Wilson and Biewald, 2013).

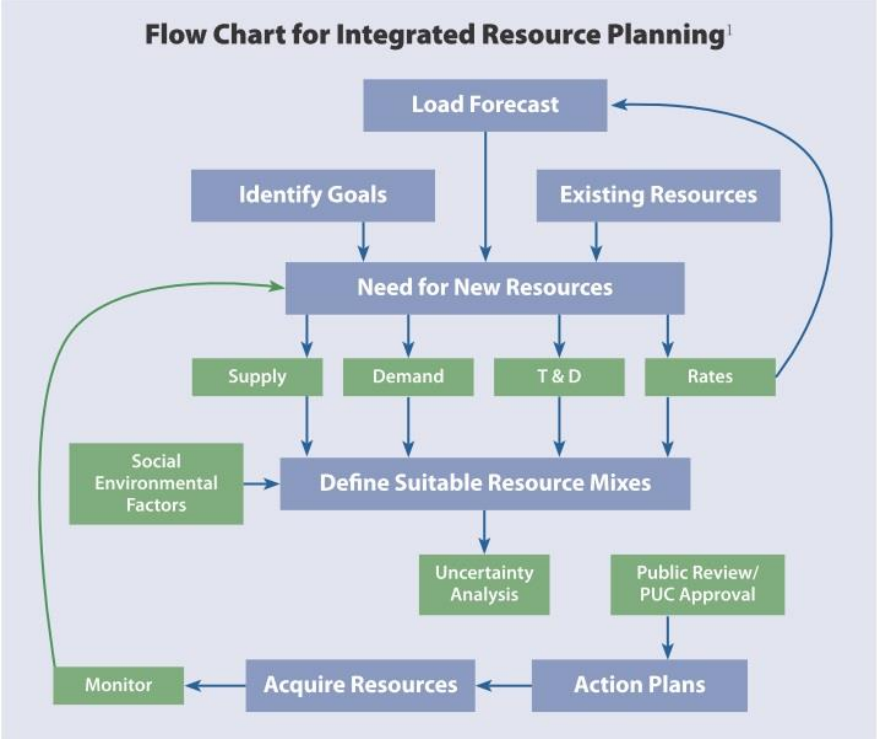


Figure 3.1 Flow Chart of the Integrated Resource Planning
Source: Wilson and Biewald, 2013

In the case of China, due to the restructuring of the electricity sector in 2002 (details of the 2002 China's power reform were introduced in the previous chapter), the traditional concept of IRP could be used as a reference. However, IRP might not be directly applied to China, since China's policy making framework is completely regulated by the government. As a result, the purpose of this section is to lead the research discussion to a feasible analytical framework, namely Integrated Resource Strategic Planning (IRSP), which could be practically embedded into the planning strategy of China's energy policymakers.

3.1.1 Demand Projection

When referencing the IRP theory into a model that is suitable for China, as emphasized by Wilson and Biewald (2013), the demand projection of future load forecast is necessary as the first step for energy roadmap. The two major approaches to forecast energy demand are econometric models and end-use models (Swisher, 2007).

3.1.1.1 Econometric Model

In comparison with the end-use model, the econometric model requires less data inputs and has a reasonable statistical base. However, the weakness of this model is, it does not take account of technical factors. According to Swisher (2007), the concept of the econometric equation is based on the classic economic function, Cobb-Douglas production function.

The original Cobb-Douglas production function is:

$$E = aY^{\alpha}P^{\beta}$$

Where:

E= electricity demand,

Y = income level,

P = energy price,

a = co-efficient,

α = income elasticity,

β = price elasticity of energy demand.

In the above equation, the two elasticity indicators, α and β, indicate how the forecasted future energy demand changes as results of changes in price and income. The elaboration function of the income elasticity is:

$$\alpha = \frac{\frac{E - E'}{E}}{\frac{Y - Y'}{Y}} = \frac{\%\ \text{changes in E}}{\%\ \text{changes in Y}}$$

Where:

α = income elasticity of energy demand,

E = demand for energy,

Y = income (GDP).

The function of price elasticity β, is defined similar with the income elasticity, α:

$$\beta = \frac{\frac{E - E'}{E}}{\frac{P - P'}{P}} = \frac{\%\ \text{changes in E}}{\%\ \text{changes in P}}$$

Where:

β = price elasticity of energy demand,

E = demand for energy,

Y = price of energy.

3.1.1.2 Forecasting Model Adjustment

The econometric model is widely used to predict future energy demand in the U.S. However, the assumptions in the model are based on a steady economic structure (Swisher, 2007). In many cases, when prices and income change dramatically in the

future, the baseline projection may not work that well in reality. For the energy demand prediction in China, it is essential to collect 2030 China's energy demand predictions from a number of other research agencies that focuses on 2030 China's electricity demand studies.

The below table summarizes the prediction results from five representative institutes, SERC (2015), World Nuclear Association (2015), U.S. EIA (2012), China National Renewable Energy Center (CNREC, 2011), and European Environment Agency (2013). Each institute sees the issue from different perspectives, for instance, NREC and World Nuclear Association studied the per capita electricity income, EIA studied the total electricity consumption, CNREC studied the total ton coal equivalent (tce), and European Environment Agency studied the total ton oil equivalent (toe). However, this dissertation is able to convert these data into a standard unit following the EIA's total electricity consumption, and the results are in the range of 7,150 TWh to 10,164 TWh in 2030.

Among these prediction studies, the SERC (2015) has the most credential results not only because it studies the electricity prediction from official data sources, but also it precisely studied China's 2030 electricity demand in 2012, 2013 and in 2014 by using the econometric model. The SERC (2015) argues that a complex model does not necessarily lead to a more accurate prediction. A popular trend in many power prediction models (NDRC, 2011; IRENA, 2014) is to set a co-efficient index - 'alpha' between electricity consumption and GDP, and continue to test and adjust the index to get an accurate demand projection.

Accordingly, the prediction in 2012 pointed out that annual electricity growth rate would be 7.2% from 2010 to 2020, and per capita electricity consumption would be 6,250 kWh in 2020. The co-efficiency 'a' during this period would be 0.95. Meanwhile, the annual electricity growth rate from 2020 to 2030 would be 3.6%, and per capita electricity consumption would be 7580 kWh in 2030. The co-efficiency 'a' during this period would be 0.6 (SERC, 2015).

The SERC prediction in 2013 argued that annual electricity demand growth rate would be between 6-7.5% from 2013 to 2020, due to China's economic structure is still moving rapidly towards the developed economic unit. From 2020 to 2030, since China will be entering in the developed economy status, annual electricity demand growth rate would be approximately 3.5%. After 2030, it is expected that China's annual electricity demand growth rate would be approaching 1% (State Energy Council, 2015).

In 2014, the SERC (2015) predicted a more accurate electricity demand based on the economic development during each FYP. The annual electricity demand increase rate for the 10th and the 11th FYP (2000-2010) was 12%; the 12th FYP (2011-2015) had a 6.7% annual electricity growth rate, and the 2014 electricity growth was 3.8%. It is predictable that annual electricity growth rate would be 5-6% during the 13th FYP (2016-2020). The annual electricity growth rate would be 2-3% from the 2020 to 2030 period.

Table 3.1 Prediction of China's 2030 electricity demand

	State Energy Regulation Commission (2015)	**World Nuclear Association (2015)**	**U.S. Energy Information Agency (2012)**	**Center for Renewable Energy**	**European Environment Agency (2013)**

				Developme nt (2011)	
Electricity consumption in 2030	7,580 kWh/year per capita	5,500 kWh/year per capita	9,850 TWh (2014)	1.33 billion tce (ton coal equivalent)	2,400 million toe (ton oil equivalent)
Reference year (Methodology)	3,538 kWh/year per capita in 2011	3,610 kWh/year in 2012	3,900 TWh in 2010	0.4 billion tce in 2007	1,200 million toe in 2006
Electricity consumption in 2030	9,750 TWh	7,150 TWh	9,850 TWh	9,935 TWh	10,164 TWh
	Lawrence Berkeley National Laboratory (2012)	**Internationa l Energy Agency (2007)**	**Green Peace (2012)**	**National Developme nt & Reform Council (2011)**	**International Renewable Agency (2014)**
Electricity consumption in 2030	7,091 TWh	8,472 TWh	10,040 TWh	8,548 TWh	10,500 TWh

Sources: State Energy Regulatory Commission, 2015; World Nuclear Association, 2015; EIA, 2012; Center for Renewable Energy Development, 2011; and European Environmental Agency, 2013.

Based on the 2030 China's energy demand forecast from received electricity predictions (as demonstrated), there are totally 10 values summarized from table 2.7 and table 3.1. After categorizing these data, it is clear that values are evenly distributed: there are 2 values fall in the range of 7000-8000 TWh, 2 values fall in the range of 8000-9000 TWh, 3 values fall in the range of 9000-10,000TWh, and there are also 3 values fall in the range above 10,000TWh.

3.1.1.3 Predicting 2030 China Electricity Demand

One method to predict the energy demand is based on the Cobb-Douglas production function (Swisher, 2007). The Cobb-Douglas production function for China's electricity prediction is:

$$E = aY^{\alpha}P^{\beta}$$

Where:

E= per capita electricity consumption,

Y = per capita GDP in China,

P = electricity price,

a = co-efficient,

α = income elasticity,

β = price elasticity of energy demand.

This dissertation uses seven steps to get the accurate prediction of 2030 China electricity demand:

- Apply natural log to Cobb Douglas Production Function
- Examination the two independent variables using P value
- Remove irrelevant variable and run regression again
- Study the confidence band
- Plug in the data of 2030 per capita GDP from 4 sources
- Plug in the China's 2030 population
- Determine China's total electricity demand in 2030

In the first step, it is essential to apply natural log to both sides of the function. And then, we need to investigate whether the independent variables are correlated with the dependent variable. By using the SAS software (coding and full results see Appendix 11, 12, and 13), the results illustrate that electricity price (X2) is not correlated with per capita electricity consumption since P value of 0.9157 is greater than 0.05.

The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: Y Y

Number of Observations Read	31
Number of Observations Used	15
Number of Observations with Missing Values	16

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	2	3.07666	1.53833	317.41	<.0001
Error	12	0.05816	0.00485		
Corrected Total	14	3.13482			

Root MSE	0.06962	R-Square	0.9814
Dependent Mean	7.66584	Adj R-Sq	0.9784
Coeff Var	0.90814		

Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	2.48640	0.78653	3.16	0.0082
X1	X1	1	1.50695	0.33367	4.52	0.0007
X2	X2	1	-0.10469	0.96862	-0.11	0.9157

In the third step, it is necessary to remove the variable of electricity price (X2), and run the regression again. Full results in SAS are attached in Appendix 11, 12, and 13. The result yielded a valid P value (smaller than 0.0001), which approves the validation between X and Y. The regression function is:

$y = 0.67\ x + 2.4$ (with adjusted $R^2 = 0.98$)

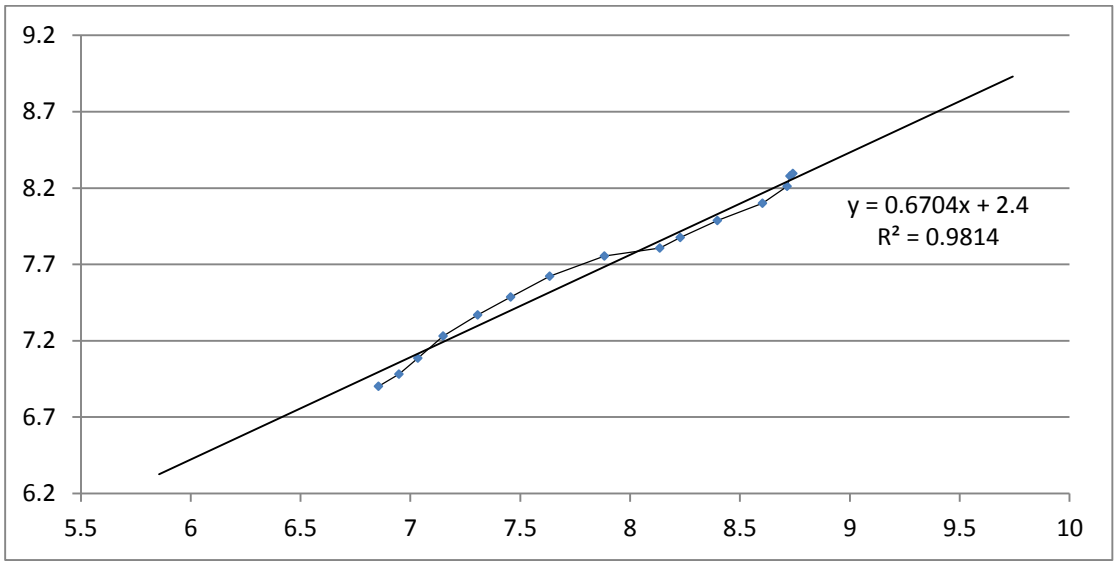


Figure 3.2 Regression of per capita GDP and per capita electricity consumption

The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: Y Y

Number of Observations Read	31
Number of Observations Used	15
Number of Observations with Missing Values	16

Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.07660	3.07660	687.04	<.0001
Error	13	0.05821	0.00448		
Corrected Total	14	3.13482			

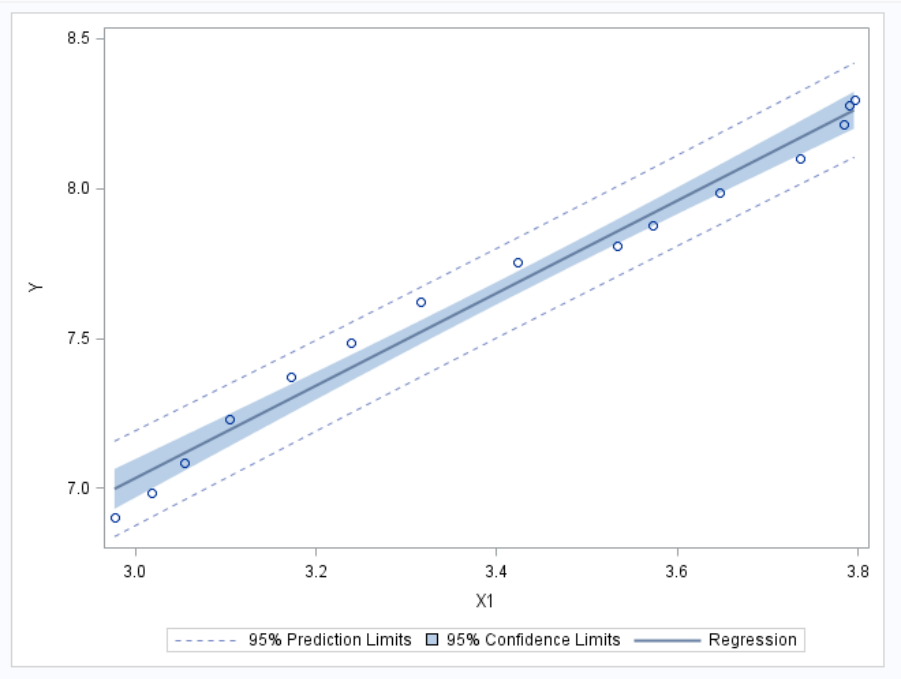
Root MSE	0.06692	R-Square	0.9814
Dependent Mean	7.66584	Adj R-Sq	0.9800
Coeff Var	0.87294		

Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	2.40447	0.20147	11.93	<.0001
X1	X1	1	1.54240	0.05884	26.21	<.0001

In this linear regression function, the dependent variable ‘y’ refers to the log of per capita electricity consumption, and the independent variable ‘x’ is the log of per capita GDP. R^2 is a goodness of fit, an indicator that indicates how well the model fits with historic values (Hansen, 2015), and adjusted R^2 indicates that increasing number of variables would not change the goodness of fit. From the result of the model, mean is

3.41, median is 3.42, and standard deviation is 0.7. Details of the full statistical results are attached in appendix 11, 12 and 13.

The forth step is to study the confidence band of the above regression line. Econometric model can also determine the confidence band, which is the region on a 95% probability plot. According to SAS, the graphic result of confidence band is shown in the below figure (coding and further details are attached in appendix 11, 12 and 13).



The fifth step is to plug in the data of predicted China's per capita GDP of 2030 into the regression model. This dissertation collects data from four sources; result in 15,930 from U.S. Data Administration (2014), 16,000 from the Union Bank of Switzerland (Magnus, 2013), 15,861 from the OECD (2012), and 15,185 from the HSBC Global Research (Ward, 2012).

Since the regression function used natural log, it is necessary to convert the above data into natural log, which are 9.68 for USDA (2014), 9.68 for UBS (Magnus, 2013), 9.67 for OECD (2012), and 9.63 for HSBC (Ward, 2012). The mean value for these data is 9.66, plug into the regression, and result in the per capita electricity consumption as 8.76 under natural log. Convert the natural log into the base number, which is e^8.76, given e=2.71, the answer is 6,303.26 kWh per capita in 2030. The United Nations (2013) predicts the 2030 population of China is 1.45 billion, multiples this number by 6303.26 kWh per capita, result in 9,989.67 TWh as the predicted total electricity consumption of China in 2030.

The sixth step is to calculate the range of 2030 China's electricity demand by using confidence interval. Since the mean value is 9,989.67, and the standard deviation is 2,031.84, applying the 1.96 standard deviation (95% confidence internal), it is clear that upper limit is 13,972.08 TWh and the lower limit is 6,007.23 TWh. Details of the coding and results are attached in appendix 11, 12 and 13.

In the final step, regarding the literature data of 9,750 for SERC (2015), 7,150 TWh for World Nuclear Association (2015), 9,850 for U.S. EIA (2012), 9,935 TWh for CNREC (2011), and 10,164 TWh for European Environmental Agency (2013), all these values are within the range of the confidence interval. This dissertation takes the mean value of the 6 values (plus the calculated mean value of 9,989.67). As a result, the mean value for China's 2030 electricity consumption is 9,473.11 TWh.

3.1.2 Power Generation Options and Demand Side Management

When determining which renewable energy types are ranked as the most available options during the process of electricity planning, Swisher (2007) points out the three major measurements: barriers, pricing and costs.

Firstly, major barriers toward highly efficient energy allocations are information barriers, legal barriers, finance barriers, and technology barriers. Lack of information to utilize renewable energy is generally recognized as the first barrier. Consumers, vendors, and manufacturers often have superior information to improve operating activities. According to Swisher (2007), even developers and facility managers are commonly unaware of new technologies and measures. Legal barriers are usually embedded within the regulators of the country's planning department. According to Swisher (2007, p85):

> "The traditional planning mind set tends to associate greater credibility with highly centralized power production centers and does not favor investments in energy conservation measures or decentralized options of electricity production".

Financial barriers are a key concern to many planners. Beyond the point of lacking investments, Swisher (2007) also argues that in some situations, energy bill payers are not responsible for selecting the equipment, for instance, house owners usually pay for their energy bill but builders are the ones who select the energy efficiency equipment. Technical barriers are seen as the least important barriers; however, they could also stand in the way for developing countries which do not have the capabilities to produce high efficiency equipment (Swisher, 2007). Thus, an alternative option for these

developing countries is to import high efficiency equipment from the foreign markets (Swisher, 2007).

After resolving the above barriers, a major determinant of energy resource allocation is price and rate signals. It is generally agreed that energy allocation is based on the minimum costs. Hence, the prices of different energy types are also playing an important role in determining what kind of energy should have the higher priority in terms of power planning.

The roles of price signal in the market economy are to: efficiently allocate different resources, give accurate price signals, and raise sufficient revenue for utility companies (Swisher, 2007). The concept of IRP indicates that the process of considering cost and raise revenue shall largely involve the externality costs, which is one part of the society cost (Malyshev, 2009). However, the traditional role of price signal usually encourages utilities to sell as much as electricity as possible under economic feasibility. The externality cost shall be actively considered when determining the total resource cost. According to the California Public Utility Commission (CPUC, 2001), total resource cost is defined as a measurement of resource option based on the total costs of the DSM program, including both the participants and the utility costs. It is applicable to energy conservation, load management, and fuel substitution programs. According to Swisher (2007), the equation of the total resource cost is:

$$\text{Total Resource Cost} = \text{Program Cost} + \text{Customer Cost}$$

Meanwhile,

$$\text{Net Benefit} = \text{Avoided Cost} - \text{Total Resource Cost}$$

It is essential for power regulators to decouple the link between electricity sales and utility profits, and hence, introducing Demand Side Management (DSM) to the utility

companies (Swisher, 2007). By implementing DSM at the utility level, utility companies would be able to gain profits and also to reduce electricity sales at the same time.

The IRSP model treats DSM options differently from IRP model. IRSP optimizes the demand-side resource through applying 'Efficiency Power Plant' (EPP) concept for load management (Kofler and Netzer, 2012; Konidari and Mavrakis, 2006; Loken, 2007; Lund, 2007; Malyshev, 2009). In the IRSP model, DSM is named as EPP since EPPs are seen as different forms of power plants. Power planning is a process that solves the problem from the power generation side, changing the term from DSM to EPP switches the concept of energy saving devices from the power demand side to the power supply side (Dell and Rand, 2001).

Hence, reduced electricity consumption can be seen as 'virtual electricity supply' that is generated from EPPs. In other words, instead of subtracting electricity reduction from total electricity demand, power regulators can fill some of the electricity supply needs with EPPs. According to Hu, Wen, Wang, and et al (2010, p4636):

> "EPPs include different applications, such as energy-saving lighting system, high-efficiency motor system, variable-speed drives, high-efficiency transformers, energy storage equipment, and high-efficiency household appliances, as well as transmission and distribution (T&D) efficiency improvement and various load management measures… EPPs can be considered as virtual power plants".

Details of DSM applications in China's contents shall be introduced in chapter four since the DSM is introduced in one out of three scenarios.

3.1.3 Integrated Supply and Demand Plan

The IRP concept was begun in the 1980s, in responding to the oil embargos of the 1970s (Wilson and Peterson, 2011). It has been a commonly accepted measure for state commissions, since utilities are enabled to create long term resource plans. The IRP is different from the traditional energy planning method. Traditionally, the objective of power planning is to meet the energy demand with energy supply at the objective of minimizing financial cost, namely using the least-cost criteria. However, the IRP changed the traditional objective by introducing the concept of DSM, which is to meet the power demand at a lower cost by increasing energy efficiencies and hence reducing the total power demand.

On the other hand, the definition of cost is also being modified. In the IRP concept, the society cost is largely being quantified. When conducting a long term planning strategy, it is important for the government to inclusively consider the associated costs from the perspective of the society, for instance, emission, instead of merely looking at the financial budget and rate of return.

Regarding the least-cost criteria for IRP, while the long-run marginal cost governs the planning of new resources, the method of environmental dispatch shall be also considered. The concept of the environmental dispatch is different from that of the economic dispatch: environmental dispatch aims to rank the available sources not only according to the short-run marginal cost, but also according to the cost of avoiding emission volumes. Thus, in the environmental dispatch, policy makers shall add emission

charges or taxation policies on top of the economic cost for some types of emitting power plants (Swisher, 2007).

As an important component of the least-cost criteria, Swisher (2007) points out that time value of money and capacity factors are being considered by both traditional and IRP concepts. When capital investments are made in different years, future investments should be discounted to present worth to reflect the time value of money, and they should be compared according to their long-run marginal costs. The ratio between the marginal costs of energy and capacity depends on the extent to which a resource runs at full capacity, reflected by the capacity factor.

The following equations summarize the IRP optimization process (Swisher, 2007, p142):

Minimize Total Costs:

$$\mathrm{CS}\ (\mathrm{E}, \mathrm{R})\ +\ \mathrm{CD}\ (\mathrm{D})\ +\ \mathrm{CP}\ (\mathrm{E}, \mathrm{D}, \mathrm{R})$$

Subject to:

$$\mathrm{E}\ +\ \mathrm{D}\ =\ \mathrm{ES}$$

Where:

E = Electricity sold to consumers

D = DSM electricity savings

R = Required emission reduction

CS (E,R) = Cost of electricity supply[4], it may include the externality cost

[4] This function includes capital and O&M costs and is a function of electricity sales *E;* also includes the cost of pollution control equipment to meet legal environmental standards and is thus also a function of *R*.

CD (D) = Cost of DSM programs

CP (E,D,R) = Cost of pollutant emissions, the value of the environmental damage to society caused by electric power production[5]

ES = Level of energy services demanded by electric customers.

Based on the above equation, the regulators, NDRC and SERC would be able to describe and to evaluate electricity supply and demand-side alternatives. The NDRC and the SERC should also estimate the environmental impacts of different energy options and associated cost effects. Regulators can now list the energy options according to cost and construct integrated resource scenarios after the inclusion of externality costs. These scenarios combine supply and demand side options together with implementation programs and power operating plans, and they finally help to create an integrated least-cost plan (Swisher, 2007, p149).

3.1.4 IRP/IRSP Concept

As mentioned above, the ultimate objective of IRP/IRSP is to maximize social-economic benefit from the perspective of power regulators, which enables the process of power planning to be more environmental friendly. The IRSP framework contains two major components: on the demand side, DSM is implemented via EPP applications, on

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[5] This is a function of the amount of electricity sales *E*, the level of DSM programs *D*, and the required level of emission controls *R*.

the supply side, traditional power plant (TPP) is substantial for integrating clean energy sources as well as contributing to China's power supply; and at a higher level, this model considers overall social and economic benefits to help addressing carbon emission concerns.

Resource optimization between actual power plants and virtual power plants is the most essential part of IRSP. It is the core determinant of how to efficiently achieving the regulator's economic and environmental objectives with minimum input. The determination of selecting resources between clean energy power plants and EPPs are optimized based on the associated investment levels. If the capital investments and operational costs for constructing new TPP clean energy generators are higher than implementing EPPs, more EPPs should be supplemented to balance the cost, and vice versa when costs of implementing EPPs are higher than TPP clean energy generators (Hu, Wen, Wang, and et al, 2010, p4636).

The objective of IRSP is to minimize total cost, according to Hu, Wen, Wang, and et al (2010, p4642), the conceptual function of minimizing cost is illustrated as:

Min (total cost) = Min ($\sum investment\ \ cost + \sum operation\ \ cost$)

Total cost is the summation of investment costs of additional power plant constructions as well as the operation and maintenance (O&M) costs, and then subtraction of power plant salvage values at the year of 2030. The Operation and Maintenance (O&M) costs include fuel costs (mainly refers to the price of coal, since China's power industry has less focus on natural gas), maintenance fee for existing power plants, and other associated costs that come with operating the power plant. The salvage

value refers to the money value for those non-retired power plants that are still available for further operations in the year of 2030, which should be subtracted. In the IRSP model, despite of the above minimizing total cost function, it is also designed to meet constrains, for example, power demand, power generation capability, fuel supply, emission caps, and etc. As mentioned in Hu, Wen, Wang, and et al (2010, p4642): "the IRSP model was developed to describe or identify optimal integrated plan of coal-fired power plants, gas-fired power plants, EPPs... to satisfy the target year's electricity demand".

3.2 The Concept of JEDI Model

The methodology of employment model from Rutovitz and Atherton (2009), named Jobs and Economic Development Impact (JEDI) model, is commonly used to calculate energy associated employment in many countries. It is based on economic data indicators and investigation of labor productivities, to estimate the impact on future employments based on constructing and operating power generation at the local and national level (Del Rio and et al, 2008). According to Rutovitz and Atherton (2009), required input variables of a comprehensive employment projection are as follows:

Installed electricity capacity by types: data obtained from the IRSP output

Employment factors: jobs per MW for each energy type

Technology Decline factors: as technology mature, there is an adjustment rate of jobs per MW every 5 years.

Regional job multipliers: adjust the employment factor in each region to take account of different stages of economic development. This variable is applicable in global energy job calculations.

Local manufacturing percentage and domestic coal and gas production percentage: this number is used to determine the proportion of manufacturing jobs and electricity production. This variable is also applicable in global energy job calculations.

Net export percentage: percentage of energy that is being net exported to neighbor countries.

Energy efficiency employments: numbers of employment in DSM. This data is independently obtained from the ministry of labor.

3.3 Modeling Tools

A wide range of analytical models in the power sector are developed by various research institutions, in order to evaluate and investigate the impacts of energy policies. Although this section does not attempt to provide a comprehensive review of all types of models that were used in the available literature, this research aims to demonstrate a brief overview of related models and model types and a description of their differences with the analytical model that this dissertation is using.

3.3.1 Overview of Different Analytical Models

Regarding model selection, several other alternatives can conduct the IRSP. This section shall compare the most popular models in the U.S., Europe, and the BRICS[6] countries: the Resource Planning Model (RPM) developed by the NREL, the National Energy Modeling System (NEMS) developed by the U.S. EIA, the MARKet ALlocation (MARKAL) model developed by the Brookhaven National Laboratory, the Regional Energy Development System (ReEDS) developed by the NREL, and the SWITCH model developed by the University of California, Berkeley.

The Resource Planning Model (RPM) is a well-known optimization model in the U.S. It is developed to inform policymakers the signal from the power market. The RPM has great transparency on power plant capacities and the objective is to represent the detailed dispatch activities based on the market requirements for a particular regional transmission organization (RTO) (Mai and et al, 2013, p9-11):

> "The RPM is designed to evaluate scenarios of renewable technology deployment to meet renewable portfolio standard (RPS) and emission-reduction goals, and to project possible deployment levels for various projections of future technology and fuel prices... The RPM model co-optimizes transmission, generation, and storage options. It considers major grid operation constraints within its purview as a capacity expansion model... The methodologies for treating renewable technologies in RPM can help improve commercial models or capacity expansion models with greater geographic scope and more limited spatio-temporal resolution… RPM is

[6] BRICS countries: commonly recognized as five developing countries with great potential to growth, Brazil, Russia, India, China, and South Africa. These countries are showing strong economic signals of high industrialization process.

> designed with a flexible structure to enable research into how investment decisions may be affected by the choice of model time periods, particularly with high levels of renewable penetration."

It is generally agreed that the RPM is a great power planning tool that fits well in the IRP conceptual framework. However, since the RPM is designed to have a strong interaction with the power market, there is a concern whether the RPM could be directly applied to the case of China's 2030 electricity planning. In a power market, tariff rates are reflected by market demand and supply. However, due to the natural of monopolistic planned economy, electricity prices in China are fixed by the government instead of fluctuated by the market.

Another commonly applied model is the National Energy Modeling System (NEMS). The NEMS model reads the entire U.S. economy based on 9 time slices per year, three seasons with three diurnal periods, and 22 electricity generation regions. According to the EIA (2009, p6):

> "The NEMS projects the production, imports, conversion, consumption, and prices of energy, subject to assumptions on macroeconomic and financial factors, world energy markets, resource availability and costs, behavioral and technological choice criteria, cost and performance characteristics of energy technologies, and demographics."

The NEMS concentrates on all kinds of energy sources, which includes both primary and secondary energy. Thus, the NEMS focus not only on electricity but also natural gas markets, as well as transportations. In comparison, IRSP specifically focuses

on electricity planning; natural gas is only analyzed if it is used for power generation. Furthermore, transportation is not considered in the IRSP model.

The MARKet ALlocation (MARKAL) model is very similar to the NEMS model. It also simulates the entire U.S. economy based on all types of energy sources. The MARKAL development is more detailed than the NEMS model, which includes 12 time slices per year (three seasons with four diurnal periods) and 10 regions.

According to Mai and et al (2013), the resolution of the MARKAL model requires a number of simplifications, including approximations of grid operations and aggregation of individual generating units into generalized technology categories. Moreover, the simplifications are generally adequate to provide insights for long-term national scenario analyses, including evaluations of national energy policies.

There are also some other policy analytical models in literature, for instance, the ReEDS model and the SWITCH model. The ReEDS model could examine the technical challenges of renewable energy integration into the grid network, and it only investigates the U.S. electricity sector. The implementation of the ReEDS includes 17 time slices per year: it monitors four seasons with four diurnal periods and one peak time slice, plus 134 balancing areas in the 48 mainland states. Similarly, the SWITCH model has greater temporal resolution than the ReEDS model. It has 144 model hours, which is the result of 12 months per year with 2 representative days per month and 6 representative hours per day. These two models only investigate the technical perspectives of the electricity grid network, however, the concept of the IRP/IRSP is to have in-depth inclusion of social-economic analysis.

3.3.2 China's IRSP Model

For a feasible analysis of China, it is essential to have a specific model that could practically fit to China's circumstances. The IRSP model can accurately represent the situation not just for the utility company but also for a large region in China. It can extensively be utilized to analyze the situation of China. IRSP is based on the platform of General Algebraic Modeling System (GAMS). The IRSP model is now extended from linear regression model to non-linear model. The IRSP model connects Excel with GAMS through the Macro programming (a feature in Excel programming platform). Thus, users can enter data and also read the output in Microsoft Excel.

The IRP and the IRSP are similar in the following features:

Future predictions: both models are trying to accurately predict the future power demand associates with economic development. On the other hand, these models are also trying to predict the essential portion of each energy type between fossil fuels and renewable energy sources.

Cost reductions and environmentally sound: both models are aimed to optimize the cost of power generation, as well as associating with carbon reduction and reducing maximum capacities of power plants.

Policy integrations: both models have close relationship with policy guidance, power planning are usually bridged between the regulators and power providers.

IRSP is an upgrade from the IRP concept. IRSP is aimed at serving the Chinese power regulators. Meanwhile, IRP has been mostly used for state level power planning in

the U.S. On the other hand, IRSP was involved in China's 2020 electricity planning, which is commonly used by the NDRC.

3.3.2.1 Functions Prototype of IRSP

The functional form of IRSP is described below:

$$\text{Total cost} = (Construction\ Cost_{new\ plants\ in\ planning\ period} - Residual\ Value_{new\ constructed\ plants\ at\ the\ end\ of\ their\ service\ life}) + Operation\ Cost_{new\ constructed\ plants} + Operation\ Cost_{existing\ plants} + Cost_{purchase\ power\ from\ external\ grid} + Total\ Investment\ Cost_{EPP} + Total\ Operation\ Cost_{EPP}$$

This function was simplified by Hu, Wen, Wang, and et al (2010, p4642), with considered time value of capital for each type of power plant:

$$\text{Min Z} = \min\{GF + BF - CZ\}$$

Where:

Z = total cost of a power plant considering time value (2010 price, same as below)

GF = total fixed costs of newly installed power plants from 2010-2030

BF = total operational costs of all power plants from 2010-2030

CZ = the salvage value of newly installed power plants in 2030

Breaking down the above three subentries, this function can be expressed as follows (Hu, Wen, Wang, and et al, 2010, p4642):

Firstly,

$$\text{GF} = \sum_{y=1}^{Y}\left[\sum_{m=1}^{M}\left(C_{y,m} * F_{y,m}\right) * \beta_y\right]$$

Where:

Y = the number of years in a planning period, here it refers to 20 years

y = each individual year

m = the identification number of a certain type of traditional and efficiency power plant, expressed as follows, where 1-5 are conventional power plants and 6-12 are EPPs (Hu, Wen, Wang, and et al, 2010, p4638):

1= coal-fired power plants;

2= gas-fired power plants;

3= hydropower plants;

4= nuclear power plants;

5= wind power plants;

6= lighting EPP;

7= electric motor EPP;

8= variable frequency drive EPP;

9= ice storage EPP;

10= efficient home appliances EPP;

11= interruptible equipment EPP;

12= energy transformer EPP;

M = 12 different types of power plant;

$C_{y,m}$ = in a certain year 'y', the total installed capacity of power plant type 'm';

$F_{y,m}$ = capacity cost per kilowatt (kW) of installed capacity of plant type 'm' in the year 'y'; and

β_y = the coefficient of time value of the capital in the year 'y'.

Secondly,

$$BF = \sum_{y=1}^{Y}\left\{\left[\sum_{m=1}^{Ml}\left(E_{y,m} * Y_{y,m}\right) + \sum_{m=Ml+1}^{M}(E_{y,m} * Y_{y,m})\right] * \beta_y\right\}$$

Where,

$E_{y,m}$ = total electricity generated from power plant type 'm' in the year 'y';

$Y_{y,m}$ = the variable costs of plant type 'm' in the year 'y'; and

Ml = the amount of conventional power plants.

In this case, as mentioned by Hu, Wen, Wang, and et al (2010), the value of Ml should be 5 since the above equation engages five types of power plants: coal-fiend power plant, gas-fired power plant, hydro power plant, nuclear power plant, and wind power plant.

In this equation, Hu, Wen, Wang, and et al (2010) point out that $E_{y,m}$ is associated with annual averaged utilization hours of plant type 'm' in the year 'y', which is:

$$E_{y,m} = \left(C_{y,m}^{0} + \varphi_{y,m} * C_{y,m}\right) * H_{y,m}$$

Where,

$C_{y,m}^{0}$= available capacity of plant type 'm' in the year 'y';

$\varphi_{y,m}$= conversion coefficient of equivalent average capacity of newly installed capacity of plant type 'm' in the year 'y'; and

$H_{y,m}$= averaged utilization hours of power plant type 'm' in the year 'y'.

Lastly,

$$CZ = \sum_{m=1}^{M}(R_{y,m} * \beta_y)$$

Where:

$R_{y,m}$= the salvage value of power plant type 'm', constructed in the year 'y' at the end of 2030, and,

β_y= the coefficient of time value of the capital in the year 'y'.

As mentioned in above, in order to achieve an optimized result with environmental responsibilities, IRSP should contain several emission constraints. Inclusively summarized by Hu, Wen, Wang, and et al (2010), there are four major constraints that are contributing to China's greenhouse gas emission:

Power demand: according to the tradition in China's electricity industry, electricity planning should allow 20% of the reserved capacity (Zhang and et al, 2013). IRSP sets that smart grid technology can better utilize existing capacity for power dispatch which could reduce the reserved capacity lower than 20%, but it should be at least higher than the predicted power demand.

$$\sum_{m=1}^{M} E_{y,m} * (1 - n_y) \geq E_y$$

Where:

n_y= the transmission loss rate from power generation to demand; and

E_y= predicted power demand in the year 'y'.

Total installed capacity: despite of rapid growth of economic demand and developing DSM mechanism, the total capacity for the period of 2010-2030 should be controlled.

$$C_{y,m}^{0} + C_{y,m} \leq C_{y,m}^{max}$$

Where:

$C_{y,m}^{max}$= the capacity limit for power plant type 'm' in the year 'y'.

Fossil energy source: it is also commonly agreed that fossil energy consumption should be lower than its supply. This condition should be set in the IRSP design.

$\beta_{y,m} * E_{y,m} \leq X_{y,m}$

Where:

$\beta_{y,m}$= the amount of fossil energy consumed by plant type 'm' (per unit of electricity generation) in the year 'y'; and

$X_{y,m}$= the limit of fossil energy supply for unit 'm' in the year 'y'.

Disposal of pollutants: there are generally three types of emissions, nitrogen dioxide (NO_2), sulfur dioxide (SO_2), and nitrogen oxide (NOx). The IRSP model also put ceilings to restrict pollutions from these sources.

$$E_{y,1} * O_{y,1} + E_{y,2} * O_{y,2} \leq O_{y,max}$$

$$E_{y,1} * S_{y,1} + E_{y,2} * S_{y,2} \leq S_{y,max}$$

$$E_{y,1} * N_{y,1} + E_{y,2} * N_{y,2} \leq N_{y,max}$$

Where:

O_y, S_y, and N_y represents the above emission sources in year 'y'. The subscripts '1' and '2' indicates the contribution of coal-fired power plant and gas-fired power plant,

respectively. Furthermore, ‘max’ is the maximum limit of these emissions that are associated with China’s 50% clean energy target in 2030.

3.3.2.2 Optimized Dynamic IRSP Model: Non-linear Regression

The concept of the above IRSP model is obviously designed as a linear model, since the structure form is a typical:

$$y = ax_1 + bx_2 + cx_3 + dx_4 \ldots$$

Within the time value of capital function, the sub-function contains:

$$E_{y,m} = \left(C^0_{y,m} + \varphi_{y,m} * C_{y,m}\right) * H_{y,m}$$

Where $E_{y,m}$ is the total electricity generation by plant type ‘m’ in the year ‘y’, and $H_{y,m}$ refers to annually averaged utilization hours of plant type ‘m’ in the year ‘y’. Here $H_{y,m}$ is a constant data in the original model. According to Ornerud (2013), $H_{y,m}$ can be optimized by the IRSP model under different policy scenarios and thus it is not necessary a fixed constant.

For instance, the traditional IRSP forecasts that total power supply for a particular year to be 1,000 GW, and shared wind power generation for that year is projected to be 100 GW, this number would be fixed for that year in the model; meanwhile, in Ornerud’s IRSP update (2013), the forecasted total power supply for a particular year would be 1,000 GW, and the shares of each type of power generation are variables, x_1, x_2, … x_n. Wind power is not necessarily 100 GW, but depends on the result of the IRSP

calculation. This method enables the IRSP projection to achieve a locally optimized result for various inputs, which is a highly effective method of minimizing the total cost of all types of power generation.

And thus, in Ornerud's IRSP (2013), in some cases, generation type *m*, are bound to stay according to various criteria of possible operational hours in year *y*. Utilities, *m*, are bound by the annual limits defined as the existing capacity, and new installation cannot exceed the total possible forecasted capacity:

$$0 \leq H_{y,m} \leq H_{y,m}^{max} \qquad \forall y, \qquad m = 1,2,3,4,5,6,9,11$$

However, some EPP equipment, i.e. transformer, has a linear implementation, meaning that once the model has taken a decision of installation, it has to be operated at its full utilization (Ornerud, 2013). Therefore, the time constraint for the 12 types of power plants needs to be considered:

$H_{y,m}^{max}$ = upper limit of utilisation hours of plant *m* in year *y* parameter.

$$H_{y,m} = H_{y,m}^{max} \qquad \forall y, \qquad m = 7,8,10,12$$

Adding Ornerud's (2013) contribution to the IRSP construction, the outcome would have to be changed from a linear function to a non-linear function. However, this enables the IRSP to be more accurate and dynamic, and thus researchers can have a detailed projection of how would different types of power generators could integrate together to contribute a minimal cost during the process of generating electricity.

In order to achieve the projected outcomes, it is necessary to obtain several sets of data as input for the IRSP model. Detailed data requirement has been attached in the full test in chapter four.

3.3.2.3 General Algebraic Modeling System (GAMS) and Microsoft Excel

After obtain data, the next step is to run the program to optimize the result. As a sophisticated non-liner program (in Figure 3.5), the principle of calculation is generally conducted in three major steps:

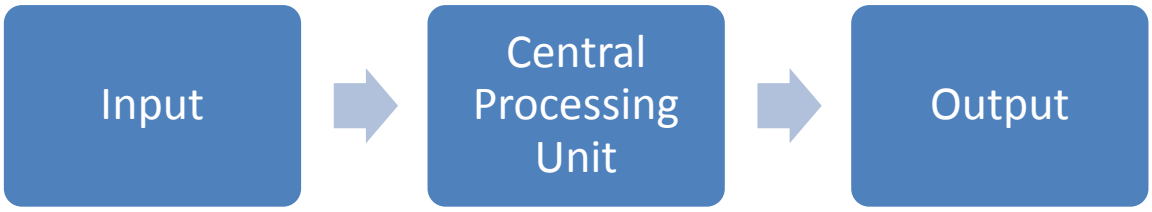

Figure 3.3 Process flows of the IRSP measures in concept

In the IRSP model, all data are entered in excel, and the entire calculation process happens in the GAMS program, and then a command leads the output back in the excel file. Thus, the following process of model algorism is shown in Figure 3.6. As demonstrated, the input variables are separated into several stages.

The first step of the model analysis is the input of technology types, including hydropower, coal power, wind, solar and etc. The second stage is the technical considerations, major constrains are life span of power plants, upper and lower limits of annual power capacities, utilization hours, and etc. Moreover, economic constrains are the third stage of considerations, e.g. subsidies on clean energy types, restrictions on coal power, and etc. Finally, after considering all of the above factors, the optimization algorism of the model investigates the result that balances between costs, technical feasibility, and emission reduction.

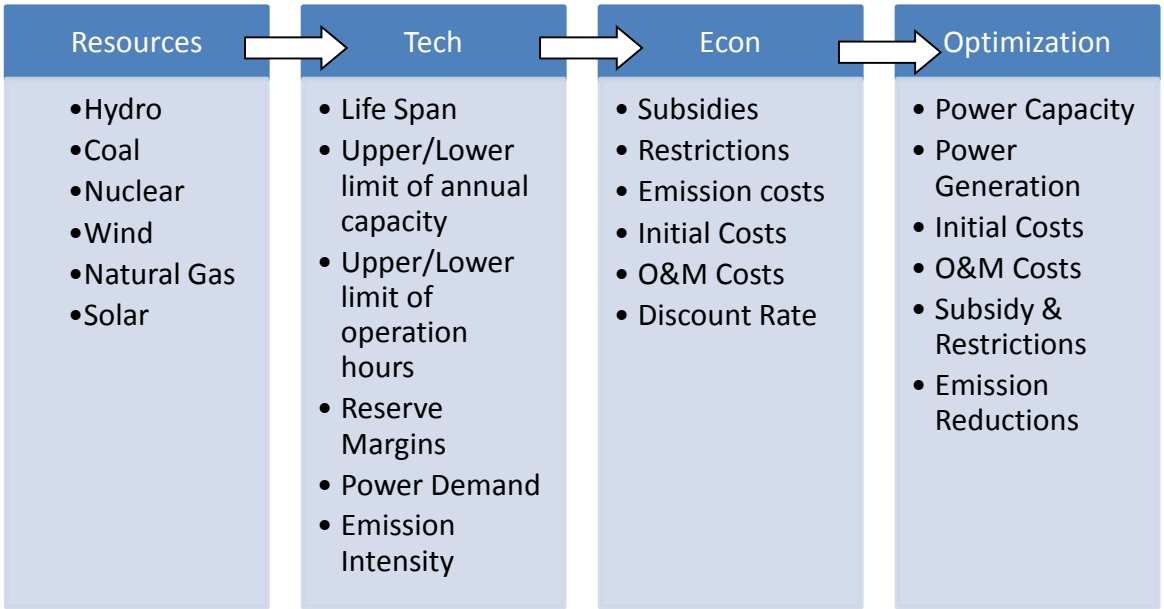

Figure 3.4 Process flows of the IRSP measures in software applications

Major calculation is processed in the GAMS model, which was developed by the Stanford University in 1960s. For non-linear regression and mixed integer optimization analysis, GAMS has its own advantage in stability enhancement and operation speed, which is particularly suitable for processing the model transformation from linear to non-linear regression, as well as frequent data adjustments (GAMS, 2015).

The IRSP model has large amount of mixed integer and sophisticated non-linear analysis after embedded the dynamic variable $H_{y,m}$. The model also requires a series of data cleaning and editing work. Therefore, GAMS model is selected to be the software platform for IRSP analysis, and excel is used as the medium for data entry and presenting outcomes.

3.3.3 The Job Creation Model

According to Rutovitz and Atherton (2009), the concept of the JEDI model can be summarized into the below four equations:

$$\text{Manufactoring (Domestic)} = \text{MW installed per year} * \text{Employment Factors (Manufactoring)} * \text{Regional job multipliers} * \text{\% Local manufactoring rate}$$

$$\text{Manufactoring (Export)} = \text{MW installed per year} * \text{Employment Factors (Manufactoring)} * \text{Regional job multipliers}$$

$$\text{Construction} = \text{MW installed per year} * \text{Employment Factors (Construction)} * \text{Regional job multipliers}$$

$$\text{O\&}M = \text{Cumulative Capacity} * \text{Employment Factors (O\&}M\text{)} * \text{Regional job multipliers}$$

Therefore, in the analytical model that is used in the dissertation research, namely Job Creation model (JC model), the number of increased jobs in each type of energy resource is:

$$\text{Job creation for each type of energy resource} = \left(\sum_{y=1}^{20}{}^{7} \text{Manufactoring (Domestic)} + \sum_{y=1}^{20} \text{Manufactoring (Export)} + \sum_{y=1}^{20} \text{Construction} + \sum_{y=1}^{20} \text{O\&}M\right) * \text{Technology Decline Factor}$$

---

[7] The total period of 20 years refers to 2011 to 2030.

Thus, the function to calculate total job creation for 2030 China's electricity industry is as follow:

$$\sum_{y=1}^{20} \text{Job creation for each type of energy resource}$$

In this dissertation, China's 2030 energy job creation will be estimated based on the above Rutovitz and Atherton's model. This model is an update from the JEDI model, which effectively projects a region's future electricity direct jobs. Rutovitz and Atherton (2009) also inclusively consider the DSM associated employments, which is suitable for the IRSP electricity planning.

Secondly, since China's electricity industry is relatively independent, it has minimum energy export and import; this dissertation shall simplify the function by withdrawing the variable of net export percentage. Furthermore, job estimation in this dissertation is for China instead of global projection, regional job multiplier and local manufacturing percentage and domestic coal and gas production percentage would not be applied (Rutovitz and Atherton, 2009).

3.4 Research Limitations and Assumptions

Every planning method has its own strength and associated limitations. There are three major constrains in this research:

This research is limited to a period span of 2015-2030. Detailed predictions are based on every five years. Output data is expected to be generated only for 2015, 2020, 2025, and 2030. The IRSP model is not able to provide data results for other years.

This research does not consider electricity trade with neighbor countries. China has less than 0.25% of net electricity export from Nepal (hydropower) and electricity export to Mongolia (EIA, 2011). Since the electricity import/export data is insignificant, it could be simply subtracted from total domestic electricity demand during data input.

The model is a pilot version of the original electricity planning model from the State Grid China Co. The original State Grid model uses 8760 hours of time interval (there are 8760 hours in one year), however, time interval in this research is limited to one year. As a result, this dissertation is unable to demonstrate peak load capacities, which leads to missing information of resource allocation during peak load hours.

Discount rate of annual financial flow in this dissertation is assumed to be 7% according to the State Grid (Liu, 2013). However, the rate is likely to change in the future given the slowing down of China's economic growth during the 13th FYP. Since the model prefer to a standard discount rate for the planning period, the research is unable to reflect any changes of future discount rate.

In terms of technology types, many studies include the development of China's biomass industry (Fridley, 2012; IEA, 2007; Green Peace, 2012). However, the model does not investigate the potential of biomass. Furthermore, the model does not separately evaluate natural gas, since natural gas are expected to have insignificant share in China's total electricity supply.

Lastly, this model assumes that there would be no major accidents[8] (economic crisis, market failure, power shortage, and etc.) happen to China's electricity system.

To sum up the methodology chapter, it is clear that an efficient electricity planning structure is essential for presenting the systematic analysis, as well as comprising the principles associated with the best method of practice. The structure of this dissertation is built upon the E4 concept, which is categorized as: energy, economics, environment and equity. In order to allocate energy types for 2030, the first step is to estimate the energy load forecast.

However, since China has its own characteristics for power sector regulation, the IRSP model is by far one of the most feasible models to facilitate the electricity planning procedure for China. The IRSP model realizes optimization by including emission charges, and then aims to achieve the total minimum cost based on the emission constrains, including CO_2, SO_2 and NO_x. From the perspective of job creation, the traditional Jobs and Economic Development Impact (JEDI) model is being adjusted for China's situation, and also breaks down into three major sections, direct job creation, indirect job creation, and induced job creation.

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[8] This model does not expect a large scale power crisis in China during the planning period.

Chapter 4

SCENARIOS & INPUTS

This chapter demonstrates main components of the three scenarios, and shows the rationale behind choosing specific input variables under each scenario. The three analytical scenarios are: Business as Usual scenario (BAU), High Renewable scenario (HR), and Renewable and DSM scenario (RD). In order to identify the differences in the data inputs between these scenarios, comparative tables are provided within sub-sections of this chapter. The tables show in detail the variables scenario associated with each scenario. The input variables for the Job Creation (JC) model are ordained from the output variables from the IRSP model. An analysis of the JC model inputs under each scenario is also shown in this chapter.

4.1 Definitions of Scenarios

In the process of energy planning, analysts usually come up with several scenarios to reduce the volatility of uncertainties. This analysis provides three different scenarios: BAU, HR, and RD. They are defined as follows:

The BAU scenario: The BAU scenario aims to project China's energy sector characteristics in 2030 following the policy incentives in the 11th FYP. Majority of these

polices were set in the 11th FYP. During the 11th FYP, China initiated the framework of renewable energy regulations. A key policy is the establishment of 'Renewable energy act' in 2006, which was further amended in 2009. A number of regulatory policies that requires regional governments to support renewable energy development were also introduced during this period. Feed-in tariff was 0.52 RMB/kWh for wind power including 0.15 RMB/kWh governmental subsidy, and 0.91 RMB/kWh for solar power including 0.55 RMB/kWh. Later in the 12th FYP, the detailed structure for renewable energy feed-in tariffs was categorized by regions (see section 2.6.3). A list of major energy policies in China are summarized in appendix 16. Before 2011, China's energy policies and incentives were based on the 11th FYP, which were very similar to the 10th FYP (Liu, 2012). Thus, the BAU scenario is based on a development trend that is still under the policy impact of the 11th FYP and policy incentives to clean energy are the same as those in the 11th FYP. In the 11th FYP, there were no limitation policies to direct conventional power plants.

The HR scenario: In 2012, the 18th National Congress of the Communist Party of China (CPC National Congress) conference changed the political administration of China's Communist Party. The presidency passed from Hu Jintao to Xi Jinping. From this perspective, the 12th FYP is often referred to as policy leapfrog from the 10th and 11th FYP. (Galbraith and Lu, 2012; Williams and Fredrich, 2008).

Its energy chapter clearly stated the importance of pushing for a reform in China's energy sector (State Council of China, 2012). A major focus of the 12th FYP affecting energy sector is to remove low efficiency coal power plants, as well as to increase the

percentage of clean energy in total power generation. Li Ke-qiang, the Premier of China, specifically emphasized the importance of accelerating the retirement of old coal power plants in the 18th CPC National Congress (State Council of China, 2012). Thus, the HR scenario optimizes 2030 energy structure by focusing on key variables which reflect updated policy incentives and regulations. Therefore, this scenario includes assessment of potential retirement of China's old coal power plants.

The RD scenario: This scenario considers the impact of China's DSM development, and the up-to-date policy impacts on China's electricity sector. The development of the RD scenario builds on the HR scenario, with additional DSM options that play a significant role in China's DSM regulatory policy. Considered technologies include: efficiency motors, variable frequency drives, ice-storage technologies, and others. The rational for including DSM in the procedure of power sector planning is to reduce total electricity demand, which can help to increase in the percentage of clean energy in total energy supply. Policy incentives and restrictions on traditional power plants in this scenario are the same as in the HR scenario.

4.2 Inputs for the IRSP model

In this section, the required variables and inputs for the IRSP model are introduced. Some data inputs are standard for all scenarios, such as, projected electricity demand for each year, the range of utilization hours of each type of power plant, emission intensity factors of CO_2, SO_2 and NOx, life span of each type of power plant, and etc. However, other data inputs are adjusted for different scenarios. For example, the policy incentives for clean energy and restrictions for traditional power generation types.

The analysis below explains and differentiates the adjustable data inputs. In order to distinguish the fixed data inputs from variable inputs, each scenario introduces a number of standard and adjustable variables, and separate tables report the values of all required input variables. There are a large sets of supportive data required for calculating the direct data inputs and they are equally important for construction of the model. For example, supportive data such as projected annual economic growth will greatly influence the electricity demand for a particular year, and China's annual inflation rate can influence unit costs of power plants.

Sections below summarize major data inputs into three general categories: power plant types, restrictions, and forecasted data. Explanations and reasoning for assigning different values to each data input are also provided.

Table 4.1 Summary of data references in the dissertation

Variables	**Data Sources**
Life span of power plant types	World Resources Institute (2015), IRENA (2014), IEA (2010), Duan (2014), Green Peace (2012), Davis & Socolow (2014)
Investment of each type of installed capacity	IRENA (2014), IEA (2010), Duan (2014), Kang (2013), Zhou (2012), Green Peace (2012), Davis & Socolow (2014), EIA (2015), Rocky Mountain Institute (2015), EPA (2012), and NREL (2010)
Operation costs of each type of	IRENA (2014),

power plant	IEA (2010), Duan (2014), Kang (2013), Zhou (2012), Green Peace (2012), Davis & Socolow (2014), EIA (2015), Rocky Mountain Institute (2015), EPA (2012), and NREL (2010)
Upper limit of power capacity	National Development and Reform Council
Lower limit of year-end power capacity	National Development and Reform Council
Upper limit utilization hours	National Development and Reform Council
Emission intensity of each type of power plant	World Resources Institute (2015), Duan (2014), Kang (2013), Zhou (2012), Green Peace (2012), Davis & Socolow (2014)

4.2.1 Power Plant Types

This section describes the most commonly used power plant types, noted as *m* in the methodology sections. As discussed in literature review, DSM technologies are considered as power generation forms (referred as EPP in methodology). Thus, there is a total of 12 power plant types by technologies (m=12, see methodology chapter for details of the function). The first 6 types are traditional power plants (TPPs) and the other 6 types are EPPs. The sections below separately explain the features of TPPs and EPPs and how they contribute to the IRSP model.

Within the 12 types of power plants, these are the inputs for each power plant:

Life span: This refers to the typical life time operation of a type of power plant reported in years. Data input of power plant life spans in this dissertation are collected from multiple sources (see Appendix 14). Different research institutes report different life span values, as a result, this dissertation use the average values reported. **Table 4.2** demonstrates the life span of each type of power plant.

Table 4.2 Life span of power plant types in China (unit: years)

	State Grid (2013)	WRI (2015)	IRENA (2014)	IEA (2010)	Duan (2014)	Mean Value
Hydropower	40	40	40	80	40	50.00
Coal power	25	30	40	40	30	33.33
Nuclear power	50	40	25	60	50	43.00
Wind power	20	20	25	25	20	22.50
Solar Power	25	30	25	25	20	25.00
Natural gas	25	25	40	30	25	32.00
EPP lamp	3	1.3	2.5		3	2.27
High efficiency motor	15				15	15.00
EPP transformer	30				30	30.00
Variable frequency drive	15				15	15.00
Ice storage technology	10				10	10.00
Home appliance	10				10	10.00
Interrupt equipment	1				1	1.00

Data Sources: State Grid (2013), World Resources Institute (2015), IRENA (2014), IEA (2010), Duan (2014), Green Peace (2012), Davis & Socolow (2014)

Table 4.3 shows the average per kilo watt (kW) overnight investment cost of each type of power plant. Data for this table is obtained from multiple sources (see Appendix 14). **Table 4.4** demonstrates the 2020 prediction of initial cost of different power plants, and **table 4.5** demonstrates the 2030 initial cost projections. Among these sources, State Grid (2013), Duan (2014) and Zhou (2012) reported the initial costs, which include the

EPPs, while other sources mainly focus on the initial costs for hydropower, coal power, nuclear power, wind and solar, and natural gas power. As demonstrated, initial cost for coal power is expected to grow from 4167 RMB per kW in 2010 to 4339 RMB per kW in 2020 and then to 4838 RMB per kW in 2030. However, initial costs for clean energy are expected to decrease during the planning period. Solar power is expected to have the largest decline rate during the period (31%), from 24395 RMB per kW in 2010 to 23025 RMB per kW in 2020, and then to 18625 RMB per kW in 2030.

Table 4.3 Initial costs of each type of power plant in China (Unit: RMB/kW)

	State Grid (2013)	IRENA (2014)	IEA (2010)	Duan (2014)	Zhou (2012)	Mean Value
Hydropower	9000	10000	10290	8500	9600	9478.00
Coal power	6000	4370	3600	4300	4530	4166.67
Nuclear power	17500	16500	14500	11075	13500	12768.75
Wind power	12500	11000	10000	9500	10500	9900.00
Solar Power	26667	27000	22100	25500	21100	24394.50
Natural gas	5167	5800	3600	3500	4200	4100.00
EPP lamp	405			435	405	420.00
High efficiency motor	300			440	300	370.00
EPP transformer	99.3			151	120	135.50
Variable frequency drive	856			500	856	678.00
Ice storage technology	157			215	157	186.00
Home appliance	500			1300	1200	1250.00
Interrupt equipment	108			100	132	116.00

Data Sources: State Grid (2013), Zhou (2012), IRENA (2014), IEA (2010), Duan (2014)

Table 4.4 2020 predicted initial cost of power plants in China (Unit: RMB/kW)

	EPA (2012)	RMI (2015)	NREL (2010)	EIA (2015)	Mean Value
Hydropower	9478	9478	9478	9478	9478
Coal power	4500	4200	4300	4355	4338.75

Nuclear power	12768	12768	12000	11500	12257.5
Wind power	9900	9500	9000	9100	9375
Solar Power	24300	23000	22800	22000	23025
Natural gas	4000	4100	4050	4030	4045

Data Sources: EPA (2012), Rocky Mountain Institute (RMI, 2015), NREL (2010), EIA (2015)

Table 4.5 2030 predicted initial cost of power plants in China (Unit: RMB/kW)

	EPA (2012)	RMI (2015)	NREL (2010)	EIA (2015)	Mean Value
Hydropower	9478	9478	9478	9478	9478
Coal power	4900	4900	4750	4800	4837.5
Nuclear power	12768	12768	12450	12600	12646.5
Wind power	9900	7500	8500	9000	8725
Solar Power	18000	15000	20000	21500	18625
Natural gas	3100	3900	4000	3950	3737.5

Data Sources: EPA (2012), RMI (2015), NREL (2010), EIA (2015)

Discount rate: this dissertation sets 2010 as a reference year, and uses 7% annual discount rate for cash flow analysis. This value was chosen based on literature review, which shows that majority of roadmaps for China's electricity sector use this value (for details see Appendix 14 and Table 4.6).

Table 4.6 Projected discount rate for China

State Grid (2013)	LBNL (2011)	WRI (2015)	Duan (2014)
7%	5-10%	7%	7-10%
IEA (2010)	Green Peace (2012)	Kang (2013)	Zhou (2012)
7%	7%	7%	7%

Data Sources: State Grid, 2013; LBNL, 2011; WRI, 2015; Duan, 2014; IEA, 2010; Green Peace, 2012; Kang, 2013; Zhou, 2012.

Variable costs: this is the per kilo-watt-hour (kWh) variable cost of each power plant, including fuel costs, O&M cost and other. Data inputs for variable costs were obtained from multiple sources (see Appendix 14). **Table 4.7** shows the variable costs of each type of power plant. Among these reports, IEA (2010) has separately listed the fuel costs of power plant types that consume fuel during power generation since fuel cost is the largest portion in variable cost (coal, nuclear, natural gas; bracketed in the IEA column in **table 4.5**). Furthermore, **figure 4.1** illustrates the variable cost break down by fuel cost, O&M and other, according to IEA (2010). **Table 4.9** and **table 4.10** show the projected costs of power plants in 2020 and 2030 respectively. Since variable costs do not show significant differences from one year to another, this dissertation uses the variable cost values for 2010, 2020, and 2030. Projections from EPA (2012), Rocky Mountain Institute (RMI, 2015), NREL (2010), and EIA (2015) are only for the electricity sector in the U.S.; however, data from the IEA (2010) reports values for both China and U.S., accordingly, investment number in **table 4.8** and **table 4.9** are converted in RMB.

Table 4.7 Variable costs of each type of power plant in China (Unit: RMB/kWh)

	State Grid (2013)	IRENA (2014)	IEA[9] (2010)	Kang (2013)	Zhou (2012)	Duan (2014)	Mean Value
Hydropower	0.02	0.08	0.07	0.06	0.04	0.07	0.06
Coal power	0.3	0.26	0.21 (0.15)	0.222	0.19	0.16	0.21
Nuclear power	0.10	0.09	0.06 (0.02)	0.06	0.05	0.05	0.06
Wind power	0.02	0.03	0.13	0.05	0.11	0.12	0.09
Solar Power	0.05	0.09	0.14	0.12	0.13	0.15	0.13
Natural gas	0.3	0.31	0.26 (0.21)	0.32	0.25	0.27	0.28

Data Sources: IRENA (2014), IEA (2010), Duan (2014), Kang (2013), Zhou (2012), Green Peace (2012), Davis & Socolow (2014)

[9] Fuel costs for coal power, nuclear power, and natural gas are separated in brackets.

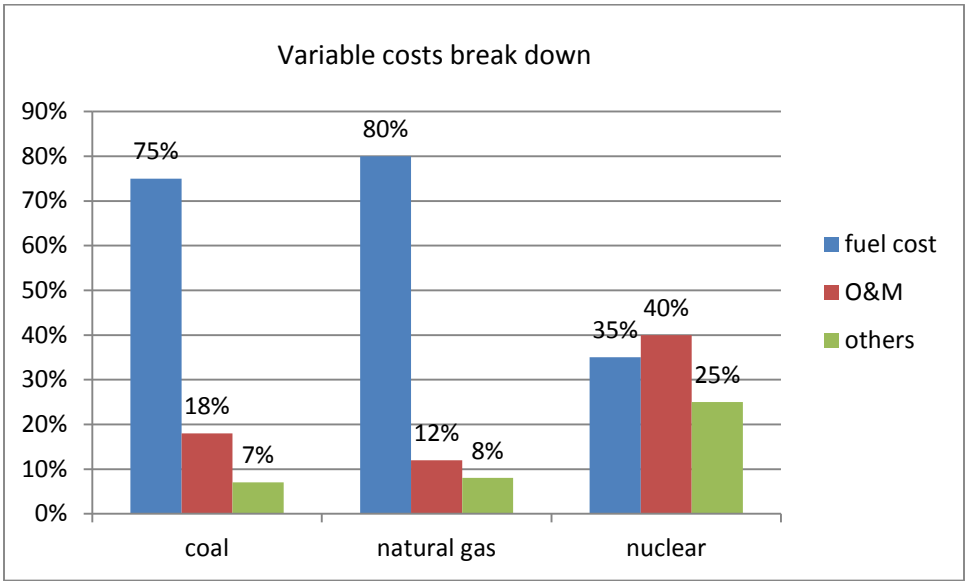

Figure 4.1 Variable costs in China break down
Data Sources: IEA, 2010

Table 4.8 2020 predicted variable cost of power plants in China (Unit: RMB/kWh)

	EPA (2012)	RMI (2015)	NREL (2010)	EIA (2015)	Mean Value
Hydropower	0.06	0.08	0.07	0.06	0.06
Coal power	0.23	0.26	0.32	0.27	0.26
Nuclear power	0.06	0.04	0.03	0.04	0.05
Wind power	0.07	0.07	0.08	0.06	0.07
Solar Power	0.1	0.11	0.12	0.11	0.11
Natural gas	0.24	0.22	0.21	0.22	0.23

Data Sources: EPA (2012), RMI (2015), NREL (2010), EIA (2015)

Table 4.9 2030 predicted variable cost of power plants in China (Unit: RMB/kWh)

	EPA (2012)	RMI (2015)	NREL (2010)	EIA (2015)	Mean Value
Hydropower	0.06	0.08	0.07	0.06	0.06
Coal power	0.25	0.25	0.33	0.26	0.27
Nuclear power	0.06	0.05	0.05	0.05	0.05
Wind power	0.07	0.07	0.08	0.07	0.07

Solar Power	0.08	0.09	0.1	0.09	0.09
Natural gas	0.23	0.22	0.21	0.22	0.22

Data Sources: EPA (2012), RMI (2015), NREL (2010), EIA (2015)

Upper limit of year-end capacities: the upper limit of available capacity for a certain type of power plant. The IRSP model has to consider the technical and geographical limitations, as well as the construction period of different power plant types. For instance, hydropower is considered one of the most affordable and clean energy resource, but many provinces have a 'geological ceiling' for hydro power capacities (Liu, 2013). Since coal power plant are still economically more feasible than renewable energy power generations, thus it is necessary to have an enforced upper limit of year-end additional capacities for coal power plants. The IRSP model could optimize a result that is based on these restrictions. The upper limits of year-end capacities are shown in **table 4.10**, data was provided by the National Development & Reform Council (NDRC, 2013).

Table 4.10 Upper limit of power capacity in China (unit: 10MW)

	2015	2020	2025	2030
Hydropower	26000	39526	46126	52725
Coal power	210000	280000	360000	400000
Nuclear power	5000	8030	11766	15045
Wind power	9500	20000	30000	40000
Natural gas	4500	7081	12020	16959
Solar Power	2805	5049	9088	16358
EPP lamp	480	1440	4320	12960
High efficiency motor	540	1620	4860	14580
EPP transformer	444	533	640	768
Variable frequency drive	480	1440	4320	12960
Ice storage technology	450	1350	4050	12150
Home appliance	300	900	2700	8100
Interrupt equipment	2490	7470	22410	67230

Data Source: National Development and Reform Council, 2013

Lower limit of year-end capacities: the lower limit of available capacity for a certain type of power plant. This is usually referring to clean energy types which are supported by regulatory policies. For instance, the 12th FYP suggested minimum requirements for wind and solar installed capacities, and mass construction of nuclear power. This category enables the IRSP model to respond to the effect of those policies. Details can be found in **table 4.11**, data from the NDRC (2013).

Table 4.11 Lower limit of year-end power capacity in China (Unit: 10 MW)

	2015	2020	2025	2030
Hydropower				
Coal power				
Nuclear power	2913	4818	7060	9027
Wind power	5692	12017	17995	19912
Natural gas				
Solar Power	1683	3029	5453	8179
EPP lamp	171	222	289	376
High efficiency motor				
EPP transformer				
Variable frequency drive	94	122	159	207
Ice storage technology				
EPP appliance				
Interrupt equipment	805	886	975	1073

Data Source: National Development and Reform Council, 2013

Upper and lower limit utilization hours of generators (maximum operation hours): the maximum and minimum hours that a typical power plant can generate electricity during a year. For instance, for wind power operational hours at full capacity is around 2000 hours per year. In IRSP, the utilization hours hours are calculated using the dynamic model instead of a fixed number, however, the result of the dynamic model must be

lower than the upper limit of utilization hours for the year, and higher than the lower limit. **Table 4.12** and **table 4.13** shows the upper and lower limits of utilization hours, data collected from the China Electricity Council (2012).

Table 4.12 Upper limit of annual utilization hours in China

	2015	2020	2025	2030
Hydropower	3450	3300	3300	3300
Coal power	5403	5000	4950	4900
Nuclear power	7324	7000	7000	7000
Wind power	2000	2100	2200	2300
Natural gas	3500	3500	3500	3500
Solar Power	1400	1400	1500	1600
EPP lamp	2500	2500	2500	2500
High efficiency motor	2195	2000	2000	2000
EPP transformer	2200	2200	2200	2200
Variable frequency drive	2500	2500	2500	2500
Ice storage technology	1500	1500	1500	1500
EPP appliance	1367	1500	1500	1500
Interrupt equipment	100	100	100	100

Data Source: China Electricity Council, 2013

Table 4.13 Lower limit of annual utilization hours in China

	2015	2020	2025	2030
Hydropower				
Coal power				
Nuclear power	3300	3300	3300	3300
Wind power	1800	1800	1800	1800
Natural gas				
Solar Power	1600	1600	1600	1600
EPP lamp				
High efficiency motor				
EPP transformer				
Variable frequency drive				
Ice storage technology				
EPP appliance				

Interrupt equipment				

Data Source: China Electricity Council, 2013

4.2.2 Restrictions

IRSP model has several restrictions for input variables. The emission intensities for each type of power plant are obtained from multiple sources (see Appendix 14), and emission limits are set based on the goals of policy regulators (mainly refers to the National Development and Reform Council as well as the State Council of China) which were set in the 12th FYP (State Council, 2012). CO_2, SO_2 and NOx are the three major emissions from electricity generation.

In this dissertation, the environment dimension of the E4 concept mainly is addressed through carbon emission instead of SO_2 and NO_x. However, data on SO_2 and NO_x emissions are reported for future studies.

The IRSP model uses emission intensities for coal power plants as well as for natural gas power plants. It is evident that natural gas plants have lower CO_2 emissions per unit of production in comparison with coal power plants. **Table 4.14** presents required environmental data and values used in IRSP model.

Table 4.14 Emission Intensities in China

Category	Unit	State Grid (2013)	WRI (2015)	Zhou (2012)	Duan (2014)	Mean Value
Coal CO_2 Emission	g/kWh	800	900	1000	800	900.00
Coal SO_2 Emission	g/kWh	4.4		5.8	4.3	5.05
Coal NOx Emission	g/kWh	2.7		2.7	2.7	2.70
Natural gas CO_2 Emission	g/kWh	430	600	510	450	481.33

Natural gas SO_2 Emission	g/kWh	0.049		0.045	0.061	0.05
Natural gas NOx Emission	g/kWh	2		0.76	1.2	0.98

Data Sources: World Resources Institute (2015), Duan (2014), Zhou (2012), State Grid (2013)

4.2.3 Forecasted Data

Since the IRSP model requires electricity demand which will be met by the electricity supply, electricity demand needs to be forecasted. Electricity demand is projected for each year until 2030. The methodology chapter describes model used for the projection.

Annual growth rate of electricity demand is calculated by the following equation:

$$\text{Growth rate } = \frac{(\text{Electricity Demand}_{\text{This Year}} - \text{Electricity Demand}_{\text{Last Year}})}{\text{Electricity Demand}_{\text{Last Year}}} \times 100\%$$

4.3 Inputs for the JC Model

The JC model investigates the potential job creation under all three scenarios. Each scenario has different projected outputs for power capacities as well as power generations. In addition, different energy sources have different impacts on job creation, thus, different scenarios are associated with different amounts of job created. In this dissertation, job creation is evaluated in terms of ‘job years’. One job year refers to one job during one year (American Recovery and Reinvestment Act, ARRA). For instance, it takes 15 years for Gezhouba Hydropower Group to construct a hydro power plant, and

each year it requires 2000 workers. The total job year for this project is calculated as: 2000*15= 30,000 job year.

It is vital to identify the scope of job creation. According to Markaki and et al (2013), the scope of job creation analysis in the energy industry is generally divided as: direct job creation, indirect job creation, and induced job creation. The definition of each scope is as follows:

Direct job creation: the direct impact of jobs created in the energy sector that results from the development of power plant constructions as well as from operation and maintenance (O&M).

Indirect job creation: the indirect effects created in the sectors of related economy activities, which could be materials and/or services; for instance, workers hired for the production of construction materials for electricity projects, etc.

Induced job creation: the induced job creation refers to a wider range of economic effects. According to Markaki and et al (2013), it is the income that will be available for household spending, which could accelerate economic development in other sectors, for example, food, logistic and entertainment industries etc.

This section introduces the required data for the JC model. All required indexes in direct, indirect, and induced job creation are the same in the three scenarios (BAU, HR, and RD). Since the inputs of JC model are the outputs of the IRSP model, and the IRSP outputs vary by scenario; therefore, it is expected to have separate JC model outputs for each scenario.

In this dissertation, since the economic dimension of the E4 concept based on not only minimizing the costs, but also increased job creation; hence, it is meaningful to compare the associated job creation under three scenarios.

Data collection on China's job creation for each type of energy source is difficult. It is feasible to use the data from another country as a reference. China's total GDP has surpassed the Europe Union since 2009; and became the second largest economy in the world after the USA. However, job creation associated with the power sector is still lower than the Average level of European countries. According to Liu (2013), China has been collaborated with its global partners in middle GDP European countries, since the labor market in China is very similar with that in those regions.

The below table is a summary of job creations in the electricity sector from five literature sources. Data sources are collected from the OECD countries (Rutovitz & Harris, 2012), U.S. (UNEP, 2008), Canada (2012), and China (Green Peace, 2012 and Rutovitz & Harris, 2012). The OECD, U.S. and Canadian studies are used as references to compare and decide what values to select between the two Chinese studies.

As illustrated in **figure 4.2**, Rutovitz & Harris (2012) working on China reported the highest values compared to other studies for hydropower, coal, nuclear, wind, and natural gas, while solar power has relatively similar value. However, Green Peace (2012) has the highest value for solar power, which is 38.4 job years per MW, comparing with 11-25 job years per MW in other sources. The job years for other power plants in Green Peace (2012) report are relatively close to other reports. As a result, this dissertation decided to use the value of solar from Rutovitz & Harris (2012a), which is the blue round

dot in the scatter chart; and the rest of the values are selected from Green Peace (2012), which are the yellow triangles in the scatter chart.

Table 4.15 Summary of job creation by job year per MW in China

	OECD (Rutovitz & Harris, 2012, p5)	U.S. (UNEP, 2008, p102)	Canada (Pembina, 2012, p3)	China (Green Peace, 2012, p15)	China (Rutovitz & Harris, 2012, p16)
Hydropower	10	10.6	11.3	11.3	19
Coal	7.7	10.5	n/a	14.4	14.63
Nuclear	14	12	11.8	16	26.6
Wind	12.5	3	3.92	15.4	23.75
Natural Gas	1.7	1.95	4	3.4	3.23
Solar	11	11	25.9	38.4	20.9

Data Sources: Rutovitz & Harris, 2012; UNEP, 2008; Pembina, 2012; Green Peace, 2012; Rutovitz & Harris, 2012.

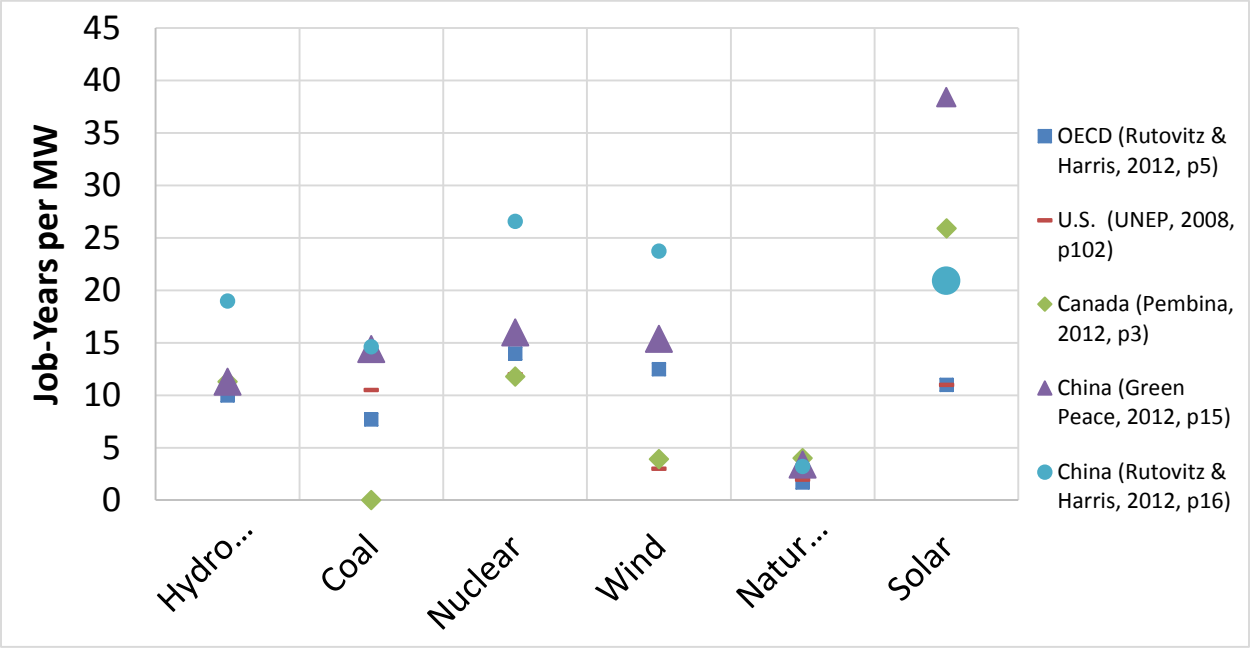

Figure 4.2 Job years per MW in scatter chart in China

Data Sources: Rutovitz & Harris, 2012a; UNEP, 2008; Pembina, 2012; Green Peace, 2012; Rutovitz & Harris, 2012b

4.4 The Evaluation Process of Equity

The most vital element in the topic of equity is the associated emission concerns during each phase of energy planning (Wang, 2000). Hence, this dissertation matches the illustration of equity analysis with the results of IRSP model and the JC model. Since equity is an intangible element, this dissertation shall use low, medium and high levels of equity goals to present the equity outcome of the 2030 clean energy roadmap. As introduced in the methodology chapter, since the emission of SO_2 and NO_x are much smaller than that of CO_2, the evaluation of levels of equity achievement shall investigate only the emission of CO_2.

A collaborative research between China Academy of Science and the NDRC argues that China should aim at a target of having 4-5 billion tons of annual CO_2 emission from the power sector in 2030 (China Energy Report, 2009). However, the European Union Commission (2010) criticized this target, claiming that it was calculated based on several radical policy regulations; and the trend of total clean energy subsidy over the next 10-20 years is expected to be kept a level of 20-30% annual growth in terms of subsidy amounts. A great concern from the EU is that whether the life span of radical policies can last until 2030, considering the rapid economic reforms in China's recent FYPs. Meanwhile, this dissertation would like to argue that China has placed great efforts to subsidize clean energy and emission control, due to the slowdown of China's economy from 10% GDP growth to 7.5% GDP growth during the 12th FYP; the burden for China to maintain a high subsidy level of 20-30% each year in the near future is economically unsustainable.

Therefore, this dissertation sets 5 billion tons of CO_2 emissions as the standard for the high level of equity achievement. A 10% increasing space shall be assigned for the medium level of equity achievement, which is 5.5 billion tons of CO_2 emission. Emission amount above the 5.5 benchmark shall be categorized as low level of equity achievement. Thus, the definitions of low, medium and high levels of equity achievements are:

- Low level of equity achievements: the net CO_2 emission from the power sector in 2030 is higher than 5.3 billion tons (CO_2 emission $\geq$ 5.5 billion tons).
- Medium level of equity achievements: the net CO_2 emission from the power sector in 2030 is between 5 billion tons and 5.3 billion tons (5 billion tons < CO_2 emission < 5.5 billion tons).
- High level of equity achievements: the net CO_2 emission from the power sector in 2030 is lower than 5 billion tons (CO_2 emission $\leq$ 5 billion tons).

This dissertation also studies the equity issue of China's hydropower development. Hydropower is clean energy; however, large scale hydropower is associated with environmental problems in local geographical area. It is necessary to provide a deeper analysis of the pros and cons of hydropower for the energy planning of China, since China is implementing the construction of the Three Gorges Dam, and look further into the potential impacts of planning large scale hydropower plants.

Furthermore, China's high energy demand in the power sector is influenced by the development of urbanization (McGuigan and et al, 2002). China has large amounts of various types of energy resources in the western inland China, but 82% of the electricity load centers are located along the eastern coastline. Electricity access for rural areas is the initial and essential step for poverty reduction and reducing the divide between rich and poor (Movius, 2007; Rayner and Malone, 2001). The analysis of equity in energy planning is not addressed in this dissertation.

Chapter 5

RESULTS OF THE ANALYSIS

This chapter presents outcomes of the IRSP and JC models for the following five perspectives: economic impacts, environmental impacts, energy structure, job opportunities, and equity impacts. The chapter explores the analytical results from the three scenarios: BAU, HR and RD, and provides comparative analysis of the scenario results.

The chapter concludes that the RD scenario is the most suitable scenario for achieving a sustainable energy target of 50% clean energy supply in China's electricity industry by 2030. Table 5.1 presents a comparison between the three scenarios. Using 2011 as a starting year to demonstrate the current status of China's energy development, this chapter marks the extent of changes needed to achieve the target.

Table 5.1 Summary of target achievements under the BAU, HR and RD scenarios

	BAU	HR	RD
Clean Energy Capacity %	29%	58%	70%
Clean Energy Generation %	22%	38%	50%
Emission (billion tons)	5,304	5,181	4,587
Total Cost[10] (billion dollars)	7,554	8,574	7,979
Direct jobs (job years)	-	64,638,413	95,358,167

[10] Note: this is the cumulative total cost based on 2015 price.

Each scenario evaluates the separate dimensions of sustainable development under the E4 framework to develop the most feasible and the most sustainable roadmap for China's 2030 energy planning. The four dimensions that construct the framework, as introduced in the literature review are: energy, economy, environment and equity. Energy results are based on the direct analysis of the optimization model, IRSP. The JC model delivers Employment. The result of which presents direct jobs only, while indirect jobs and induced jobs are not studied in this dissertation due to lack of relevant data. However, Green Peace (2012) and Rutovitz & Harris (2012) both agree that total jobs (including direct jobs, indirect jobs, and induced jobs) should be no more than 300% of direct jobs. Equity is not presented in terms of quantitative data. Therefore, analysis of the equity is being qualitatively presented from the following four major perspectives: levels of CO_2 reduction, biodiversity, community impacts, and urban/rural development.

In general, this chapter's analysis confirms that the RD scenario is the most effective when considering economics and emissions. The model contains four dimensions of analysis: cost and return, required subsidy level, emission reductions, as well as detailed analysis of each type of energy source. The analysis below clearly explains the reasoning behind the RD scenario, and why it requires minimum financial investment, lower subsidy level, and has maximum reduction in CO_2 emissions when compared with other scenarios.

5.1 The BAU Scenario

The BAU scenario sets the baseline forecast for China's 2030 electricity demand and supply under current economic development conditions, electricity policies, and tariff system. To understand projected electricity demand and BAU achievement in 2030, it is

vital to investigate the BAU scenario set in other literature. As mentioned in the chapter two, there are five literature sources that have provided detailed studies on China's 2030 energy roadmap, and four of them clearly demonstrate their shares of power generation under the BAU scenario: LBNL (Fridley, 2013; IEA, 2007; Green Peace, 2012; and IRENA, 2014). The table 5.2 summarizes the power generation in TWh and in percentages under the BAU scenarios according to these literature sources. The LBNL provides the penetration of power generation instead of actual value for each technology. The section of 'Adjustment' reflects the weighted average of each type of power technology.

Table 5.2 Power generation of BAU scenarios (TWh)

	IEA	Green Peace	IRENA	LBNL	Average	Adjustment
Hydro	1,005 (12%)	1,249 (15%)	1,600 (17%)	12%	14%	13%
Coal	6,586 (78%)	6,483 (77%)	N/A	67%	74%	72%
Wind	133 (2%)	492 (6%)	648 (7%)	6%	5%	5%
Nuclear	256 (3%)	723 (9%)	192 (2%)	13%	5%	5%
Solar	15 (1%)	49 (1%)	197 (2%)	1%	1%	1%
Natural Gas	313 (4%)	438 (5%)	N/A	2%	4%	4%
Total	8,472	9,607	9,312	9,100	103%	100%

Sources from: Fridley, 2013; IEA, 2007; Green Peace, 2012; IRENA, 2014

As listed in the table above, hydropower generally would share between 12% and 17% of the total power generation, and coal power would share between 67% and 78%. Wind power and nuclear power had broader range of values, which were 2% to 7% for wind power and 2% to 13% for nuclear power. All examined sources agreed that solar power would share between 1% and 2%, and natural gas would share between 2% and 5%. The mean of these values are summarized in the 'average' column. However, since the sum of these mean values are greater than 100%, an adjustment would be required.

The adjusted values are listed in the last column of the table, which is the value that is applied in the BAU scenario of this dissertation.

According to the IEA (2011), China's power consumption from 2011 to 2030 is projected to grow 4.5% annually, this is also supported by the State Council (2012) and the SGCC (2013). Thus, to predict the BAU scenario for China in 2030, this section uses the reference from China's 2011 power capacity that was published by the SGCC11 (2013), and utilizes an annual discount rate of 7%, according to the State Council (2012) and the SGCC (2013).

- Cost factors
- Capacity and energy factors
- Emission volumes

5.1.1 Cost Indicators

As discussed in the literature review, the two quantifiable indicators during the electricity planning process are economic costs and environmental benefits. The term "costs" refers to investments during the planning period (2011-2030). The structure of a projected electricity system usually requires different power generator configurations, and hence, a number of factors need to be compared for the best outcome (e.g. annual total costs, initial costs, and O&M costs). This section provides results the BAU scenario, and will be used as reference for comparative analysis in the later phase of this chapter. The following factors are listed:

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[11] As indicated in literature review, SGCC holds the primary access to China's power regulation, and thus it is responsible for publishing China's official electricity data. Data from SGCC are widely referenced by State Council, China Electricity Council, and many other governmental departments in China.

First, the total cumulative cost of the BAU model is estimated to be 7,554 billion USD from 2011 to 2030. **Table 5.3** demonstrates the annual total costs in 2015, 2020, 2025 and 2030. The annual total costs are summation of initial power plant costs and variable costs. The total cost under the BAU scenario will increase from $381.81 billion in 2015 to $628.78 billion in 2030. The total cost of the BAU scenario is an important indicator for power planning for it acts as benchmark indicator that will be compared with the HR scenario and with the RD scenario in the final analysis of this dissertation.

Table 5.3 Annual total costs required in China from 2015 to 2030 (billion dollars)

	2015	2020	2025	2030
Total Cost	381.81	473.61	527.5	628.78

Table 5.4 shows the annual initial cost of each type of energy source in those particular years. As shown below, the initial cost of coal power in China will be $31.2 billion dollars in 2015, and it is expected to rise to $145.95 billion by 2030. This 467% increase in investment is the highest among all the energy sources. Under the BAU scenario, it is clear that coal power will still dominant the investment of newly installed power capacities during the period from 2020 to 2030. Meanwhile, solar capacity will experience the highest growth among other types of clean energy sources, from 2015's $20.91 billion to $45.5 billion in 2030 given a growth rate of 1.18 fold.

Table 5.4 Annual initial costs for each type of energy source in China (billion dollars)

	2015	2020	2025	2030

Hydro	23.85	72.81	28.26	25.27
Coal	31.20	47.04	76.59	145.95
Nuclear	72.65	31.17	32.06	23.06
Wind	33.30	67.88	49.46	40.83
Natural Gas	8.24	7.78	13.20	10.64
Solar	20.91	24.61	58.45	45.50
Total	190.15	251.29	258.02	291.25

Furthermore, **Table 5.5** presents the variable costs of different types of energy sources in these particular years. It becomes apparent that a large portion of investment will be spent on operating coal power plants. The variable cost for coal power will be $183.78 billion in 2015, then $313.21 billion in 2030 granted the growth rate of 70.42%. At the same time, the highest operation investment growth in clean energy rests nuclear power from a 2015, $4.53 billion to a 2030, $15.81 billion at 3.49 times growth rate.

Wind power and solar power also experience high growth in this category, and since the function of natural gas is utilized mainly to meet the peak load demand, the variable cost of natural gas is comparatively low during the planning period. Natural gas in China costs three times more than in the US, and therefore, its contribution in terms of power generation is projected to be very limited during the planning period (Liu, 2013). Yet, China still encourages building natural gas power plants in the current planning period as preparation for continued, periodic electric supply after 2030.

Table 5.5 Annual variable costs for each type of energy source in China (billion dollars)

	2015	2020	2025	2030
Hydro	2.75	3.85	4.66	5.34
Coal	183.78	208.98	250.46	313.21
Nuclear	4.53	8.18	12.14	15.81
Wind	0.51	0.90	1.42	1.92

Natural Gas	0.00	0.00	0.00	0.00
Solar	0.09	0.41	0.80	1.25
Total	191.66	222.32	269.48	337.53

As illustrated in **Table 5.3**, the total cost of the BAU scenario will increase from $322.02 billion in 2015 to $412.13 billion in 2030 (based on 2015 price level), which is approximately $90 billion of net growth. The investment increase in wind and solar power capacity are stronger than that of nuclear and hydropower. Coal power still plays a major role as a power generator. In fact, it dominates the electricity industry. From the increasing amount of power capacity investment and the financial variable costs of operational activities, it is clear that coal power will still be the major source beyond 2030 under the BAU scenario.

5.1.2 Capacity and Energy Indicators

For utility planning, it is important to separately report installed capacity and energy consumption. Furthermore, it is important to take into the consideration the volume of retired capacities. To compensate for retired capacity, increased future electricity demand generally requires higher capacity installations. Thus, it makes more sense to use the term ‘net growth’ to precisely demonstrate analytical results in this dissertation, in which the results derive after subtracting the retired capacities from gross capacity. In order to reflect the net growth, studying the retired capacities of key contributors to China’s electricity sector becomes essential.

As shown in the table below, the data sets illustrate a similar phenomenon that is described in the previous section's investment tables. Coal power capacity still plays a key role in power capacity whilst the growth rate decreases. Concurrently, coal power in China also has the largest number of retirement capacities.

Table 5.6 displays installed capacity additions for each type of energy source in 2015, 2020, 2025, and 2030 under the BAU scenario. Capacity additions for coal power will grow from 18 GW in 2015 to 133 GW in 2030 at a growth rate of 639%. The highest growth in clean energy sources is solar power, growing from 3 GW in 2015 to 9 GW by 2030. Wind power will also experience two-fold growth rate from 9 GW to 18 GW during this period. Although solar power and wind power may experience 2-3 times growth, their total net capacity will remain low in comparison with traditional energy types.

Table 5.6 Annual capacity additions in China under BAU (net; GW)

	2015	2020	2025	2030
Hydro	9	33	15	15
Coal	18	32	60	133
Nuclear	15	7	9	7
Wind	9	22	19	18
Natural Gas	6	6	12	11
Solar	3	4	10	9
Total	60	104	125	193

Table 5.7 illustrates total capacities of each type of energy source in five-year intervals. Coal power still catches readers' attention by having almost two-fold growth

during the planning period (from 904 GW in 2015 to 1557 GW in 2030), and by 2030, it will share 57% of the total capacity.

Despite this observation, solar power and wind power also share great growth in terms of percentages (12 times growth for solar power and 2.64 times growth for wind power). Moreover, the total capacities of these two types of energy sources are still pale in comparison with that of coal power. Nuclear power will also see three times growth from 50 GW to 150 GW, and hydropower, 2.03 times growth from 260 GW to 527 GW during the planning period 2015-2030.

Table 5.7 Capacities for each type of energy source in China (net; GW)

	2015	2020	2025	2030	2030%
Hydro	260	395	461	527	19%
Coal	904	1008	1229	1557	55%
Nuclear	50	80	118	150	5%
Wind	88	160	240	320	11%
Natural Gas	45	71	120	170	6%
Solar	10	40	80	120	4%
Total	1357	1754	2248	2844	100%

Table 5.8 shows the retired capacities of each type of energy source. Coal power and hydropower are the only two types of energy sources that have retired capacities. Coal power will have 10 GW retired capacities in 2015 and 62 GW of retired capacities in 2030. On the other hand, hydropower will only have 1-2 GW of retired capacities during these particular years.

Table 5.8 Retired capacities per year for each type of energy source in China (GW)

	2015	2020	2025	2030

Hydro	2	1	1	1
Coal	10	14	14	62
Nuclear	0	0	0	0
Wind	0	0	0	0
Natural Gas	0	0	0	0
Solar	0	0	0	0
Total	12	15	15	63

Table 5.9 looks at the contribution of energy consumption and provides information about the total energy consumption in 2015-2030 by energy source types. **Figure 5.4** shows the composition of each type of energy consumption in 2030. Supply from coal power, currently providing 70.44%, will increase from 3890 TWh in 2015 to 6630 TWh in 2030. By 2030, coal power will provide 67% of total electricity supply according to the BAU scenario.

Meanwhile, **Table 5.9** shows that the consumption of wind power will increase by 277% from 163 TWh in 2015 to 615 TWh in 2030. In 2030, wind power is expected to provide 6% of the total energy supply. The generation of solar power will increase 1,345% from 11 TWh in 2015 to 159 TWh in 2030, which by that year will provide 2% of the total energy supply. Hydropower supply will increase by 94.53% from 878 TWh in 2015 to 1,708 TWh in 2030, and it will be the largest contributor of clean energy by 2030, providing 16% of the total electricity generation. Since natural gas in China is associated with very high cost, its share will remain low during the planning period.

Table 5.9 Annual power generation in China under BAU scenario (TWh)

	2015	2020	2025	2030	2030%
Hydro	878	1231	1490	1708	13%
Coal	3890	4423	5301	6630	72%

Nuclear	291	527	781	1018	5%
Wind	163	289	454	615	5%
Natural Gas	22	116	310	405	4%
Solar	11	52	102	159	1%
Total	5233	6522	8128	10535	100%

The illustration of China's power generation during the planning period clearly shows that coal power stands as the dominant electricity supply near future. Under the BAU scenario, coal power is expected to have more than two-thirds of the total power capacity, as well as provide 72% of the total power generation. This status remains practically unchanged from the current structure of China's energy resource allocation. In order to achieve the low-carbon development in 2030, it is necessary for China to adopt a scenario with higher restrictions on coal power. Renewable energy sources under BAU will have a slightly larger portion of power generation. Wind power will have 5% of the total power generation. Solar power will have 1% of the total power generation. Hydropower will have 13% of the total power generation. Nuclear power will share 5% of total power generation.

5.1.3 Emission Volumes

Every scenario has its associated emission generation contribution. Emission volumes of each scenario are compared and analyzed in the later phases. As introduced in the methodology chapter, electricity generation emissions covered in this dissertation includes: CO_2, SO_2 and NOx. **Table 5.10** shows calculated emissions of these polluters

for 2015, 2020, 2025, and 2030 under the BAU scenario. From 2015 to 2030, as described in the table, emissions for the most significant GHG polluter, CO_2 increases from 3,112 million tons in 2015 to 5,304 billion tons in 2030. **Figure 5.1** shows the growth of CO_2 emissions. SO_2 and NOx are other important air plotters detrimentally affecting air quality in China and are also reported in Table 5.10.

Table 5.10 Power sector emission and pollution under the BAU scenario (million tons)

	2015	2020	2025	2030
CO_2	3,112	3,539	4,241	5,304
SO_2	22	26	27	28
NO_x	14	17	18	19

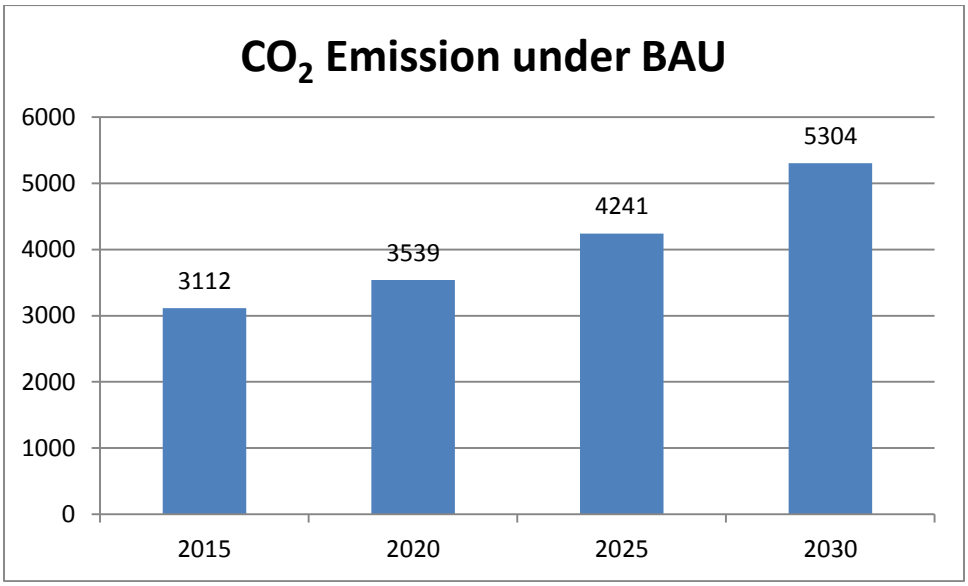

Figure 5.1 CO_2 emission under the BAU scenario in China (unit: million tons)

5.2 The HR Scenario

The HR scenario analysis assumes high incentives for clean energy but without integrating DSM technologies. However, this scenario targets optimization based on costs, emissions and pollutions, and clean energy developments in terms of both power capacity and power generation. The output results can be summarized in the following categories:

- Cost factors
- Capacity and energy factors
- Emission volumes
- Job creation

5.2.1 Cost Factors

The model provides an economically optimized outcome based on two constraints: environmental responsibilities and the encouragement of clean energy generation sources. The first restriction of this model is designed to be economically sound. In a market economy, low-carbon economy could enhance the response of market interactions only if such a scenario leads to better economic outcome for market participants (Liu, 2010). Meeting future electricity demand in China requires new investments. This section shall list the major types of investments under the HR scenario (e.g. annual total costs, initial costs, and O&M costs, which is a reference for the comparative analysis in the later stage).

First, the total cost of fulfilling the planning stage under the HR model is estimated to be $13,883 billion from 2011 to 2030. **Table 5.11** presents the total cost over the analysis years. As shown, the curve of total cost is expected to experience a smooth

increase until 2020 (grow from $268.19 billion in 2015 to $275.52 billion in 2020). Then, it will experience a decline rate until 2030 (from $275.52 billion in 2020 to $262.66 billion in 2030). The peak of total cost is projected to happen in 2020, and then it will fall slightly afterwards.

Table 5.11 Total costs in particular years in China (billions dollars)

	2015	2020	2025	2030
Annual total cost	268.19	275.52	251.12	262.66

Table 5.12 describes the initial investments for each type of energy. Under the BAU scenario, coal power will increase from $25.18 billion in 2015 to $34.27 billion in 2020, and then it will see a decline to zero from 2025 till 2030. Initial investment in nuclear power will experience a significant decline from $98.99 billion in 2015 to $16.83 billion in 2030 (68.26% decline). Investment in hydropower will decline by 25% in 2030 ($26.17 billion) in comparison with the 2015 level ($20.78 billion). The initial investment of solar power will experience a boost of 136% during the planning period, from $17.71 billion in 2015 to $27.84 billion in 2030. For wind power, the initial investment will decline from $24.20 billion to $17.21 billion during 2015 to 2030.

Table 5.12 Initial annual costs for each type of energy source in China (billion dollars)

	2015	2020	2025	2030
Hydro	20.78	73.86	31.37	26.17
Coal	25.18	34.27	0.00	0.00
Nuclear	98.99	22.74	0.00	16.83
Wind	24.20	40.52	29.25	17.21
Natural Gas	0.00	0.00	0.00	0.00
Solar	17.71	19.73	30.65	27.84

Total	186.86	191.13	91.27	78.05

Table 5.13 illustrates the variable cost for each type of energy source in the specific years. As shown in the table, it is clearly indicated that coal power will still share the largest component in China's electricity structure during the planning period. In 2015-2030, coal power's variable cost will increase from $142.68 billion to $216.04 billion. Hydropower has the highest variable cost among all other clean energy types. It has $8.30 billion in 2015, and it would gradually increase to $16.87 billion in 2030. Whereas wind power and solar power experience the highest growth, wind power would have $1.62 billion in 2015, and increase to $6.26 billion dollars in 2030. Solar power would grow from $810 million (or $0.81 billion) in 2015, and increase to $4.20 billion dollars in 2030. Furthermore, natural gas would have $2.91 billion in costs in 2015, and would reduce to $600 million (or $0.60 billion) in 2030.

Table 5.13 Variable costs for each type of energy source under HR (billion dollars)

	2015	2020	2025	2030
Hydro	8.30	12.16	14.72	16.87
Coal	142.68	162.36	189.02	216.04
Nuclear	0.99	2.42	3.19	4.68
Wind	1.62	3.46	5.43	6.26
Natural Gas	2.91	2.91	1.22	0.60
Solar	0.81	1.52	2.73	4.20
Total	157.32	184.82	216.30	248.64

5.2.2 Capacity and Energy Factors

An increase in electricity demand requires new capacity. The analysis conducted in this dissertation uses net amount of capacity to precisely demonstrate total capacity of a particular year, as well as the annual increases from capacity additions. This dissertation studies the potential of retired capacities of each type of energy source.

Table 5.14 shows the capacity additions of each type of energy source. The annual increasing capacity of coal power in China will decline from 21 GW in 2015 to zero GW in 2020. For nuclear power, China will have 27 GW of additional units in 2015, and new installations will decline in the subsequent years reaching 7 GW by 2030. Hydropower and wind power will see increasing growth in terms of capacity additions from 2015 to 2020, and then will gradually decline. Solar power capacity will experience constant annual growth from 3 GW in 2015 to 6 GW in 2030.

Table 5.14 Annual capacity additions in China under HR (net; GW)

	2015	2020	2025	2030
Hydro	8	32	16	15
Coal	21	34	0	0
Nuclear	27	7	0	7
Wind	9	17	14	4
Natural Gas	0	0	0	0
Solar	3	3	6	6
Total	67	93	36	33

Table 5.15 displays installed capacities for each type of energy source in five-year intervals. The most significantly growing power sources are solar, wind, and nuclear. Solar power has the highest growth rate, which will increase 382% from 17 GW

in 2015 to 82 GW in 2030. Wind power comes second with a 249% increase from 57 GW in 2015 to 199 GW in 2030. Nuclear power is expected to rise three-fold from 50 GW in 2015 to 150 GW in 2030. Meanwhile, coal power will have the growth rate of 76% during the planning period, from 1,001 GW in 2015 to 1,762 GW in 2030.

As illustrated in the HR scenario of 2030, the biggest power supplier in China still will be coal power (62% of the total energy supply), and the second biggest energy source will be hydropower (19% of the total energy supply). Wind power (7%) and solar power (3%) together can match the contribution of hydropower in 2030, which will be a great improvement for renewable energy sources.

Table 5.15 Installed capacities by energy source in China (net; GW)

	2015	2020	2025	2030	2030%
Hydro	260	395	461	527	19%
Coal	1001	1143	1829	1762	62%
Nuclear	50	80	101	150	5%
Wind	57	120	180	199	7%
Natural Gas	26	26	76	76	3%
Solar	17	30	55	82	3%
Total	1411	1796	2702	2797	100%

Table 5.16 shows power plant capacity retirements by energy source. The projection shows that a large number of coal power plants will retire from 2015 to 2030, and this number will increase at a fast pace. Along with coal power plant retirement, hydropower will experience 1-2 GW of power capacity retirement during this time period.

Table 5.16 Retired capacities per year for each type of energy source in China (GW)

	2015	2020	2025	2030
Hydro	2	1	1	1
Coal	10	14	14	62
Nuclear	0	0	0	0
Wind	0	0	0	0
Natural Gas	0	0	0	0
Solar	0	0	0	0
Total	12	15	15	63

As shown in the above sets of data illustrations, from 2015 to 2030, the most significant component in China's electricity sector is still coal power. Despite a declining trend in coal power's capacity growth, coal is still expected to be the largest power provider in China. Coal power is expected to be 1,001 GW in 2015, and it will be 1,762 GW in 2030, which is 62% of China's total energy capacity. On the other hand, coal also has the largest number of retirement capacities.

By studying the contribution of energy consumption, **Table 5.17** provides information on the total energy consumption over the time period of 2015-2030 by different types of energy source input.

Table 5.17 Total power generation per year in China under HR (TWh)

	2015	2020	2025	2030	2030%
Hydro	878	1287	1557	1785	19%
Coal	4314	4909	5716	6533	69%
Nuclear	105	256	338	495	5%
Wind	115	244	383	442	5%
Natural Gas	66	66	28	14	0.1%
Solar	40	74	133	205	2%
Total	5518	6837	8155	9473	100%

These results elucidate that the dominant force of power generation in China's near future under the HR scenario will be coal power, however, this scenario also enables significant occupancy of clean energy power generations. As shown in **Table 5.20**, China's coal power generation will be 6,533 TWh in 2030, and is expected to represent 69% of the total power generation in the country. Natural gas will continue to make very limited contribution to China's total power generation in the near future under this scenario since it is mainly used to adjust the peak load. Wind power will occupy 5% of the total power generation with solar power at 2%, hydropower at 19%, and nuclear power at 5% of the total power generation in 2030.

5.2.3 Emission Volumes

As introduced in the methodology chapter, GHG emissions as well as air pollutants in China are composed of three major sources: CO_2 emission, SO_2 emission and NOx emission. **Table 5.18** shows the GHG emissions and air pollutants for 2015, 2020, 2025, and 2030 under the HR scenario. **Figure 5.2** displays the growth of CO_2 emission in a bar chart to highlight the growth of CO_2 emissions.

Table 5.18 GHG emission and air pollutions for the HR scenario (billion tons)

	2015	2020	2025	2030
CO_2	3109	3481	4006	5181
SO_2	22	26	27	28
NOx	14	17	18	19

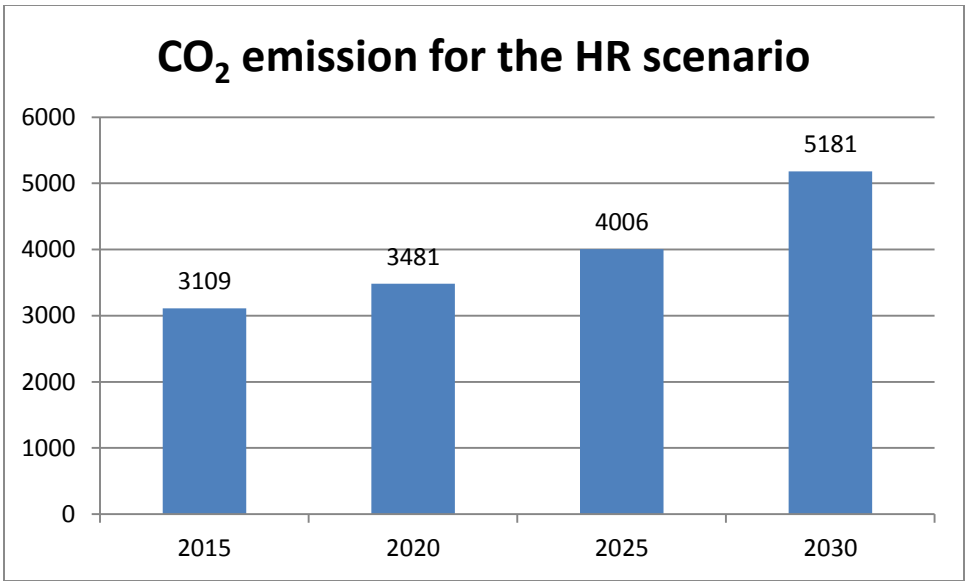

Figure 5.2 CO_2 emission for China's HR scenario (in billion tons)

From 2015 to 2030, CO_2 emissions will steadily increase 40.65% from 4,032 billion tons in 2015 to 5,671 billion tons in 2030. During this period, SO_2 emissions will increase from 22 billion tons to 28 billion tons at a growth rate of 27.27%, while NOx emissions will rise from 14 billion tons to 19 billion tons at a growth rate of 35.71%.

Thus, it becomes evident that under the HR scenario, CO_2 emissions account for the largest penetration of emissions and pollutions. CO_2 also has the highest growth rate according to the results of this analysis. It is urgent, yet necessary for the NDRC to regulate the associated emitting activities from China's electricity industry as a whole. Moreover, the future emission level of CO_2 should be a more specific concern for China.

5.2.4 Job Creation

According to the calculation (same method used in the BAU scenario), the total number of jobs created under the HR scenario is 64,638,413 direct job years. Thus,

readers can conclude that total job years as 193,915,239 based on the 300% multiplier suggested by Rutovitz & Harris (2012). Since Green Peace (2012) illustrates China's regional factor in three phases, 2011-2015, 2016-2020, and 2021-2030, this dissertation shall also separately investigate job creation of the three different phases, and then sum up their respective job creations after utilizing the regional factors of each phase. Detailed job creation for each type of energy resource can be found in the tables below.

Table 5.19 depicts direct job creation in 2011-2015. One can conclude that coal power plants in China can contribute to 20,770,345 direct job years, and hydropower can contribute to 2,493,226 direct job years. The total amount of job creation of coal power is higher than that of the sum of all other energy resources. The highest direct job creation in renewable energy is wind power, with 1,211,906 direct job years, and solar power can create 512,218 direct job years.

Table 5.19 Direct job years created in China under the HR scenario in 2011-2015

Energy Type	Power capacity accumulations (MW)	Power generation accumulations (GWh)	Job years
Hydro	51000	4094	2,493,226
Coal	481000	19545	20,770,345
Nuclear	39000	850	1,328,403
Wind	59000	587	1,211,906
Natural Gas	19000	476	110,431
Solar	10000	29	512,218

Data Source: Green Peace, 2012 and Rutovitz & Harris, 2012

Reading into **Table 5.20,** which describes direct job creation in 2016-2020, one can conclude that coal power plants in China can contribute to 8,551,752 direct job years,

and hydropower can contribute to 5,607,215 direct job years. The total amount of job creation of coal power is still the highest among all other energy resources, but it is much smaller comparing with that in 2011-2015. The highest direct job creation in renewable energy is solar power with 1,241,158 direct job years. Also, wind power can create 1,194,562 direct job years.

Table 5.20 Direct job years created in China under the HR scenario in 2016-2020

Energy Type	Power capacity accumulations (MW)	Power generation accumulations (GWh)	Job years
Hydro	142000	5329	5,607,215
Coal	245000	25430	8,551,752
Nuclear	30000	2234	825,389
Wind	72000	1150	1,194,562
Natural Gas	26000	979	122,183
Solar	30000	176	1,241,158

Data Source: Green Peace, 2012 and Rutovitz & Harris, 2012

Table 5.21 shows direct job creation in 2021-2030. Coal power plants in China can contribute to 9,578,242 direct job years and hydropower can contribute to 4,174,930 direct job years. From 2016-2020, the total amount of jobs created by coal power is still the highest among all other energy resources, but much smaller than that in the 2011-2015 phase. For renewable energy sources, they are approximately experiencing a 200% increase as compared with that in the 2016-2020 period. The highest direct job creation in renewable energy is wind power with 2,844,167 direct job years, and solar power at 2,364,126 direct job years.

Table 5.21 Direct job years created in China under the HR scenario in 2021-2030

Energy Type	Power capacity accumulations (MW)	Power generation accumulations (GWh)	Job years
Hydro	148000	15109	4,174,930
Coal	384000	54204	9,578,242
Nuclear	70000	7996	1,375,627
Wind	240000	5976	2,844,167
Natural Gas	99000	4422	332,531
Solar	80000	1211	2,364,126

Data Source: Green Peace, 2012 and Rutovitz & Harris, 2012

5.3 The RD Scenario

This section presents the results from the RD scenario analysis. Both the RD and HR scenarios are optimized scenarios, however, the key difference between the RD and HR scenarios is optimization in the HR scenario excludes considering DSM implementations. Conversely, the RD scenario engages inclusively the cost-benefit analysis of energy efficiency via DSM technologies as power generators. Using the same indicators as in the HR scenario, namely, cost factors, capacity and energy factors, emission factors, and job creation, the analysis below provides the detailed outcome of the RD scenario. Same as the HR scenario, the RD scenario separately investigates job creation under the three different phases, and then sums up job creation values after utilizing the regional factors for each phase.

As introduced in the methodology, one of the most significant advantages of IRSP is the engagement of DSM options. According to Liu (2012), most of the electricity planning tools were developed by power producers, hence, these tools are primarily

focusing on the power supply for meeting power demand. Meanwhile, power regulators in China have, in recent years, aimed to regulate power supply as well as power demand (State Council, 2012). Thus, in order to utilize energy efficiency on the demand side, DSM technologies should be included in the electricity planning process.

5.3.1 Cost Factors

According to Liu and Li (2009), electricity sector's capital structure in China's composed of 49.14% funds coming from the debt financing from the China Development Bank, 33.15% from the funds raised through Initial Public Offering (IPO), and 17.71% from the retained revenues from electricity sales. For a long time, Power generation companies in China were providing low-cost electricity through coal. China has a large amount of coal mines in its western and central areas. The cost of converting the coal resource to electricity is lower in comparison to that of utilizing other energy sources.

Accordingly, environmental conditions and air quality were sacrificed, since coal power plants usually produce high levels of CO_2, SO_2 and NOx pollutions compared to other alternatives. The effectiveness of energy investment is a high priority for China's electricity regulators. The literature review chapter indicates that DSM technologies require less maintenance costs, so variable costs of these DSM technologies are less significant than other energy types. Hence, it is important to include DSM technologies in the analysis in order to find out the most optimized solution.

China's electricity regulators promised to increase the share of clean energy in the total resource consumption for electricity generation, but the more immediate question to be asked is: how the country will reduce the costs of meeting energy demand, while simultaneously meeting social-environmental requirements (State Council of China, 2012)? The analytical perspectives below answer the financial concerns of improving China's clean energy penetration:

- Annual total costs
- Initial costs
- Variable costs

According to the model output, the cumulative total costs from 2011 to 2030, is projected to be $14,773 billion under the RD scenario. Salvage values have been deducted. To begin with, **Table 5.22** presents the total cost and subsidies in 2015, 2020, 2025 and 2030, while **Table 5.23** shows the variable cost for each type of energy source in those years.

As illustrated in **Table 5.22**, the total required amount of investment in the RD scenario will be $257.44 billion in 2015, then it would gradually decline during the planning period, and by 2030 it will have reduced to $223.14 billion.

Table 5.22 Annual costs in China under the RD scenario (billion dollars)

	2015	2020	2025	2030
Annual Cost	257.44	256.01	238.33	223.14

As shown in **Table 5.26**, the initial cost would experience a declining trend from 2015 to 2030. The decline of increasing initial investments means a slower development

of a particular power plant. Solar power will experience the highest increase of 57.2% from $17.71 billion to $27.84 billion. Wind power will experience a decrease of 28.89% from $24.20 billion to $17.21 billion. Hydropower will experience an increase of 25.94% from $20.78 billion to $26.17 billion. The initial cost of coal power over these years will experience a decrease from $10.19 billion dollars to zero. Most of the EPP cost of capacities will generally experience small increases, though they are insignificant in comparison with other forms of power capacities. Demand response would experience a boost from $0.35 billion to $12.53 billion during the planning period.

Table 5.23 Initial costs for each type of energy source under RD (billion dollars)

	2015	2020	2025	2030
Hydro	20.78	73.86	31.37	26.17
Coal	10.19	2.49	0.00	0.00
Nuclear	98.99	22.74	0.00	16.83
Wind	24.20	40.52	29.25	17.21
Natural Gas	0.00	0.00	0.00	0.00
Solar	17.71	19.73	30.65	27.84
Lamp EPP	0.12	0.42	1.37	4.16
Motor EPP	0.06	0.15	0.38	1.02
Transformer EPP	0.01	0.01	0.01	0.01
VFD EPP	0.06	0.15	0.38	1.04
Ice Storage EPP	0.03	0.08	0.00	0.00
Other Residential EPP	0.10	0.26	0.00	0.00
Demand Response	0.35	1.29	4.10	12.53
Total	172.62	161.69	97.51	96.81

In terms of variable costs, the result of this dissertation illustrates a growing trend in all types of energy sources, including both traditional and clean, along with efficiency measures (see **Table 5.24**). Demand Response clearly has the highest growth rate in terms of operational investment. This growth is due to the maturity of innovative

technologies that gives Demand Response a high market demand. This pattern parallels the policy analysis that was stated in the literature review chapter.

In contrast, under the effective policy regulation of the 12th FYP, the variable cost of coal power will gradually increase from $140.52 billion to $156.57 billion during the planning period. The variable cost of hydropower will increase from $8.30 billion to $16.87 billion. The variable cost of natural gas power will stay the same at $2.91 billion, while the variable costs of wind and solar power will experience a significant increase of 2.86 times and 3.39 times, respectively. Wind power will grow from $1.62 billion to $6.26 billion, and solar power will grow from $0.81 billion to $4.20 billion. Nuclear power would also increase from $0.99 billion to $4.68 billion.

Table 5.24 Variable costs for each type of energy source under RD (billion dollars)

	2015	2020	2025	2030
Hydro	8.30	12.16	14.72	16.87
Coal	140.52	155.80	168.29	156.57
Nuclear	0.99	2.42	3.21	4.68
Wind	1.62	3.46	5.43	6.26
Natural Gas	2.91	2.91	2.91	2.91
Solar	0.81	1.52	2.73	4.20
Lamp EPP	0.00	0.00	0.00	0.00
Motor EPP	0.00	0.00	0.00	0.00
Transformer EPP	0.00	0.00	0.00	0.00
VFD EPP	0.00	0.00	0.00	0.00
Ice Storage EPP	0.00	0.00	0.00	0.00
Other Residential EPP	0.00	0.00	0.00	0.00
Demand Response	0.00	0.00	0.00	0.00
Total	155.17	178.27	197.29	199.49

5.3.2 Capacity and Energy Factors

The RD scenario investigates the indicators of each type of power plant separately. These include annually increasing capacities, total capacities, retired capacities, and energy consumptions. In the RD scenario, the EPP category is included, which not only increases energy diversity, but also effectively contributes to power generation through less CO_2 emissions.

The result of the RD scenario shows that China's coal power in 2030 is project to be 876 GW, which will be 30% of China's total power capacity. It is still a significant percentage in total power capacity, however, it is comparatively much less than the share of 70% in 2010. Wind and solar capacities will experience a great take-off in this period. In 2030, wind capacity will grow to 199 GW (7% of the total power capacity) and solar capacity will be 82 GW (3% of the total capacity).

The performances of hydro and nuclear power are similar with that of the HR scenario's 527 GW of hydropower and 150 GW of nuclear power in 2030. Hydropower will be the second biggest source of power generation with 1,785 TWh. Other types of clean energy sources, such as wind power and solar power will increase rapidly during the planning period, though their penetrations are still small.

Coal power will continue to play a key role in power generation until 2030, but it shows a gradually declining trend. In 2030, China's coal power generation will be 4,735 TWh, which is 9% (977TWh) lower than that in the HR scenario. DSM technologies are also experiencing high growths in terms of both power capacity and power generation. Some types of the DSM technologies are easily market compatible, especially Lighting

EPP (1,117 TWh in 2030), and Demand Response (DR, 507.6 TWh in 2030). Power generation in China shows a similar trend as the capacity distribution.

Table 5.25 shows the total capacities per year for each type of power plant. As demonstrated, the power capacity distribution in 2030 is expected to be: 30% coal power, 18% hydropower, 7% wind power, 3% solar power, and 1% natural gas. It is great to see the penetration of coal power capacity decline from 70% in 2010 to 30% in 2030 with the gap being filled by renewable energy sources.

Table 5.25 Total capacities per year for each type of energy source under RD (net, GW)

	2015	2020	2025	2030	2030%
Hydro	260	395	461	527	18%
Coal	948	985	943	876	30%
Nuclear	50	80	100	150	5%
Wind	57	120	180	199	7%
Natural Gas	26	26	26	26	1%
Solar	17	30	55	82	3%
Lamp EPP	5	14	43	130	2%
Motor EPP	5	16	49	146	0
Transformer EPP	4	5	6	8	0
VFD EPP	5	14	43	130	0
Ice Storage EPP	5	14	18	9	0
Other Residential EPP	3	9	12	6	0
Demand Response	25	75	224	672	22%
Total	1410	1785	2160	2961	100%

Table 5.26 shows the projected amount of power consumption of different energy types in these four particular years (2015, 2020, 2025, and 2030). Similar with the capacity perspective, coal power will continue to play a key role in power generation in

2030. China's coal power generation will be 4,735 TWh in 2030, and will provide 50% of China's total power generation. This number is by 9% (977 TWh) lower than that in the HR scenario. Hydropower will be the second biggest source of contribution with 1,785 TWh, or 19% of the total generation in 2030. Nuclear (495 TWh), wind (442 TWh) and solar power (205 TWh) will also be significant contributors to China's total power generation in 2030, they will provide 5%, 5% and 2% of the total power generation, respectively.

Reading into the development of DSM technologies, the share of lighting EPP (1,117 TWh) will be 11% of the total power generation by 2030. This growth represents a great success in the development of DSM technologies. Demand Response (506 TWh) will occupy 5% of China's total power generation by 2030. DSM technologies are significant in China's 2030 total power generation mix. They have shown great potential in the near 20 years of China's electricity industry.

Table 5.26 Total power generation for each type of energy source under RD (TWh)

	2015	2020	2025	2030	2030%
Hydro	878	1287	1557	1785	19%
Coal	4249	4711	5089	4735	50%
Nuclear	105	256	340	495	5%
Wind	115	244	383	442	5%
Natural Gas	66	66	66	66	1%
Solar	40	74	133	205	2%
Lamp EPP	39.9	124.1	372.3	1117.0	11%
Motor EPP	1.6	5.0	15.1	45.4	0%
Transformer EPP	2.2	2.6	3.1	3.7	0%
VFD EPP	2.5	7.8	23.3	69.8	0%
Ice Storage EPP	0.0	0.0	0.0	0.0	0%
Other Residential EPP	0.7	2.3	3.6	2.0	0%

Demand Response	18.1	56.4	169.2	507.6	5%
Total	5518	6837	8155	9473	100%

Table 5.27 clearly shows the annual installed capacities of each type of power plant. The table shows that some types of power plants will experience a significant rate of capacity growth such as natural gas and EPPs, while some types of power plants will experience a declining rate of capacity growth, like coal power.

Table 5.27 Annual capacity additions in China under RD (net, GW)

	2015	2020	2025	2030
Hydro	8	32	16	15
Coal	9	2	0	0
Nuclear	27	7	0	7
Wind	9	17	14	4
Natural Gas	0	0	0	0
Solar	3	3	6	6
Lamp EPP	2	7	23	71
Motor EPP	1	3	10	30
Transformer EPP	0	0	0	0
VFD EPP	1	3	9	27
Ice Storage EPP	1	3	0	0
Other Residential EPP	1	2	0	0
Demand Response	19	69	218	666
Total	80	148	295	827

The annual increased capacity of coal power will decline from 9 GW in 2015 to zero in 2030. Solar power's annual capacity installation will increase from 3 GW in 2015 to 6 GW in 2030. Furthermore, hydropower and wind power will experience very rapid growth until 2020, then their growth rate will slow down through 2030. The annual capacity additions of hydro power will increase from 8 GW in 2015 to 32 GW in 2020, then it will decrease to 15 GW in 2030. The annual capacity additions of wind power will increase from 9 GW in 2015 to 17 GW in 2020, and then it will be 4 GW in 2030.

Table 5.28 Retired capacities per year for each type of energy source under RD (GW)

	2015	2020	2025	2030
Hydro	2	1	1	1
Coal	10	14	34	62
Nuclear	0	0	0	0
Wind	0	0	0	0
Natural Gas	0	0	0	0
Solar	0	0	0	0
Lamp EPP	2	10	10	22
Motor EPP	0	0	0	2
Transformer EPP	0	0	0	0
VFD EPP	0	0	0	2
Ice Storage EPP	0	0	1	2
Other Residential EPP	0	0	1	6
Demand Response	19	56	174	533

Furthermore, the retirement capacity for coal power is expected to be 10 GW in 2015, 14 GW in 2020, 34 GW in 2025, and 62 GW in 2030. When comparing the retirement capacities and increased capacities, China's power regulators, especially the NDRC and the SGCC should be glad to see that coal power has a larger number of retired capacities (62 GW) than increased capacity (58 GW) in 2030. This is the outcome for achieving environmental sustainability by enabling more potential for clean energy sources. The result of the RD scenario closely matches the planning result of NDRC policy, which calls for the closing down of all medium and small size (power capacity under 10,000 kW), un-efficient coal power plants. Moreover, the biggest retirement capacity is expected to be Demand Response (533 GW) in 2030, followed by the retirement of coal power (62 GW), and finally, lamp EPP (22 GW) as the third best performer.

5.3.3 Emission Volumes

As stated in the methodology, the core objective of utilizing the IRSP model is to seek the most optimized path for China's electricity industry to implement low-carbon and low-pollution sustainable development. Thus, the capability of realizing an environmentally sound outcome is one of the most important components of the optimization model design.

Table 5.29 shows the projected emission levels for CO_2, SO_2 and NO_x for 2015, 2020, 2025 and 2030. **Figure 5.3** demonstrates the growth of CO_2, SO_2 and NO_x emissions under the RD scenario in these particular years.

In the previous sections, it is confirmed that the HR scenario is environmentally more effective than that of the BAU scenario. Comparing the HR scenario with that of the RD shows even further growth in effectiveness. The HR scenario predicts a total CO_2 emission of 5,197 billion tons. According to the RD scenario, China's CO_2 emissions are projected to fall another 610 billion tons in 2030 to a total of 4,587 billion tons.

Table 5.29 Emission and pollutants for the RD scenario (in billion tons)

	2015	2020	2025	2030
CO_2	2971	3130	3658	4587
SO_2	21	24	25	24
NOx	13	14	17	17

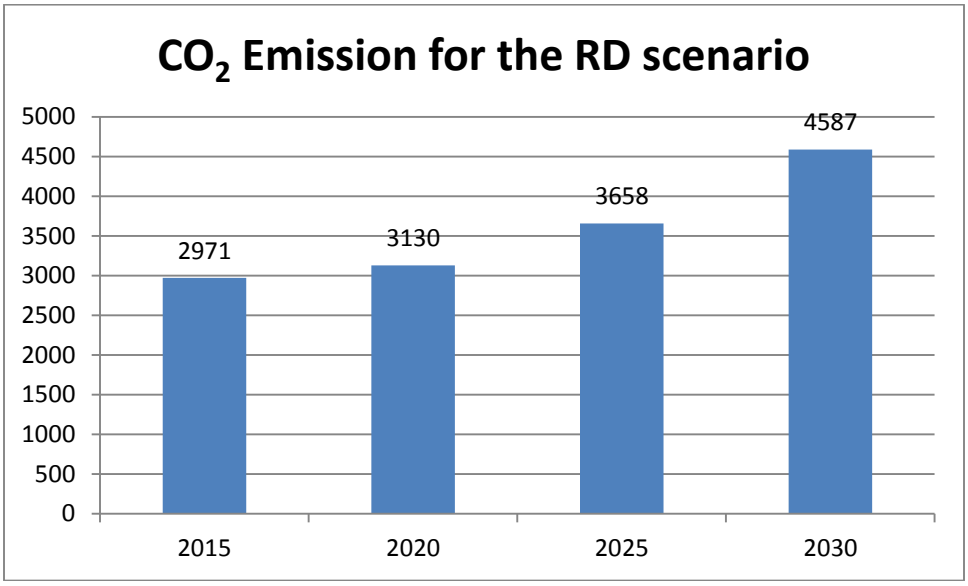

Figure 5.3 CO_2 emission for the RD scenario in China (billion tons)

Additionally, in 2030, the reduced SO_2 emissions under the RD scenario (total SO_2 emission of 24 billion tons) are expected to be 4 billion tons lower than that of the HR scenario (total SO_2 emission of 28 billion tons), and there will be 2 billion tons less NO_x emission reduction in the RD scenario (total NO_x emission of 17 billion tons) than that of the HR scenario (total NO_x emission of 19 billion tons). As a result, RD scenario is the most environmentally friendly scenario of the three during the planning period.

5.3.4 Job creation

According to the JC model, the direct job creation under the RD scenario is 95,358,167 job years. Readers can conclude that total job creation (including direct, indirect, and induced jobs) is approximately 286,074,500 job years based on the

suggested 300% multiplier by Rutovitz & Harris (2012). A detailed account of three phases for each type of energy resources can be found in the tables below.

As illustrated in **Table 5.30**, which describes direct job creation from 2011-2015, coal power in China can contribute to 14,855,771 direct job years, which is higher than that of the sum of all other energy resources. Hydropower also has a very high direct job creation of 2,493,226. The highest direct job creation in clean energy is wind power with 1,211,906 direct job years. Nuclear power can directly create 1,211,906 job years. Solar power has 512,218 direct job years. Regarding DSM sections, efficiency lights could create 946,459 job years and efficiency transformers could create 473,230 jobs.

Table 5.30 Direct job years created under the RD scenario in China in 2011-2015

Energy Type	Power capacity accumulations (MW)	Power generation accumulations (GWh)	Job years
Hydro	51000	4094	2,493,226
Coal	344000	19285	14,855,771
Nuclear	39000	850	1,328,403
Wind	59000	587	1,211,906
Natural Gas	19000	476	110,417
Solar	10000	29	512,218
Lamp EPP	28000	246	946,459
Motor EPP	10000	2.7	338,021
Transformer EPP	14000	0	473,230
VFD EPP	6000	2.9	202,812
Ice Storage EPP	4000	0	135,208
Other Residential EPP	4000	2.3	135,209

Data Source: Green Peace, 2012 and Rutovitz & Harris, 2012

Reading into the 2016-2020 direct job creation (**Table 5.31**), the RD scenario enables higher job creation from hydropower than that from coal power. Coal power in

China can contribute to 4,716,372 direct job years, and hydropower has even higher direct job creation of 5,607,215. The highest direct job creation in renewable energy is solar power with 1,241,158 direct job years. Wind power has 1,194,562 direct job years. Nuclear power can directly create 825,389 job years. Regarding DSM sections, efficiency lights could create 1,447,037 job years, and efficiency motors could create 546,050 job years during this period.

Table 5.31 Direct job years created in China under the RD scenario in 2016-2020

Energy Type	Power capacity accumulations (MW)	Power generation accumulations (GWh)	Job years
Hydro	142000	5329	5,607,215
Coal	135000	23796	4,716,372
Nuclear	30000	2234	825,389
Wind	72000	1150	1,194,562
Natural Gas	26000	979	122,195
Solar	30000	176	1,241,158
Lamp EPP	53000	1523	1,447,037
Motor EPP	20000	23	546,050
Transformer EPP	16000	0	436,850
VFD EPP	14000	34	382,234
Ice Storage EPP	6000	0	163,817
Other Residential EPP	16000	14	436,834

Data Source: Green Peace, 2012 and Rutovitz & Harris, 2012

The table of direct job creation in 2021-2030 shows a similar situation as that in 2016-2020 (see **Table 5.32**). That is, coal power is no longer the most active energy resource, yet it can create 3,774,759 direct job years. Hydropower can create 4,174,930 direct job years, which is the highest job creator during this time period. Meanwhile, wind power can create 2,844,167 direct job years, which is the highest job generator

among renewable energy resources. Solar and nuclear job creation are also high at 2,364,126 direct job years for solar and 1,375,627 direct job years for nuclear. DSM can also create a large number of direct job years during this period, and efficiency lights could create 3,217,796 direct job years, as well as other residential appliances possibly creating 1,657,620 direct job years.

Table 5.32 Induced job creation of the RD scenario

Energy Type	Power capacity accumulations (MW)	Power generation accumulations (GWh)	Job years
Hydro	148000	15109	4,174,930
Coal	151000	48524	3,774,759
Nuclear	70000	7996	1,375,627
Wind	240000	5917	2,844,167
Natural Gas	99000	4398	332,531
Solar	80000	1211	2,364,126
Lamp EPP	165000	4518	3,217,796
Motor EPP	40000	150	780,084
Transformer EPP	25000	0	487,566
VFD EPP	66000	263	1,287,103
Ice Storage EPP	18000	0	351,033
Other Residential EPP	85000	124	1,657,620

Data Source: Green Peace, 2012 and Rutovitz & Harris, 2012

5.4 Comparative Research of BAU, HR and RD Scenario Outputs

This dissertation has conducted an analysis of three individual scenarios: BAU, HR and RD. This section compares the advantages and disadvantages in terms of China's long term electricity planning procedure. The purpose is to study the changes of variables under different policy incentives. Each variable is investigated by comparing the value through different regulatory scenarios. The analysis consists of the following variables:

- Total annual costs
- Emission volumes
- Equity achievement

5.4.1 Total Costs

As stated in **Table 5.33**, the first issue to investigate is the economic cost difference between the BAU, HR and RD scenarios from 2011 to 2030. These economic costs were derived from optimized outcomes according to the IRSP model.

Table 5.33 Total costs under the BAU, HR and RD scenarios from 2011 to 2030

	BAU	HR	RD
Total cost[12] (billion USD)	7,553.56	8,574.33	7,979.20

As seen from the table above, the BAU scenario has the lowest total cost of $7,553.56 billion, whilst the HR scenario has the highest total cost of $8,574.33 billion. The RD scenario sits in the middle between BAU and HR scenarios at $7,979.20 billion. Although the BAU scenario seems to have the lowest cost, due to the economic externalities discussed in the previous chapters, the BAU scenario is the least feasible planning scenario for China's sustainable environment future. Instead, it is recommended to implement an alternative scenario, either the HR scenario or the RD scenario.

[12] Note: this is the cumulative total cost based on 2015 price.

Looking at the HR and RD scenarios, the cost of implementing the RD scenario is substantially lower than that of the HR scenario due to the contribution of DSM technologies. DSM technologies successfully reduce the amount of power plants needed, and the construction and variable costs that come with it. On the other hand, the HR scenario provides the maximum amount of electricity supply through renewable energy sources, but fails to consider energy efficiency solutions from the power demand side. Thus, from the perspective of total costs, the RD scenario is the better alternative than the HR scenario.

5.4.2 Emission Volumes

The two previous sections looked at three scenarios from the financial perspective, as well as the power generation perspective. In order to gain a reliable and comprehensive result of the planning achievement, it is also important to investigate the scenarios from the perspective of emissions volumes.

Equity analysis is more focused on qualitative research in comparison with the previously discussed quantitative analytical sections. This section aims to find a connection between quantitative and qualitative analysis for studying the achievements of the equity element. For the BAU scenario, the CO_2 emission level is expected to be 5,304 billion tons. As stated in the previous chapter, the evaluation of equity achievement is dependent on the scales.

The emission volume of 5,304 billion tons under the BAU scenario fits in the category between 5 billion tons and 5.5 billion tons, which is the medium level of equity achievement.

In the HR scenario, the carbon emission level is expected to be 5,181 billion tons. As stated in the previous chapter, the evaluation of equity achievement is dependent on the scales, and thus, the emission level of 5,181 billion tons can be place at a medium level of equity achievement, which yields similar result as that of the BAU scenario. A more comprehensive comparison of the equity issue will be presented in later sections.

The IRSP model was set to realize an optimized solution in terms of power plant investment and emission reduction. The output of the IRSP model gives two sets of data: a locally optimized result without DSM implementation, and a globally optimized result with DSM implementation. The terms ‘local’ and ‘global’ are derived from the GAMS programming commands (they are commonly used codes in the SQL programmable language). Local optimization means mathematically achieving the most cost-effective solution when part of the program structure is outside consideration. Global optimization demonstrates the most cost-effective result considering the balance of the entire structure.

The analysis of this dissertation shall only focus on the CO_2 index. The IRSP model calculates the changes of emissions volume in the years of 2015, 2020, 2025 and 2030 for the BAU, HR and RD scenarios. **Figure 5.4** illustrates the growth trend of CO_2 emission from 2015 to 2030.

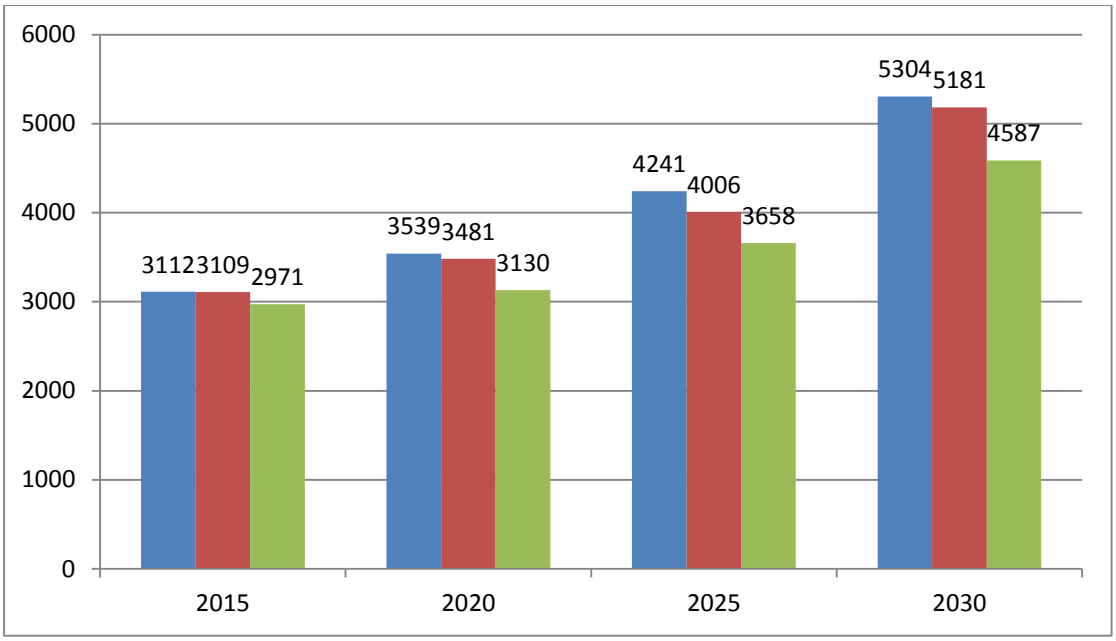

Figure 5.4 CO_2 emission growing trend from 2015 to 2030 in China

(Blue: BAU scenario, Orange: HR scenario, Grey: RD scenario)

According to **Figure 5.4**, CO_2 emissions for all scenarios will experience increasing trends in these particular years from 2015 until 2030. The BAU scenario has the highest amount of CO_2 emissions in comparison with the other two scenarios. As shown in the figure, the emissions volumes of the RD scenario are much lower than that of the HR scenario. Between 2015 and 2030, the CO_2 emissions of the HR scenario increase by 41.2%, whereas that of the RD scenario increases by 29.8%. Under the RD scenario, the level of CO_2 emissions is 12.1% lower in 2030 than that of the HR scenario.

From the perspective of emissions and pollutants, the outcome of this analysis closely matches the hypothesis that the RD scenario emits the least, followed by the HR scenario, and then the BAU scenario respectively. A key reason that the RD scenario can

achieve this objective is due to the high penetration of DSM technologies, which effectively brings down the total electricity demand during the planning period.

In the RD scenario, the CO_2 emission level is expected to be 4,587 billion tons. As stated in the previous chapter, the evaluation of equity achievement depends on the scale. So, the emission level of 4,587 billion tons fits within the high level of equity achievement category, which is the only scenario that achieves the high level among the three scenarios. This result closely matches with our hypothesis that the RD scenario is the most effective scenario, and it could help China's 2030 development planning to be more sustainable.

5.5 Equity Impact

The equity dimension is an illustration of humanity during the planning procedure. It is vital to categorize the determinants of equity levels (low, medium, and high) by studying the environmental impacts of CO_2 emissions. The dissertation also includes wind and solar power in terms of developing rural China's electricity accessibility. This is a part of the equity dimension.

Energy demand in China has long been associated with urbanization (Malyshev, 2009; Markandya and Halsnaes, 2002). While the east coast of China is experiencing a rapid growth of electricity consumption, communities in the inland regions are still suffering from lack of electricity access (Chen, 2002). This dissertation finds it essential

to deliver research on rural/urban equity influence from the perspective of energy planning.

In Wang (2000), major equity issues refer to the social and political concerns that are closely connected with energy supplies. One of the most important chapters in the 12th FYP is to enable China to initiate a social economic transformation (China Social Science Academy, 2012). Since China's open-up policy was introduced in 1978, Deng Xiaoping's target was economic development. Since then, the Chinese government's primary focus has been economic development. This singular focus persisted until the 11th FYP, when the Chinese government realized that economic growth should not be the only purpose of China's national development agenda. Social development is equally important to achieve the goal of a harmonious society (Li and Oberheitmann, 2009; Liu and et al, 2013). Detailed policies and regulations to create a harmonious society in China match the principles of the E4 model (Wang, 2000). As a result, the element of equity should be highlighted, since it has been long ignored in China, and this element is actually what China would need to enhance.

In Wang's (2000) E4 model, the equity element indicates several layers of priority of clean energy sources. Accordingly, wind power and solar power are favorable types for sustaining society. These types of power are clean, sustainable, feasible, and capable of mass implementation, and have the smallest effect on the local community. Once again, China is also facing a transition period for its energy structure (Liu, 2013). The detailed introduction about the advantages of wind and solar power and their acceptance in China's power industry can be seen in the literature review.

Hydropower is the second layer of clean energy priority. It is also clean, sustainable and feasible; however, building a large scale hydro dam (more than 500 MW) could cause unexpected environmental side-effects such as changing local ecological conditions. The Three Gorges Dam in Southern China is the largest dam in the world. Policies and regulations restricting dam size were not properly structured when the Three Gorges Dam was approved (China Social Science Academy, 2012).

However, as explained in the literature review, China has posted a new hydropower restriction limiting the development of large scale dams in the 12th FYP. Moreover, building a large scale dam causes relocations of local communities. Its impact is not only on the residents themselves, but the embedded historical culture of the community becomes entirely removed from the original landscape.

The third layer of priorities is nuclear power (Wang, 2000). Nuclear power is also emission free. However, nuclear power contains high risks of operation, as well as great concerns of nuclear waste treatments. Most countries in Europe have very comprehensive regulation frameworks for nuclear power plant management. The approval process for installing a new nuclear power plant is much more complex than that in China. Electricity regulation in China should be more conservative in terms of nuclear power's contribution to its 2030 clean energy scenario.

The least encouraged energy sources are the traditional methods of energy supply, like coal power. This resource is dominating China's power generation due to its massive supply. It has long been economically and technologically feasible for a country like China. However, the country is gradually realizing the externalities of using coal power

to support its development. During the 11th FYP, China started to focus on economic transformation. A very important chapter of the 11th FYP plan entailed a transition in future energy supply from conventional energy resources to clean energy resources.

China is the biggest global energy consumer. Energy consumption for electricity supply is a major focus of China's economic transformation. It is generally agreed that traditional forms of social structure are more suitable for the traditional energy mix (Fang and Zhang, 2007; Farrington and Clarke, 2006). To some degree, the traditional social structure is incompatible with the new era of clean energy power generation. Associated social transformations are also facing severe challenges for China (China Social Science Academy, 2012). Wang (2010), Lu (2009), and Pan (2010) argue that hydropower usually causes the most comprehensive equity challenges. The first topic in the equity element would be studying the impacts of hydropower. Urban and rural unequal development is another social problem during the transition.

In many developing countries, electricity planning is seen as a great tool to help less developed regions transition from rural communities to modern life (Adams, 2003). In China, NDRC has long been working on the 'last mile program', which builds extra miles of electric wires from major gird networks to local rural communities (Shan, 2013).

Before clean energy becomes the norm for powering rural communities, power generations on the supply side have been typically fueled by coal. Constructing extra miles of electric lines to the rural community where utility consumption is lower in than major cities usually ends in longer pay back periods (Ju and et al, 2013; Kanagawa and et al, 2008). Calling upon the policy requirement from the NDRC, the State Grid has

voluntarily paid a large amount of construction cost to support rural electrification in the last 30 years (Yadoo and Cruickshank, 2012).

However, the high cost of supporting rural electricity program would come down when clean energy is introduced as a new form of power generation. Clean energy is a great contributor to a more balanced structure of urban and rural development. It is evident that most wind farms, solar power plants and hydro dams are located in western China where neighborhoods are less developed (Shan, 2013). As a result, constructing extra miles of electric wires are not necessary. Wind and solar power can generate electricity in the community where power is scarce without connections to the national ultra-high voltage grid network. This method also avoids line losses over long distance power delivery.

Wind farms can be directly located on sites where electricity is needed, and in smaller scale communities, solar panels can be placed on the rooftop of each individual building (Laumanns and et al, 2004). Enormous benefits are delivered to the local residents. For those un-electrified communities, it provides access to modern life and equal opportunity to achieve a higher standard of living. The costs of operating wind power and solar power are also affordable for most rural communities (Shan, 2013). Once the devices are installed, maintenance is only required from the fifth year of operation, and each year the price is substantially lower.

The financial costs of constructing transforming stations and mapping wires can thus be largely reduced. The principle of a low-carbon economy, as emphasized in the first chapter, is to accomplish the win-win business solution of reducing carbon emissions

during electricity delivery and not increasing the financial burden on the economy. On the one hand, the development of clean energy is also a win-win solution in achieving urban/rural development, and on the other, this method does not require a large amount of financial investment in comparison with traditional energy types.

The IRSP model has already quantitatively demonstrated the economic advantages of clean energy development. It is also vital to realize the qualitative significance of how clean energy could effectively contribute to an equal economic development and reduction in the gap between the urban and rural regions in China. From the perspective of power dispatch, clean energy's contribution to rural development could realistically reduce the risk of high temperature fire accidents during DC/AC voltage transformation, which is a good step toward guaranteeing the security of ultra-high voltage grid system operations.

5.6 Conclusions

To sum up the analysis of this chapter, the most sophisticated and precise solution is the RD scenario. The IRSP model is one of the most important analytical tools. Hence, a comprehensive analysis of the IRSP model outcome is presented. The JEDI model also inspired my research in investigating the associated job creation in all three scenarios in 2030. Based on precise and reliable data from several governmental agencies, potential job opportunities were able to be calculated for each scenario. The RD scenario provides the highest job creation for China when it is compared to the HR scenarios. It matches the

result that was announced by the JEDI model development team. A concrete comparison between the three outputs: BAU, HR, and RD, is illustrated in **table 5.1**.

Each scenario evaluates each of the elements that could help the E4 model separately, in order to determine the most sustainable roadmap for China's 2030 energy development. The four elements are energy, economy, employment and equity. The RD scenario provides the most effective plan in *Economic* terms. The data on *Energy* is produced through a direct analysis of the optimization model, IRSP. Information on *Employment* is delivered by the JC model. *Equity* is not presentable in terms of quantitative data performance. Therefore, analysis of the equity issue is qualitatively presented from four major perspectives: levels of CO_2 reduction, community impacts, and urban/rural development.

In general, the IRSP model confirms that the RD scenario is the most effective scenario from the perspectives of economics and emissions. The model contains four dimensions of analysis: cost and return, emission reductions, as well as detailed analysis of each type of energy source. By using the ROI measurement, the model clearly demonstrates that the RD scenario entails the minimum level of financial investment and the lowest subsidy requirement of the three scenarios and it produces the maximum reduction in CO_2 emissions.

As summarized in the above **table 5.44**, the RD scenario can enable 50% of China's clean energy generation in 2030. This scenario displays the greatest penetration of renewables among all four scenarios. The RD scenario is also the only scenario that successfully meets the hypothesis of this dissertation of having at least 50% of clean

energy generation in China's electricity sector. Meanwhile, the RD scenario is associated with 4,587 billion tons of carbon emission, and $7,979 billion of total cost, making it the most environmentally friendly and reasonable cost scenario among all.

Figure 5.5 and **figure 5.6** together show the changes in power capacity and power generation in China from 2011 to 2030. These tables clearly demonstrate that coal power will still be the biggest contributor to China's electricity sector but steadily stay at the mild peak level under the RD scenario. However, clean energy sources in China will achieve a high level of growth in the next 20 years.

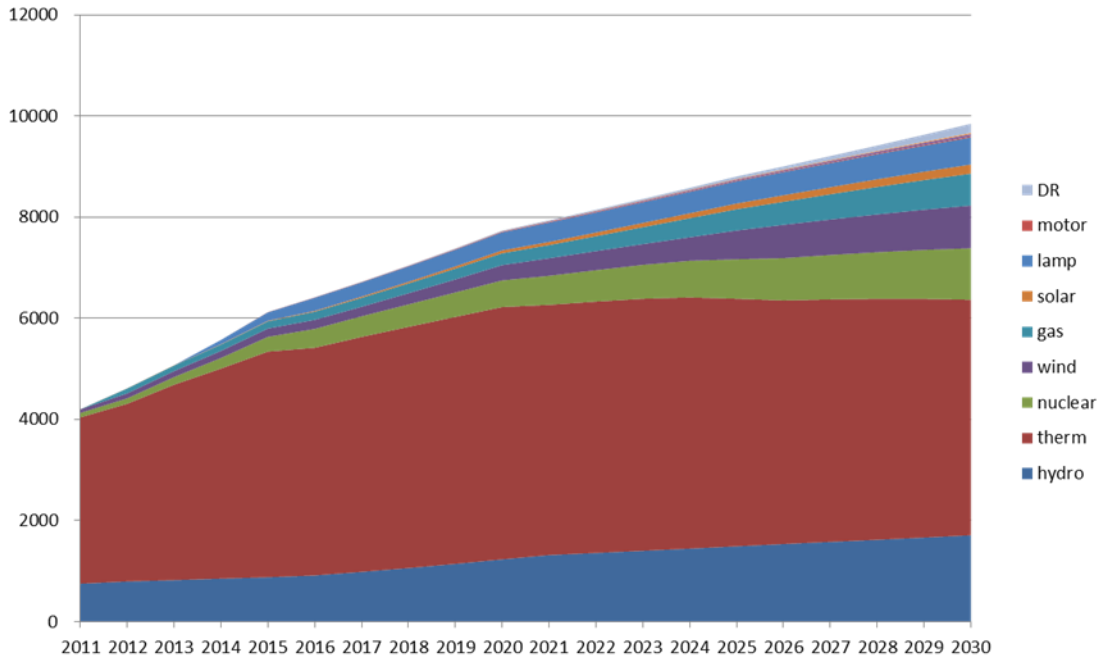

Figure 5.5 Power capacities in China's electricity sector (unit: GW)

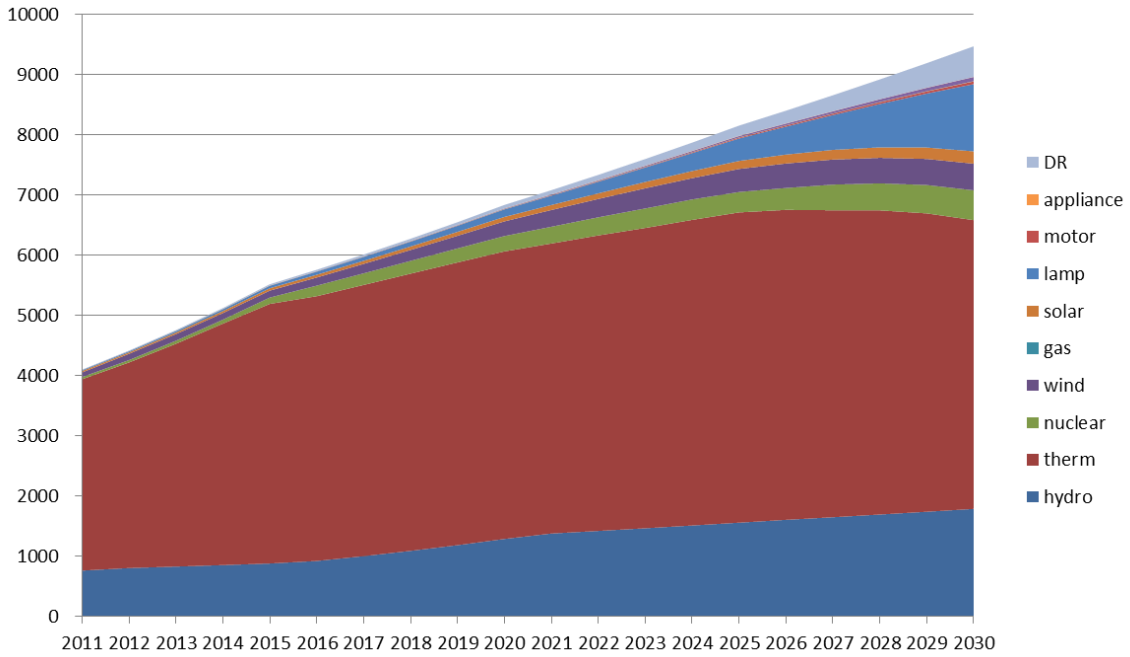

Figure 5.6 Power generation in China's electricity sector (unit: TWh)

Moreover, EPP will account for a significant percentage of power capacity and power generation. In 2011, there was almost zero EPP contribution in China's power sector. Until 2030, motor EPP and transformer EPP will each have 120 GW of power capacity. VFD EPP, lamp EPP, and ice storage EPP's power capacity will also be 80 GW, 55 GW, and 40 GW respectively. The phenomenon of EPP power generation shows a slightly different situation. Lamp EPP will have 534.9 TWh in 2030. Transformer EPP will have 48 TWh, and motor EPP will have 32.7 TWh of power generation in 2030. In spite of demand response, EPP's high contribution in power capacity will only have 14.2 TWh in power generation. Meanwhile, the VFD EPP will also have higher capacity and lower power generation in 2030. The result of direct job creation in this dissertation

matches the result from other literatures. According to Green Peace (2012) and Rutovitz & Harris (2012), total job creation is approximately 300% of the direct job creations.

Each scenario evaluates each of the elements that could help the E4 model separately, in order to determine the most sustainable roadmap for China's 2030 energy development. The four elements are energy, economy, employment and equity. The RD scenario provides the most effective plan in *Economic* terms. The data on *Energy* is produced through a direct analysis of the optimization model, IRSP. Information on *Employment* is delivered by the JC model. *Equity* is not presentable in terms of quantitative data performance. Therefore, analysis of the equity issue is qualitatively presented from four major perspectives: levels of CO_2 reduction, community impacts, and urban/rural development, as well as illustrative of China's major ecological topics.

Chapter 6

RECOMMENDATIONS

This dissertation explores opportunities for meeting China's growing power demand through clean energy sources. The model contains four dimensions of analysis: cost and return, required subsidy level, emission reductions, as well as detailed analysis of each type of energy source. This dissertation demonstrates that the RD scenario entails the minimum level of financial investment and the lowest subsidy requirement of the three scenarios and it produces the maximum reduction in CO_2 emissions.

In order to achieve 50% clean energy penetration in China by 2030, it is clear that RD scenario would be the more feasible scenario from the perspectives of economics and emissions. The utilization of China's clean energy sources as well as demand-side management (DSM) is still at the initial phase, strong incentives and governmental subsidies are required in the next 20 years. The RD scenario displays the greatest penetration of renewables among all four scenarios, which is also the only scenario that successfully meets the hypothesis of this dissertation of having at least 50% of clean energy generation in China's electricity sector. Meanwhile, the RD scenario is associated with 4,587 billion tons of carbon emission, and $7,979 billion of total cost, making it the most environmentally friendly and reasonable cost scenario among all.

Another contribution of this dissertation is that the pattern of China's energy consumption illustrates the peak of coal power generation coming before 2030. The Premier of China, Li Keqiang, announced at the 2015 United Nation's COP 21 Paris Climate Change Conference that China's carbon emissions will peak by around 2030, and China would work hard to achieve the target even earlier (Briggs, 2015). As introduced in chapter 1, power sector is the biggest emission sector in China, and coal power generation shared over 70% of China's total power generation (IEA, 2011). In order to achieve the peak of carbon emission before 2030, it is important to achieve the peak of coal consumption in China's power sector before 2030.

The result of this dissertation demonstrates that the peak of China's coal power generation would be achieved by 2027, which could help policy makers to plan China's energy roadmap strategically in order to realize Li Keqiang's commitment to the United Nations at COP 21. As shown in **figure 5.21** in chapter 5, after coal power consumption achieves the peak level in 2027, it would experience a strong decline trend from 2028 to 2030. Due to the increasing penetration of clean energy sources and DSM technologies from 2015 to 2030, as well as increasing policy supports of coal power reduction from the Chinese government, it is feasible to forecast that coal power would continually to decline after 2030.

Despite of planning a feasible roadmap for China to achieve 50% clean energy generation in 2030, this research has several limitations, including 1) the inability of capturing the seasonality patterns of annual capacity growth, and 2) the reflection of power curtailment issues in China's power sector.

Feed in tariff level for renewable energy usually changes every five years in accordance with each of the Five-Year-Plan (FYP) period. Firstly, since we are able to know the costs of renewable energy generation as well as the governmental-led tariff rates in future years, this dissertation is unable to predict the changes of feed in tariff rates. Second, capacity growth of renewable energy sources shows a steady growth trend according to the output of my research. However, the annual capacity growth is driven by feed in tariff rates, which shows a significant seasonality pattern: clean energy capacity would experience a strong increase by the end of each FYP period, and rapidly decline at the beginning of a new FYP period. The seasonality pattern of China's power capacity installation growth could not be captured by this dissertation.

Given large amount of renewable energy capacity being installed each year, the grid network capability of integrating renewable energy generation has been substantially low. As illustrated in **figure 6.1**, wind curtailment rate in China has been 13.4% in average in the past 5 years. Curtailed energy generation is not being reflected in my dissertation, largely due to the uncertainties of curtailment rates in future years. However, since there are rapid increases of renewable capacities installations but lack of effective governmental actions to reduce curtailment problems, curtailment rate in China's renewable energy sector would not expected to decline in the next FYP period until 2020.

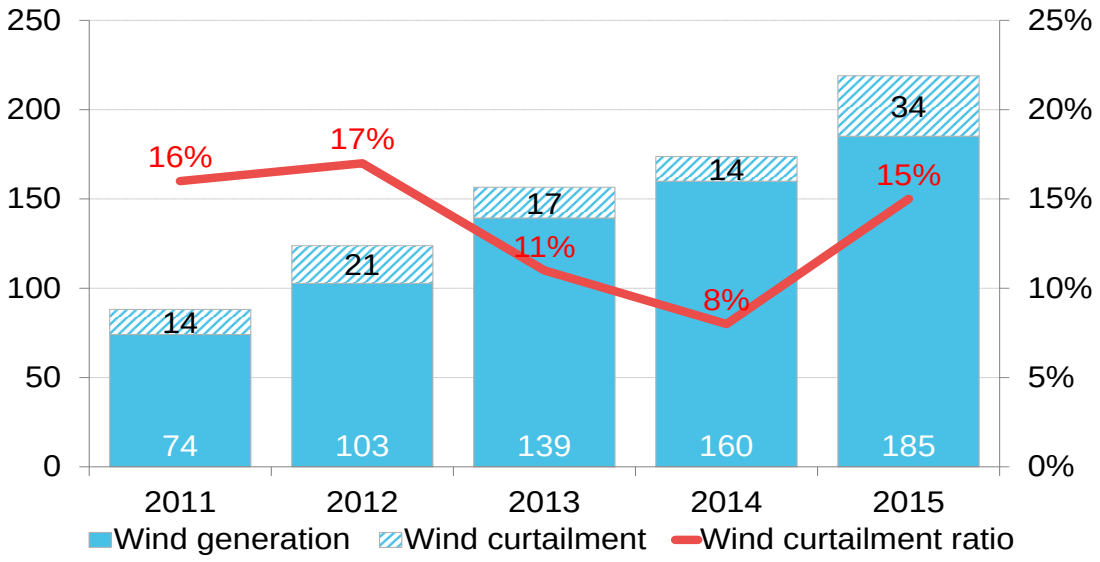

Figure 6.1 China wind power generations and curtailment rates (unit: TWh)

Source: China Electricity Council, 2016

Power industry in China is currently experiencing the transformation period from ‘national-planned power sector development’ to ‘marketplace-oriented power market’. In future research on China’s clean energy roadmap, I strongly recommend researchers to deep-dive into China’s on-going power market progress and feasible policies that benefits such market trend. Instead of fixed hours that were annually established by the NDRC, this dissertation used the dynamic theory of annual flexible hours of energy technologies, which is the ‘very initial step’ of analysis into power market. Following researchers should create more comprehensive analytical frameworks to reflect the latest updates of China’s power market developments, and produce hands-on and practical policy suggestions for China’s power regulators.

The U.S. and EU27 are estimated to have 45-50% clean energy capacity in 2030, whilst China's official was not able to provide a projection so far. Hence, this dissertation proposes a precise estimation for China's 2030 clean energy scenario. According to the investigation, China is confident in its claim of a feasible, yet exciting post 2020 energy target of having 50% clean energy generation in 2030. Yet, the optimized 2030 target in this dissertation is not completely met by a composition of traditional power plants, but also an engagement of DSM technologies. Clean energy development has come relatively late to China's energy sector. DSM technologies shall be largely encouraged in order to complement China's 2030 environmental commitments to the global society, and most importantly, to fulfill China's sustainable energy development.

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APPENDIX

APPENDIX A POWER GENERATION AND CAPACITY UNDER THE REFERENCE SCENARIO

Reference Scenario: China

	Electricity generation (TWh)				Shares (%)			Growth (% p.a.)	
	1990	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total generation	**650**	**2 544**	**5 391**	**8 472**	**100**	**100**	**100**	**7.8**	**4.9**
Coal	471	1 996	4 326	6 586	78	80	78	8.0	4.9
Oil	49	61	58	49	2	1	1	–0.5	–0.9
Gas	3	26	98	313	1	2	4	14.2	10.5
Nuclear	0	53	123	256	2	2	3	8.8	6.5
Hydro	127	397	717	1 005	16	13	12	6.1	3.8
Biomass and waste	0	8	17	110	0	0	1	7.7	10.9
Wind	0	2	49	133	0	1	2	37.4	18.2
Geothermal	0	0	2	5	0	0	0	36.1	18.2
Solar	0	0	0	15	0	0	0	–	22.6
Tide and wave	0	0	0	0	0	0	0	–	4.7

	Capacity (GW)			Shares (%)			Growth (% p.a.)	
	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total capacity	**517**	**1 110**	**1 775**	**100**	**100**	**100**	**7.9**	**5.1**
Coal	368	814	1 259	71	73	71	8.3	5.0
Oil	12	14	11	2	1	1	1.9	–0.3
Gas	10	31	98	2	3	6	12.0	9.6
Nuclear	7	15	31	1	1	2	8.4	6.3
Hydro	117	215	300	23	19	17	6.3	3.8
Biomass and waste	2	4	18	0	0	1	4.8	8.5
Wind	1	17	49	0	2	3	29.8	15.7
Geothermal	0	0	1	0	0	0	26.8	14.8
Solar	0	0	9	0	0	0	–	21.4
Tide and wave	0	0	0	0	0	0	–	3.9

	CO_2 emissions (Mt)				Shares (%)			Growth (% p.a.)	
	1990	2005	2015	2030	2005	2015	2030	2005-2015	2005-2030
Total CO_2 emissions	**2 244**	**5 101**	**8 632**	**11 448**	**100**	**100**	**100**	**5.4**	**3.3**
Coal	1 914	4 199	7 067	8 977	82	82	78	5.3	3.1
Oil	304	811	1 342	2 059	16	16	18	5.2	3.8
Gas	26	91	223	413	2	3	4	9.4	6.2
Power generation	**652**	**2 500**	**4 450**	**6 202**	**100**	**100**	**100**	**5.9**	**3.7**
Coal	598	2 424	4 328	5 997	97	97	97	6.0	3.7
Oil	52	59	62	51	2	1	1	0.3	–0.6
Gas	2	16	60	155	1	1	2	13.8	9.4
Total final consumption	**1 507**	**2 400**	**3 777**	**4 693**	**100**	**100**	**100**	**4.6**	**2.7**
Coal	1 265	1 652	2 442	2 572	69	65	55	4.0	1.8
Oil	225	688	1 196	1 897	29	32	40	5.7	4.1
of which transport	*83*	*321*	*649*	*1 243*	*13*	*17*	*26*	*7.3*	*5.6*
Gas	17	60	138	224	3	4	5	8.7	5.4

Source: International Energy Agency, 2007

APPENDIX B POWER GENERATION AND CAPACITY UNDER ALTERNATIVE POLICY SCENARIO

Alternative Policy Scenario: China

	Electricity generation (TWh)		Shares (%)		Growth (% p.a.)		Change vs. RS (%)	
	2015	2030	2015	2030	2005-2015	2005-2030	2015	2030
Total generation	**5 297**	**7 435**	**100**	**100**	**7.6**	**4.4**	**–1.7**	**–12.2**
Coal	3 932	4 736	74	64	7.0	3.5	–9.1	–28.1
Oil	58	48	1	1	–0.5	–0.9	–0.5	–0.8
Gas	170	427	3	6	20.6	11.8	72.7	36.6
Nuclear	168	459	3	6	12.2	9.0	36.0	79.4
Hydro	871	1 270	16	17	8.2	4.8	21.4	26.4
Biomass and waste	36	222	1	3	15.9	14.1	109.0	102.6
Wind	59	207	1	3	40.0	20.3	20.9	55.4
Geothermal	2	7	0	0	36.1	19.3	–	25.8
Solar	3	59	0	1	41.9	29.3	n.a	n.a
Tide and wave	0	0	0	0	–	10.4	–	n.a

	Capacity (GW)		Shares (%)		Growth (% p.a.)		Change vs. RS (%)	
	2015	2030	2015	2030	2005-2015	2005-2030	2015	2030
Total capacity	**1 110**	**1 627**	**100**	**100**	**7.9**	**4.7**	**0.0**	**–8.4**
Coal	743	910	67	56	7.3	3.7	–8.8	–27.7
Oil	13	11	1	1	1.6	–0.1	–2.8	4.5
Gas	44	120	4	7	16.0	10.5	42.6	21.5
Nuclear	20	55	2	3	11.8	8.9	36.0	79.4
Hydro	261	380	23	23	8.3	4.8	21.1	26.8
Biomass and waste	7	39	1	2	10.9	11.9	76.1	116.2
Wind	21	79	2	5	32.4	18.0	21.8	62.7
Geothermal	0	1	0	0	26.8	15.8	–	25.5
Solar	2	31	0	2	37.4	27.6	n.a.	n.a.
Tide and wave	0	0	0	0	–	9.4	–	n.a

	CO_2 emissions (Mt)		Shares (%)		Growth (% p.a.)		Change vs. RS (%)	
	2015	2030	2015	2030	2005-2015	2005-2030	2015	2030
Total CO_2 emissions	**8 092**	**8 877**	**100**	**100**	**4.7**	**2.2**	**–6.3**	**–22.5**
Coal	6 550	6 757	81	76	4.5	1.9	–7.3	–24.7
Oil	1 283	1 660	16	19	4.7	2.9	–4.4	–19.3
Gas	259	460	3	5	11.1	6.7	16.2	11.4
Power generation	**4 131**	**4 726**	**100**	**100**	**5.2**	**2.6**	**–7.2**	**–23.8**
Coal	3 973	4 465	96	94	5.1	2.5	–8.2	–25.5
Oil	61	50	1	1	0.3	–0.7	–0.6	–0.9
Gas	97	210	2	4	19.4	10.7	62.1	36.0
Total final consumption	**3 560**	**3 647**	**100**	**100**	**4.0**	**1.7**	**–5.7**	**–22.3**
Coal	2 280	1 913	64	52	3.3	0.6	–6.6	–25.6
Oil	1 139	1 507	32	41	5.2	3.2	–4.7	–20.6
of which transport	*618*	*948*	*17*	*26*	*6.8*	*4.4*	*–4.8*	*–23.7*
Gas	141	227	4	6	8.9	5.5	1.6	1.4

Source: International Energy Agency, 2007

APPENDIX C POWER GENERATION UNDER THE REFERENCE SCENARIO

TWh/a	2009	2015	2020	2030	2040	2050
Power plants	**3,640**	**5,624**	**7,275**	**9,607**	**11,538**	**12,569**
Coal	2,826	4,111	4,984	6,483	7,702	8,020
Lignite	0	0	0	0	0	0
Gas	82	172	239	425	689	962
Oil	17	16	16	13	10	8
Diesel	0	0	0	0	0	0
Nuclear	70	149	520	723	820	918
Biomass	2	53	92	167	238	301
Hydro	616	868	1,079	1,249	1,355	1,461
Wind	27	235	318	492	629	765
of which wind offshore	0	2	15	75	130	170
PV	0	17	25	49	84	119
Geothermal	0	1	2	3	6	8
Solar thermal power plants	0	0	1	2	3	4
Ocean energy	0	0	0	1	2	4
Combined heat & power plants	**95**	**178**	**266**	**425**	**583**	**740**
Coal	95	156	214	292	361	430
Lignite	0	0	0	0	0	0
Gas	0	22	48	116	179	232
Oil	0	0	0	0	0	0
Biomass	0	1	4	16	40	73
Geothermal	0	0	1	2	3	4
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	0	30	56	117	179	241
Autoproducers	95	148	210	308	404	499
Total generation	**3,735**	**5,802**	**7,541**	**10,032**	**12,121**	**13,309**
Fossil	3,020	4,477	5,501	7,328	8,941	9,651
Coal	2,921	4,267	5,198	6,775	8,063	8,450
Lignite	0	0	0	0	0	0
Gas	82	194	286	541	867	1,194
Oil	17	16	16	13	10	8
Diesel	0	0	0	0	0	0
Nuclear	70	149	520	723	820	918
Hydrogen	0	0	0	0	0	0
Renewables	**645**	**1,176**	**1,521**	**1,981**	**2,360**	**2,740**
Hydro	616	868	1,079	1,249	1,355	1,461
Wind	27	235	318	492	629	765
of which wind offshore	0	2	15	75	130	170
PV	0	17	25	49	84	119
Biomass	2	53	95	183	279	374
Geothermal	0	1	2	5	9	12
Solar thermal	0	0	1	2	3	4
Ocean energy	0	0	0	1	2	4
Distribution losses	186	253	308	388	455	498
Own consumption electricity	439	595	726	914	1,072	1,174
Electricity for hydrogen production	0	0	0	0	0	0
Final energy consumption (electricity)	**3,106**	**4,950**	**6,502**	**8,720**	**10,578**	**11,612**

Source: Green Peace, 2012

APPENDIX D POWER CAPACITY UNDER THE REFERENCE SCENARIO

GW	2009	2015	2020	2030	2040	2050
Power plants	**899**	**1,387**	**1,707**	**2,195**	**2,573**	**2,779**
Coal	629	877	1,028	1,305	1,507	1,542
Lignite	0	0	0	0	0	0
Gas	33	65	86	129	191	253
Oil	15	15	15	13	11	8
Diesel	0	0	0	0	0	0
Nuclear	11	21	68	94	107	120
Biomass	1	13	17	30	41	50
Hydro	197	266	320	370	402	433
Wind	13	115	150	222	266	305
of which wind offshore	0	1	5	23	37	46
PV	0	15	22	30	45	62
Geothermal	0	0	0	1	1	1
Solar thermal power plants	0	0	1	2	2	3
Ocean energy	0	0	0	0	1	1
Combined heat & power production	**21**	**41**	**59**	**95**	**127**	**159**
Coal	21	33	44	59	71	85
Lignite	0	0	0	0	0	0
Gas	0	7	14	33	48	61
Oil	0	0	0	0	0	0
Biomass	0	0	1	3	7	13
Geothermal	0	0	0	0	0	1
Hydrogen	0	0	0	0	0	0
CHP by producer						
Main activity producers	0	7	13	26	39	54
Autoproducers	21	34	46	68	88	105
Total generation	**920**	**1,428**	**1,766**	**2,290**	**2,700**	**2,938**
Fossil	698	997	1,187	1,538	1,829	1,949
Coal	650	910	1,072	1,364	1,578	1,627
Lignite	0	0	0	0	0	0
Gas	33	72	100	162	239	314
Oil	15	15	15	13	11	8
Diesel	0	0	0	0	0	0
Nuclear	11	21	68	94	107	120
Hydrogen	0	0	0	0	0	0
Renewables	**212**	**410**	**511**	**657**	**765**	**869**
Hydro	197	266	320	370	402	433
Wind	13	115	150	222	266	305
of which wind offshore	0	1	5	23	37	46
PV	0	15	22	30	45	62
Biomass	1	13	18	32	48	63
Geothermal	0	0	0	1	1	2
Solar thermal	0	0	1	2	2	3
Ocean energy	0	0	0	0	1	1
Fluctuating RES (PV, Wind, Ocean)	14	130	172	252	311	368
Share of fluctuating RES	1%	9%	10%	11%	12%	13%
RES share (domestic generation)	**23%**	**29%**	**29%**	**29%**	**28%**	**30%**

Source: Green Peace, 2012

APPENDIX E POWER GENERATION UNDER THE [R]EVOLUTION SCENARIO

TWh/a	2009	2015	2020	2030	2040	2050
Power plants	**3,640**	**5,322**	**6,357**	**7,627**	**8,746**	**9,240**
Coal	2,826	3,881	4,212	3,850	2,441	28
Lignite	0	0	0	0	0	0
Gas	82	138	199	192	85	52
Oil	17	10	5	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	70	149	250	200	146	0
Biomass	2	39	44	55	34	31
Hydro	616	812	990	1,150	1,340	1,460
Wind	27	265	498	1,200	2,148	3,134
of which wind offshore	0	2	35	190	357	519
PV	0	25	95	365	1,014	1,525
Geothermal	0	2	8	97	313	512
Solar thermal power plants	0	1	55	482	1,115	1,858
Ocean energy	0	0	2	35	110	640
Combined heat & power plants	**95**	**219**	**429**	**955**	**1,467**	**1,772**
Coal	95	137	190	302	265	52
Lignite	0	0	0	0	0	0
Gas	0	47	113	384	636	721
Oil	0	0	0	0	0	0
Biomass	0	34	123	234	432	611
Geothermal	0	0	2	36	115	310
Hydrogen	0	0	0	0	19	78
CHP by producer						
Main activity producers	0	34	164	505	834	993
Autoproducers	95	185	265	450	633	779
Total generation	**3,735**	**5,541**	**6,786**	**8,582**	**10,213**	**11,012**
Fossil	3,020	4,213	4,719	4,728	3,427	853
Coal	2,921	4,018	4,402	4,152	2,706	80
Lignite	0	0	0	0	0	0
Gas	82	185	312	576	721	773
Oil	17	10	5	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	70	149	250	200	146	0
Hydrogen	0	0	0	0	19	78
Renewables	**645**	**1,179**	**1,817**	**3,654**	**6,621**	**10,081**
Hydro	616	812	990	1,150	1,340	1,460
Wind	27	265	498	1,200	2,148	3,134
of which wind offshore	0	2	35	190	357	519
PV	0	25	95	365	1,014	1,525
Biomass	2	73	167	290	466	642
Geothermal	0	2	10	133	428	822
Solar thermal	0	1	55	482	1,115	1,858
Ocean energy	0	0	2	35	110	640
Distribution losses	186	213	221	252	208	203
Own consumption electricity	439	497	515	468	312	187
Electricity for hydrogen production	0	0	6	55	241	556
Final energy consumption (electricity)	**3,106**	**4,827**	**6,038**	**7,797**	**9,436**	**10,041**

Source: Green Peace, 2012

APPENDIX F POWER CAPACITY UNDER THE [R]EVOLUTION SCENARIO

GW	2009	2015	2020	2030	2040	2050
Power plants	**899**	**1,267**	**1,588**	**2,088**	**2,616**	**2,949**
Coal	629	776	823	755	498	9
Lignite	0	0	0	0	0	0
Gas	33	50	66	56	27	21
Oil	15	9	5	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	11	21	33	26	19	0
Biomass	1	10	8	10	6	5
Hydro	197	249	294	341	397	433
Wind	13	130	234	517	845	1,139
of which wind offshore	0	1	11	57	99	133
PV	0	22	83	221	542	803
Geothermal	0	0	1	16	51	83
Solar thermal power plants	0	1	42	138	203	295
Ocean energy	0	0	1	9	28	161
Combined heat & power production	**21**	**53**	**98**	**220**	**323**	**378**
Coal	21	29	39	61	55	17
Lignite	0	0	0	0	0	0
Gas	0	16	35	112	171	188
Oil	0	0	0	0	0	0
Biomass	0	8	23	42	75	107
Geothermal	0	0	0	6	19	50
Hydrogen	0	0	0	0	4	15
CHP by producer						
Main activity producers	0	8	39	120	183	216
Autoproducers	21	45	59	100	140	162
Total generation	**920**	**1,320**	**1,686**	**2,308**	**2,939**	**3,327**
Fossil	698	880	968	984	750	236
Coal	650	805	862	816	553	27
Lignite	0	0	0	0	0	0
Gas	33	65	102	168	198	209
Oil	15	9	5	0	0	0
Diesel	0	0	0	0	0	0
Nuclear	11	21	33	26	19	0
Hydrogen	0	0	0	0	4	15
Renewables	**212**	**420**	**685**	**1,298**	**2,166**	**3,076**
Hydro	197	249	294	341	397	433
Wind	13	130	234	517	845	1,139
of which wind offshore	0	1	11	57	99	133
PV	0	22	83	221	542	803
Biomass	1	18	31	51	81	112
Geothermal	0	0	2	22	69	133
Solar thermal	0	1	42	138	203	295
Ocean energy	0	0	1	9	28	161
Fluctuating RES (PV, Wind, Ocean)	14	152	317	746	1,416	2,103
Share of fluctuating RES	1%	11%	19%	32%	48%	63%
RES share (domestic generation)	**23%**	**32%**	**41%**	**56%**	**74%**	**92%**

Source: Green Peace, 2012

APPENDIX G 2030 POWER GENERATION AND POWER CAPACITY IN CHINA

1. Electricity generation		Unit	2012	Reference Case 2030	REmap 2030	Difference between REmap 2030 and Reference Case
Installed Capacity	**Renewable energy**	GW_e	**345**	**1 005**	**1 467**	**462**
	hydroelectricity (excl. pumped storage)	GW_e	249	400	400	0
	hydroelectricity pumped storage	GW_e	20	100	100	0
	Wind onshore	GW_e	63	269	501	232
	Wind offshore	GW_e	0.3	46	60	14
	Biomass (incl. biogas, industry CHP)	GW_e	7.7	38	65	27
	Solar PV utility scale	GW_e	4	98	190	92
	Solar PV rooftop	GW_e	1.4	41	118	77
	Solar CSP	GW_e	0.014	12	32	20
	Geothermal & Ocean	GW_e	0.03	1	1	0
Electricity Generation	**Renewable energy**	TWh	**1 006**	**2 643**	**3 660**	**1 109**
	Hydropower	TWh	864	1,600	1,600	0
	Wind	TWh	100	647	1,263	692
	Biomass	TWh	38	190	358	168
	Solar	TWh	4	197	446	249
	Geothermal & Ocean	TWh	0	9	9	0

Source: IRENA, 2014

APPENDIX H 2030 EMISSION UNDER REFERENCE AND REMAP SCENARIO

	2010 (Mt/year)	Reference Case 2030 (Mt/year)	REmap 2030 (Mt/year)	Total avoided (Mt/year)
Power and district heat generation	3 595	5 762	4 544	1 218
Industry	2 327	2 746	2 528	217
Transport	529	1 199	1 123	76
Buildings	467	478	298	181
Total emissions from fossil fuel combustion for energy services	**6 917**	**10 185**	**8 493**	**1 692**

Source: IRENA, 2014

APPENDIX I SUMMARY OF JOB CREATION IN NEBRASKA WIND POWER INDUSTRY

All dollar values are millions of 2008 constant dollars			Low[2]	High[3]
7,800 MW	Average Employment Impact	Total Jobs Impact (Direct, Indirect, and Induced)	1,600	2,925
		Direct Wind Industry Jobs	840	1,580
	Financial Impacts	Total Economic Output	$7,800	$14,100
		Total Land-Lease Payments	$547	$641
		Total Property Tax Payments	$570	
1,000 MW	Average Employment Impacts	Total Jobs Impact (Direct, Indirect, and Induced)	345	659
		Direct Wind Industry Jobs	184	363
	Financial Impacts	Total Economic Output	$868	$1,640
		Total Land Lease Payments	$70	$82
		Total Property Tax Payments	$73	

[1]Average annual impacts for 7,800 MW assume a 20-year construction period and 20 years of operations for a total lifetime impact spread over 40 years. Average annual impacts for 1,000 MW assume a 2-year construction period and 20 years of operations for a total impact spread over 22 years.
[2]Low results represent the traditional development low scenario.
[3]High results represent the C-BED high scenario.

Source: Lantz, 2009

APPENDIX J CHINA'S POWER SECTOR TOTAL EMPLOYMENT IN 2030

THOUSAND JOBS		REFERENCE			ENERGY [R]EVOLUTION		
	2010	2015	2020	2030	2015	2020	2030
By sector							
Construction and installation	1,725	868	571	339	883	514	499
Manufacturing	930	394	280	159	702	444	390
Operations and maintenance	478	504	539	429	495	554	459
Fuel supply (domestic)	5,318	3,730	2,842	1,836	3,957	3,229	1,888
Coal and gas export	-	-	-	-	-	-	-
Total jobs	**8,451**	**5,496**	**4,233**	**2,762**	**6,038**	**4,741**	**3,235**
By technology							
Coal	5,969	3,972	3,010	1,894	3,618	2,725	1,428
Gas, oil & diesel	223	223	213	302	250	263	262
Nuclear	231	185	101	53	40	18	9
Total renewables	**2,028**	**1,116**	**908**	**512**	**2,130**	**1,735**	**1,536**
Biomass	*802*	*563*	*486*	*275*	*733*	*662*	*454*
Hydro	*381*	*306*	*224*	*151*	*270*	*197*	*168*
Wind	*427*	*161*	*138*	*56*	*438*	*338*	*314*
PV	*137*	*44*	*23*	*11*	*370*	*104*	*195*
Geothermal power	*1.9*	*1.0*	*0.7*	*0.5*	*8*	*16*	*22*
Solar thermal power	*1.3*	*3.7*	*2.1*	*0.8*	*162*	*162*	*83*
Ocean	*0.04*	*0.03*	*0.11*	*0.16*	*2.1*	*7.2*	*6.2*
Solar - heat	*258*	*33*	*29*	*16*	*121*	*179*	*220*
Geothermal & heat pump	*18.6*	*3.0*	*7.2*	*2.4*	*26*	*71*	*75*
Total jobs	**8,451**	**5,496**	**4,233**	**2,762**	**6,038**	**4,741**	**3,235**

Source: Green Peace, 2012

APPENDIX K SAS CODING FOE 2030 ELECTRICITY DEMAND CALCULATION

```
PROC IMPORT OUT= WORK DATAFILE= "C:\Users\mac\Desktop\elec.xlsx"
            DBMS=xlsx REPLACE;
     GETNAMES=YES;
RUN;

proc print data=work;
run;

proc reg data=work;
model y=x1 x2;
run;

proc reg data=work;
model y=x1;
run;

proc univariate data=work cibasic;
   var x1;
run;

proc sgplot data=work;
  reg x=x1 y=y / CLM CLI;
run;

proc means data=work (firstobs=1 obs=15);
  var per_capita_GDP__USD_;

  run;
```

APPENDIX L SAS RESULTS FOR 2030 ELECTRICITY DEMAND CALCULATION

The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: Y Y

Number of Observations Read	31
Number of Observations Used	15
Number of Observations with Missing Values	16

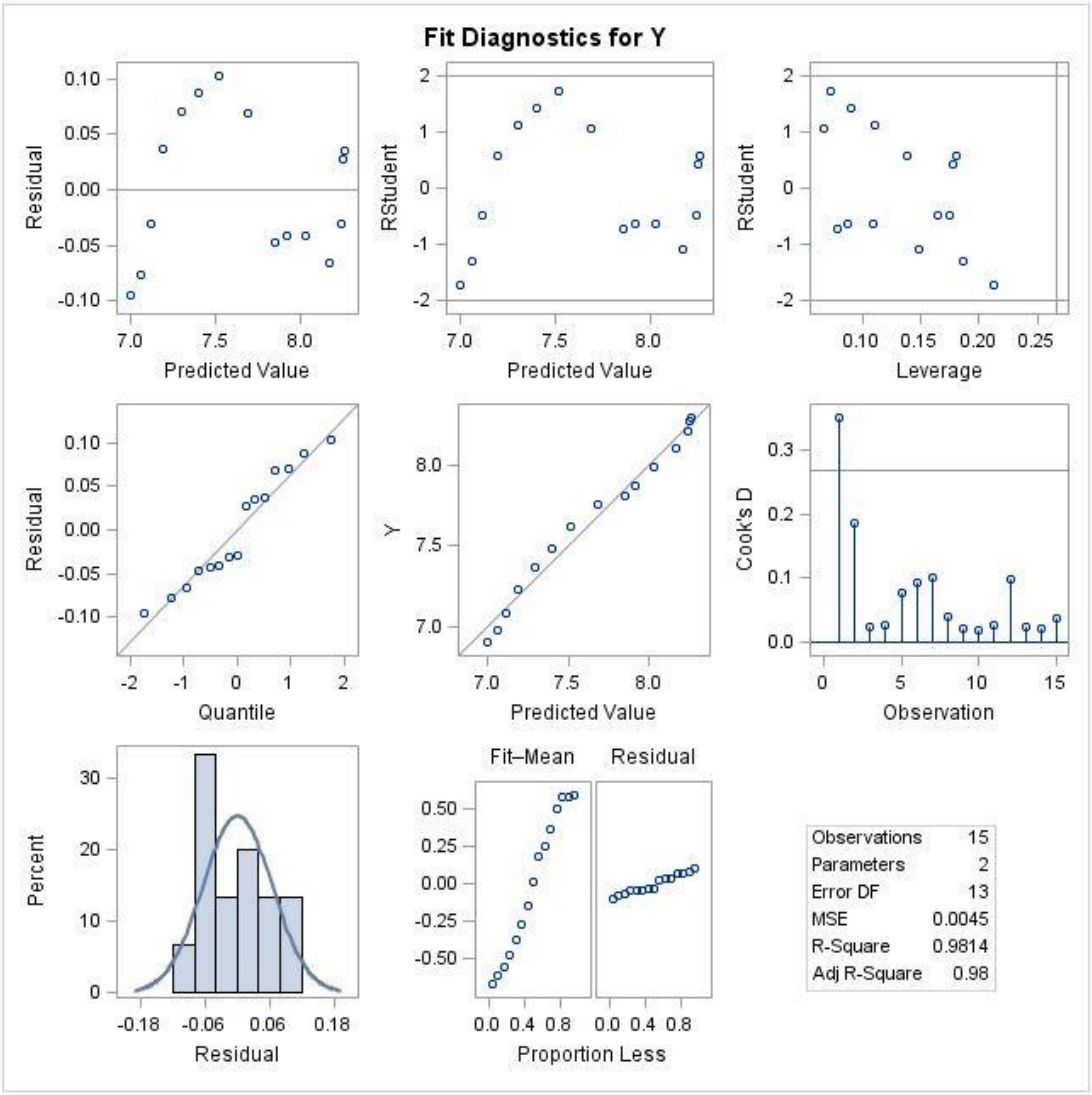
Analysis of Variance					
Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	1	3.07660	3.07660	687.04	<.0001
Error	13	0.05821	0.00448		
Corrected Total	14	3.13482			

Root MSE	0.06692	R-Square	0.9814
Dependent Mean	7.66584	Adj R-Sq	0.9800
Coeff Var	0.87294		

Parameter Estimates						
Variable	Label	DF	Parameter Estimate	Standard Error	t Value	Pr > |t|
Intercept	Intercept	1	2.40447	0.20147	11.93	<.0001
X1	X1	1	1.54240	0.05884	26.21	<.0001

The SAS System

The REG Procedure
Model: MODEL1
Dependent Variable: Y Y



The SAS System

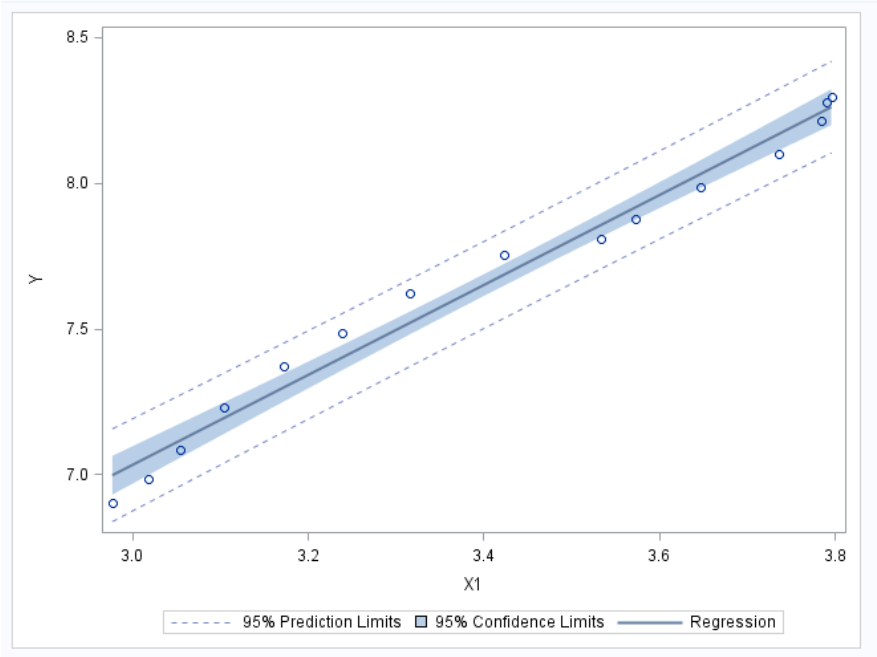
The UNIVARIATE Procedure
Variable: X1 (X1)

Moments			
N	15	Sum Weights	15
Mean	7.85450179	Sum Observations	117.817527
Std Deviation	0.6998289	Variance	0.48976049
Skewness	-0.0544899	Kurtosis	-1.6353535
Uncorrected SS	932.254622	Corrected SS	6.85664689
Coeff Variation	8.90990824	Std Error Mean	0.18069505

Basic Statistical Measures			
Location		Variability	
Mean	7.854502	Std Deviation	0.69983
Median	7.882790	Variance	0.48976
Mode	.	Range	1.88554
		Interquartile Range	1.45324

Basic Confidence Limits Assuming Normality			
Parameter	Estimate	95% Confidence Limits	
Mean	7.85450	7.46695	8.24205
Std Deviation	0.69983	0.51236	1.10370
Variance	0.48976	0.26252	1.21815

Tests for Location: Mu0=0				
Test	Statistic		p Value	
Student's t	t	43.46827	Pr > |t|	<.0001
Sign	M	7.5	Pr >= |M|	<.0001



The SAS System

The MEANS Procedure

Analysis Variable : per_capita_GDP__USD_ per capita GDP (USD)				
N	Mean	Std Dev	Minimum	Maximum
15	3193.50	2031.84	949.1800000	6255.00

APPENDIX M SAS LOG FOR 2030 ELECTRICITY DEMAND CALCULATION

```
NOTE: Copyright (c) 2002-2012 by SAS Institute Inc., Cary, NC, USA.
NOTE: SAS (r) Proprietary Software 9.4 (TS1M1)
      Licensed to SFA T&R, Site 70080595.
NOTE: This session is executing on the X64_7PRO  platform.



NOTE: Updated analytical products:

      SAS/STAT 13.1
      SAS/ETS 13.1
      SAS/OR 13.1
      SAS/IML 13.1
      SAS/QC 13.1

NOTE: Additional host information:

 X64_7PRO WIN 6.1.7601 Service Pack 1 Workstation

NOTE: SAS initialization used:
      real time           0.96 seconds
      cpu time            0.87 seconds

1    PROC IMPORT OUT= WORK DATAFILE= "C:\Users\mac\Desktop\elec.xlsx"
2                DBMS=xlsx REPLACE;
3         GETNAMES=YES;
4    RUN;

NOTE:    Variable Name Change.  per capita kWh -> per_capita_kWh
NOTE:    Variable Name Change.  per capita GDP (USD) -> per_capita_GDP__USD_
NOTE:    Variable Name Change.  Price RMB -> Price_RMB
NOTE: The import data set has 31 observations and 9 variables.
NOTE: WORK.WORK data set was successfully created.
NOTE: PROCEDURE IMPORT used (Total process time):
      real time           0.03 seconds
      cpu time            0.01 seconds


5
6    proc print data=work;
NOTE: Writing HTML Body file: sashtml.htm
7    run;

NOTE: There were 31 observations read from the data set WORK.WORK.
NOTE: PROCEDURE PRINT used (Total process time):
      real time           0.29 seconds
      cpu time            0.15 seconds


8
9    proc reg data=work;
10   model y=x1 x2;
11   run;

12

NOTE: PROCEDURE REG used (Total process time):
      real time           3.05 seconds
      cpu time            0.59 seconds
```

```
13   proc reg data=work;
14   model y=x1;
15   run;

16

NOTE: PROCEDURE REG used (Total process time):
      real time           4.00 seconds
      cpu time            1.10 seconds


17   proc univariate data=work cibasic;
18      var x1;
19   run;

NOTE: PROCEDURE UNIVARIATE used (Total process time):
      real time           0.03 seconds
      cpu time            0.01 seconds


20
21   proc sgplot data=work;
22     reg x=x1 y=y / CLM CLI;
23   run;

NOTE: PROCEDURE SGPLOT used (Total process time):
      real time           0.15 seconds
      cpu time            0.03 seconds

NOTE: There were 31 observations read from the data set WORK.WORK.

24   proc means data=work (firstobs=1 obs=15);
25    var per_capita_GDP__USD_;
26    run;

NOTE: There were 15 observations read from the data set WORK.WORK.
NOTE: PROCEDURE MEANS used (Total process time):
      real time           0.01 seconds
      cpu time            0.01 seconds
```

APPENDIX N DATA ASSUMPTION OF SCENARIOS

		Davis & Socolow (2014)	International Atomic Energy Agency (2014)	LBNL (2011)	WRI (2015)	IRENA (2014)	IEA (2010)	Green Peace (2012)	Kang (2013)	Zhou (2012)	Duan (2014)	**Mean Value**
lifespans												
hydro	中大型水电				40	40	80				40	50.00
coal	usc ultra su	40			30	40	40	20			30	33.33
nuclear	cpr-1000 改进型压水		40		40	25	60				50	43.00
wind	onshore wind				20	25	25				20	22.50
solar	c-Si solar PV				25	25	25				25	25.00
natural gas	close loop	40			25	40	30				25	32.00
light EPP				2.5	1.3						3	2.27
motor											15	15.00
transformer											30	30.00
frequency											15	15.00
ice											10	10.00
appliance											10	10.00
DR											1	1.00
initial costs												
hydro						10000	10290		9000	8500	9600	9478.00
coal						6200	4500	6300	4800	4700	5100	5266.67
nuclear							14500		12000	11075	13500	12768.75
wind						11000	10000		8500	9500	10500	9900.00
solar						27000	22100		24000	25500	21100	23940.00
natural gas						5800	3600	3200	4300	3500	4200	4100.00
light EPP										435	405	420.00
motor				0.34	1.88					440	300	185.56
transformer										151	120	135.50
frequency				1.41	4.12					500	856	340.38
ice										215	157	186.00
appliance				12						1300	1200	837.33
DR										100	132	116.00
O&M costs												
hydro						0.08	0.07		0.06	0.04	0.07	0.06
coal						0.26	0.21		0.3	0.19	0.16	0.22
nuclear						0.09	0.06		0.06	0.05	0.05	0.06
wind						0.03	0.13		0.05	0.11	0.12	0.09
solar						0.09	0.14		0.12	0.13	0.15	0.13
natural gas						0.31	0.26		0.32	0.25	0.27	0.28
light EPP												
motor												
transformer												
frequency												
ice												
appliance												
DR												
emission factors	kg/MWh											
CO2 coal		800			900			1100	800	1000	800	900.00
SO2 coal										5.8	4.3	5.05
NOx coal										2.7	2.7	2.70
CO2 natural		490			600			430	408	510	450	481.33
SO2 natural										0.045	0.061	0.05
NOx natural										0.76	1.2	0.98
discout rate		7%		7%	4-10%		5-10%	7%	7-10%	10%	7%	0.08
population		1.54 (UN, 2012)		1.46				1.45				1.46

APPENDIX O ANALYSIS OF EACH TYPE OF ENERGY SOURCE

Investigation of the power capacities and generation of each type of energy resource from present to 2030 could present more sophisticated outcomes. The analysis below focuses on hydro, coal, nuclear, wind and solar, and natural gas, as well as applicable EPPs. In order to provide a clear comparison, the analysis of each type of energy resource is divided into two major sections: power capacity and power operation.

Hydropower

As shown in the previous analysis, hydropower is one of the most important components (in terms of power capacity and power generation) of China's clean energy development. Not only is it associated with very low operation and maintenance costs, but it can also provide reliable power supply to both the national grid network and local communities. **Table 5.37** presents the development of hydropower in term of capacity, operation and cost respectively. As shown in **table 5.38**, all scenarios are equally supportive in China's 2030 hydropower development. **Table 5.38** also presents the details of hydropower's capacity development under the RD scenario.

Figure 5.14 demonstrates China's hydropower capacity of each year under the RD scenario. Around 2020, the growth of China's hydropower shows a slight boost, and then slows down afterwards. This is probably due to completion of the remaining planned large scale hydropower plant projects in previous FYPs. All constructions after 11th FYP are only supposed to be of small to medium scale, which is less than 500 GW. In

addition, hydropower capacity is expected to grow more than two fold by 2030. Under all scenarios, China starts with 231 GW and 671 TWh of hydropower in 2010, and grows to achieve 527 GW in power capacity and 1708 TWh in power generation by 2030. Thus, the results of the three scenarios do not differ much.

Table 5.38 Comparison of hydropower development under different scenarios

	2010	2030 BAU	2030 HR	2030 RD
Capacity (GW)	231	527	527	527
Operation (TWh)	671	1708	1708	1708

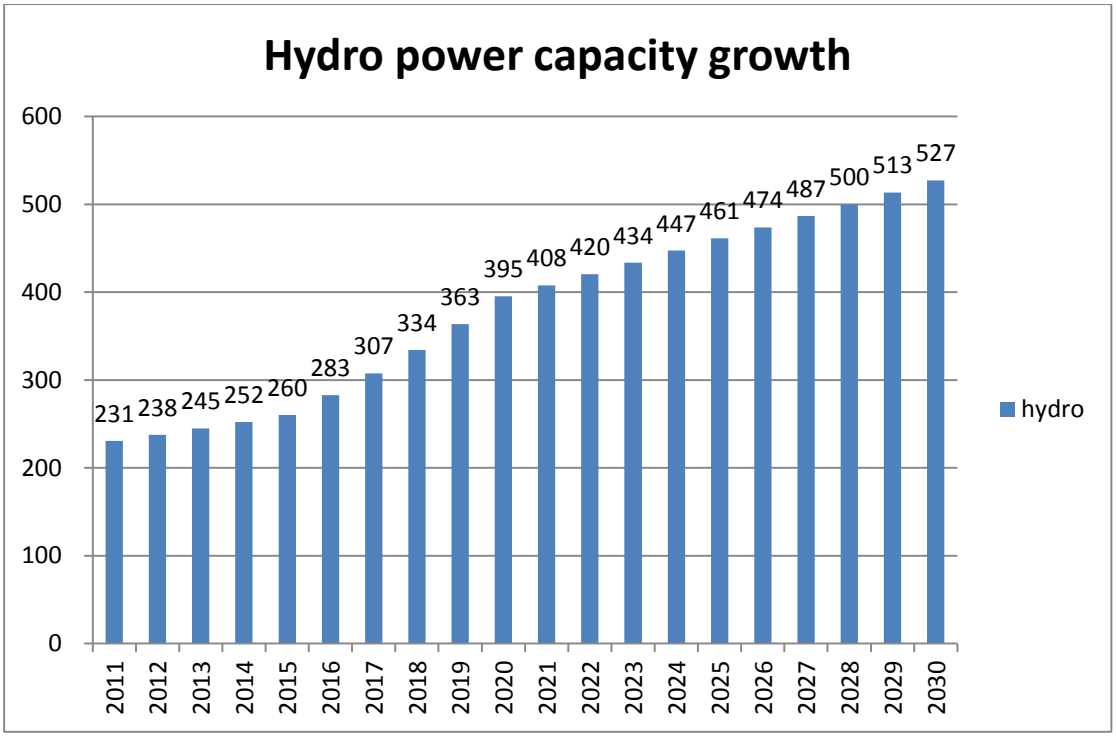


Figure 5.14 Hydropower capacity in China under the RD scenario (unit: GW)

Coal

As discussed in the literature review, coal resource plays a dominant role in China's electricity industry, and will continue to be a major input for China's energy strategy in the next several decades. **Table 5.39** demonstrates that in 2030, coal will still be a key contributor in China's power generation. This situation is in line with the statement of the State Council (China Social Science Academy, 2012), which says that the precondition to optimizing energy supply is to guarantee energy security. Thus the use of coal power plants can only be reduced if doing so doesn't pose a security risk to the power supply.

The effort on coal power that China's power regulators made during the 12th FYP is hard to be evaluated completely through the below data performance, since the key policy for the 12th FYP is to turn off small-scale coal power (power capacity under 100 MW) plants nationwide. By 2013, China turned off 54.07 GW of small scaled coal power plants nationwide, recognized as a great achievement of the 12th FYP. As a result, it is practical for China to continue utilizing large scale coal power plants for the purpose of power generation in China's near energy future, given the fact that the purpose of policy guide is to optimize the solution, at the same time consider what is realistic to China.

Full implementing of the RD scenario will significantly restrict new installed coal power capacities while gradually retiring current coal power plants between 2015 and 2030. In the RD scenario, coal power will be 4658 TWh in 2030, which is much less compared with that of 5463 TWh in the HR scenario and 6630 TWh in BAU scenario. In

2010, coal power capacity was 852 GW in China; however, by Liu (2013), in 2030, the coal power capacity will be 983 GW for the RD scenario, 1057 GW for the HR scenario, and 1557 GW for the BAU scenario.

Looking at the annual power capacity growth, we can see from **figure 5.15** that the growth of newly installed coal power will continue from 2010 to 2030. In comparison with the other scenarios, the RD scenario contains the least amount of coal power capacities and power generation in 2030. The new large-scale power plants have high power efficiency than existing smaller coal power plants, and are more reliable for energy security (State Council of China, 2012).

Table 5.39 Comparison of coal power growth under different scenarios

	2010	2030 BAU	2030 HR	2030 RD
Capacity (GW)	822	1557	1057	983
Operation (TWh)	3303	6630	5463	4658

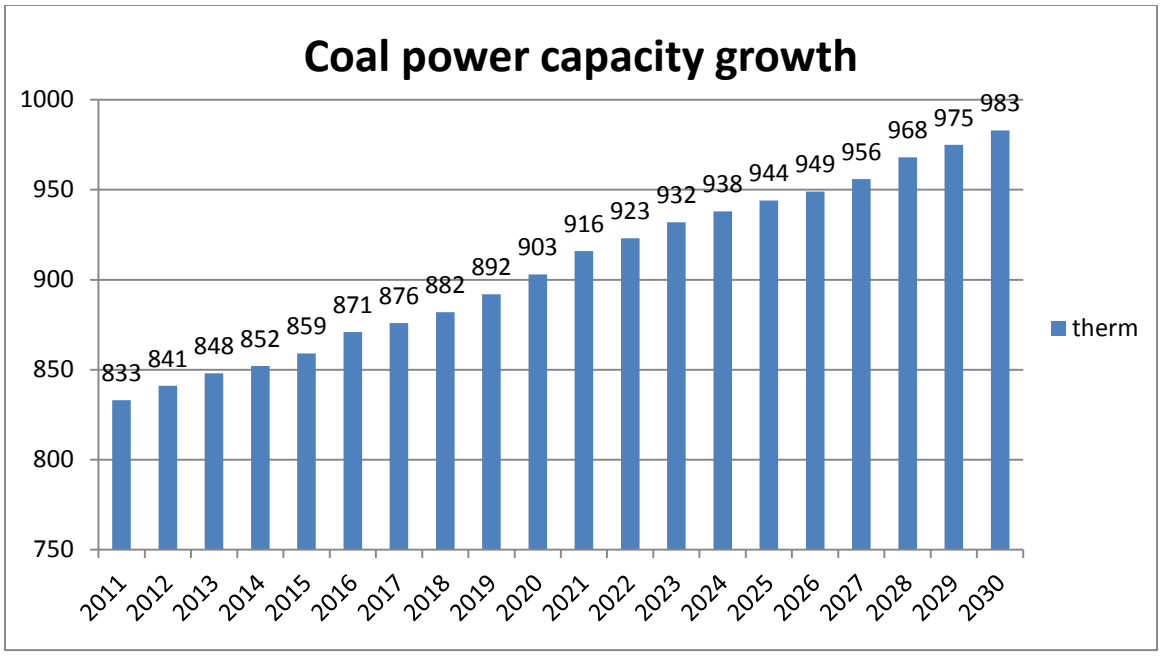


Figure 5.15 Coal power capacity in China under the RD scenario (unit: GW)

Nuclear

Nuclear power is relatively new to China's energy sector compared with other types of power generation. By the end of 11th FYP (2005-2010), there were only 10.73 GW of nuclear power capacity in China. Nuclear power was only enabled to generate 80 TWh of electricity to the grid network in 2010 due to technical concerns (China Social Science Academy, 2012).

Table 5.40 demonstrates the future development of nuclear power in different scenarios. As we can see, the RD scenario allows for 150 GW in 2030, which is the same as that of the HR scenario. The capacity of nuclear power will increase from 13 GW in 2011 to 150 GW in 2030, which will be a 11.5 times growth under the RD scenario.

This dissertation agrees with Wang (2000) on nuclear power in the E4 model: In order to maintain a sustainable development of nuclear power in the long run, nuclear power should not have a 'the larger the better' approach. Instead, China's nuclear power regulatory agency should re-evaluate the current management structure of estimating the level of nuclear safety, while its development is still at the initial stages. Before the 11th FYP, measurements on China's nuclear regulation were much less comprehensive than that of the developed countries.

However, the 12th FYP released several restrictions on evaluating nuclear power safety issues. This dissertation also agrees with the State Council (2012): unlike other energy resources, providing safe and stable power supply is more meaningful in term of nuclear power generation. The development and reassessment of the safety of nuclear power, as well as the Evaluation, Measurement and Verification (EM&V) of safety standards should be comprehensively enhanced during China's 12th FYP in its energy sector planning.

Table 5.40 Comparison of nuclear power under different scenarios

	2010	2030 BAU	2030 HR	2030 RD
Capacity (GW)	10.73	150	150	150
Operation (TWh)	80	1018	1018	1018

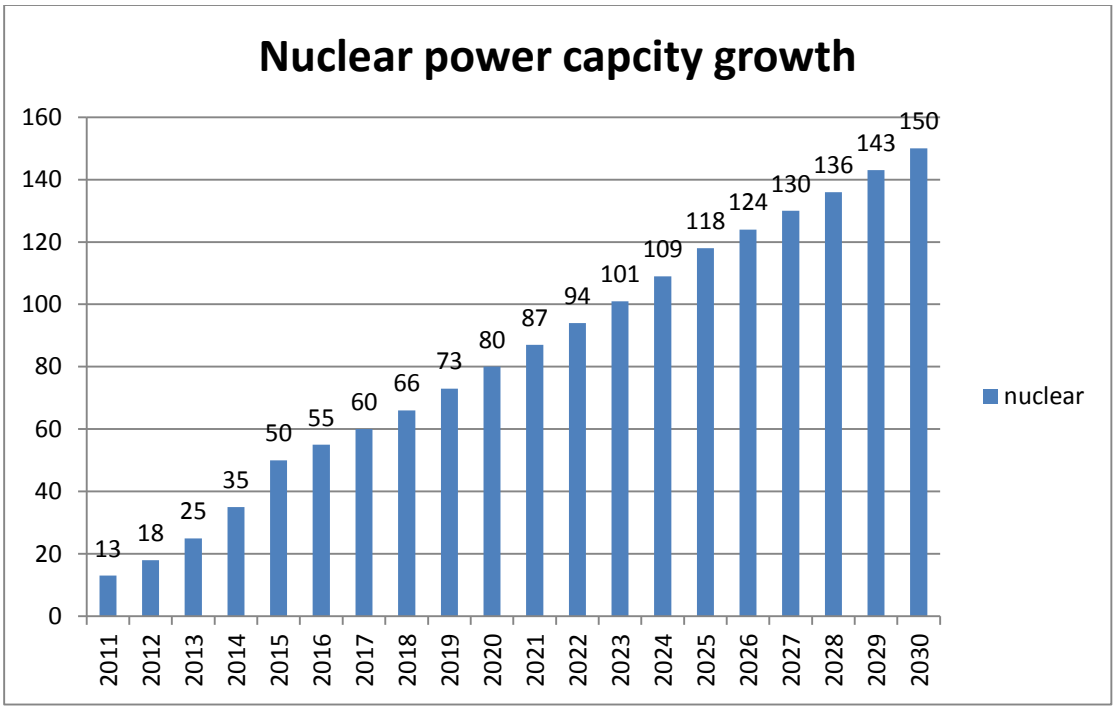


Figure 5.16 Nuclear power capacity in China under the RD scenario (unit: GW)

Wind

Wind power has received high attention from China's electricity policy regulators since 2000s. **Table 5.41** predicts the future development of wind power in China under various scenarios, and **figure 5.17** illustrates wind power capacity development in China from 2011 to 2030 under the RD scenario. As we can see from **figure 5.17**, it is obvious that wind power will experience a boost after 2019: the total wind capacity is expected to rise from 120 GW in 2018, to 172 GW by the end of 2019. The capacity of wind power in 2030 will achieve 400 GW in China according to the RD scenario, which will be approximately 10 times the 2011 level.

The RD scenario enables China's wind power to achieve 400 GW of power capacity and 846 TWh of electricity generation by 2030 (**figure 5.17**). This results matches with the current development trend of China's wind power capacities. This outcome is much higher than the BAU scenario, which would achieve 320 GW in power capacity, and 615 TWh of power generation.

Table 5.41 Comparison of wind power under different scenarios

	2010	2030 BAU	2030 HR	2030 RD
Capacity (GW)	45	320	400	400
Operation (TWh)	63	615	846	846

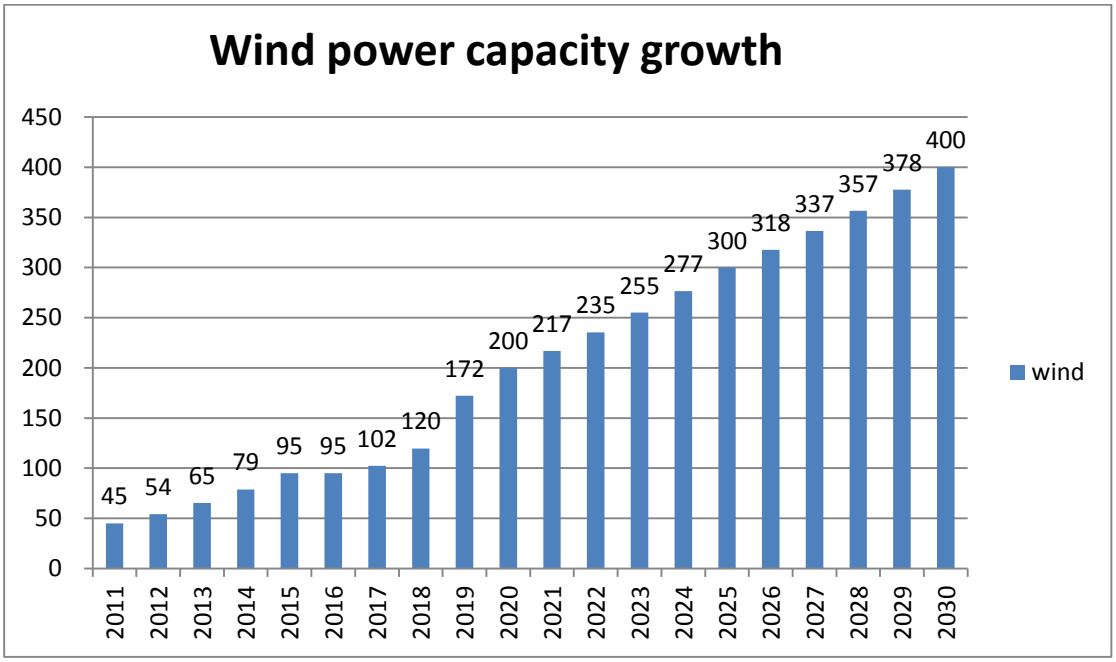


Figure 5.17 Wind power capacity in China under the RD scenario (unit: GW)

Solar

As seen from the analysis in literature review, the contribution of solar power in China's clean energy development will be largely unprecedented in the next 20 years. Solar power will experience the highest growth rate among all energy resources. China's 2030 achievement in solar power capacity is expected to grow 60 times of the 2010 level, from 2 GW in 2010 to 120 GW in 2030.

The projection in this dissertation is based on the effectiveness of strong policy subsidies on China's domestic solar programs, which were emphasized in the 12th FYP of the State Council in 2010, which were collaborated by the NDRC, Ministry of Finance, Ministry of Information and Technology. These policy incentives were carefully implemented by the SGCC on the ground level in each province. As introduced in literature review, China has initiated several strong incentives to encourage solar power development in the past 10 years.

Table 5.42 illustrates the potential of solar power under different scenarios, and figure 33 shows the growth of solar power capacity from 2011 to 2030 under the RD scenario. The BAU, HR and RD scenarios all measure to be equally beneficial for solar power, since policy support remains strong in all scenarios. In 2010, China had only 2 GW of solar capacity and 2 TWh of utilized solar power generation. Under the RD scenario, China is projected to have 120 GW of solar power capacity and 182 TWh of solar power generation by 2030 (**figure 5.18**).

Table 5.42 Comparison of solar power development in different scenarios

	2010	2030 BAU	2030 HR	2030 RD
Capacity (GW)	2	120	120	120
Operation (TWh)	2	159	182	182

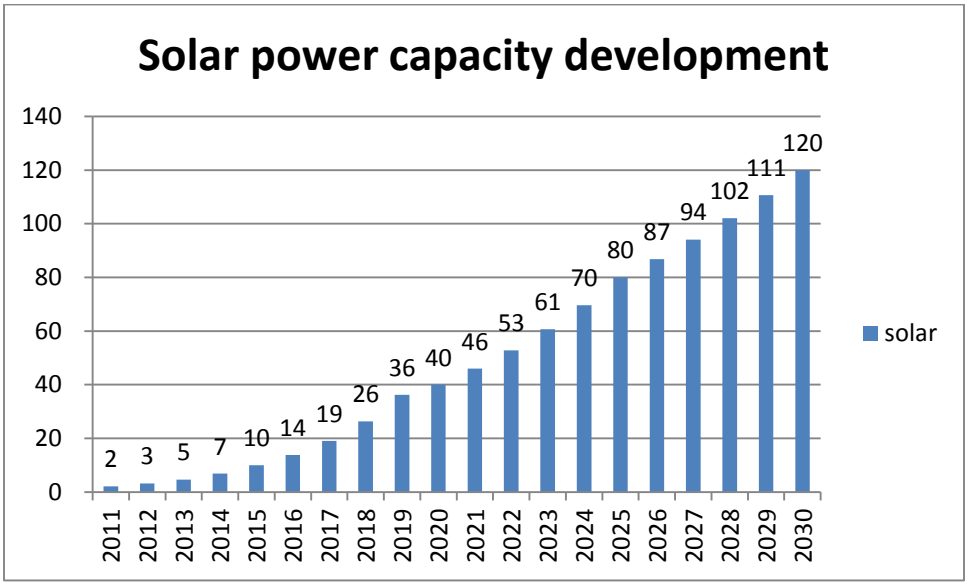


Figure 5.18 Solar power capacity in China under the RD scenario (unit: GW)

Natural gas

The category with the lowest amount of power generation is natural gas. As introduced in the literature review, the price of natural gas in China is three times more expensive than that in the U.S. Hence, in electricity planning, China's natural gas resource has long been considered for peak load adjustments. In China, oil supply is highly dependent on foreign imports and trades, which is associated with a higher price than other types of energy resources (Leung, 2010). As a result, oil is not normally used

unless under emergency circumstances. Due to the insignificant contributions in the past decades, the electricity planning procedures normally does not categorize oil as power generation (Leung, 2010).

Table 5.43 shows China's future demand of natural gas under different scenarios, and **figure 5.19** illustrates the power capacity of natural gas from 2011 to 2030. RD still provides the best scenario of the largest amount of capacity and the highest power generation amount. As shown in **figure 5.19**, there will be substantial growth of natural gas power capacity in China before 2020, and then due to the uncertainty of supportive policy incentives, the model is unable to predict future capacity growth of natural gas power plants. The post 2020 natural gas power capacity is predicted to be 170 GW. Since natural gas is very expensive in China and is only used for peak load adjustments, its demand as a power supply remains very low during the planning period.

In the next few decades, China's market for natural gas could largely improve due to two major development trends: 1) market structure changes could reduce the cost of utilizing domestic natural gas resources for the purpose of power generation, and 2) technology innovations could make huge progress in increase convenient access to potential natural gas resources. Currently, China is actively exploring the natural gas market, and has invested into R&D studies that will innovative natural gas technologies.

Table 5.43 Comparison of natural gas under different scenarios

	2010	2030 BAU	2030 HR	2030 RD

Capacity (GW)	26	170	170	170
Operation (TWh)	1	300	631	631

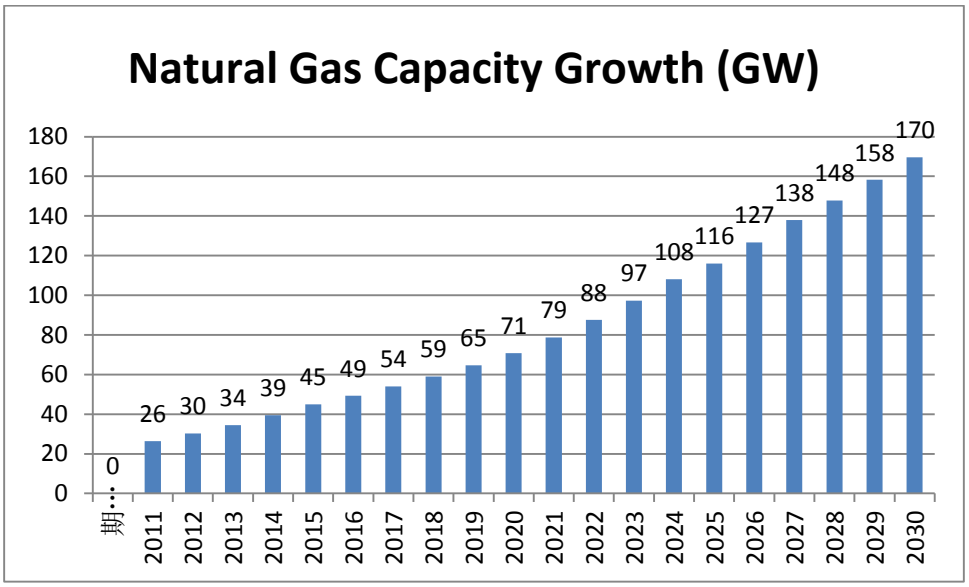


Figure 5.19 Natural gas power capacity in China under the RD scenario (unit: GW)

Appendix 16: Renewable energy policies in China during the 10th, 11th and 12th FYP

Period	Year	Policy
10th FYP	2001	Guidance of supporting domestic wind turbine technologies
		Announcement of wind power fiscal policies
	2002	Policy on supporting the development of renewable energy generation
	2003	Announcement of planning for large-scale wind farms
		Guidance of supporting the development of large-scale wind farms
	2004	Requirements of wind farm constructions
		Standards of wind resources evaluations
	2005	Announcement of the draft of renewable energy act
		Guidance of renewable energy industrial development
		Requirement of wind farm operations and maintenance
		Advices of development domestic wind power technologies and supports
11th FYP	2006	Pricing policies of renewable energy sources
		Regulations of renewable energy generation
		Management of renewable energy funding
	2007	Resource conservation act
		Mid-term to long-term renewable energy subsidy funding regulation
		Standards of renewable energy integration
	2008	Guidance of renewable energy project management
		Adjustment of large-scale wind power turbines taxation
		Management of solar power subsidies
	2009	Amendment of renewable energy act
		Announcement of off-shore wind farm planning policies
		Announcement of implementing wind power competition mechanism
		Guidance of accelerating solar power development
		Announcement of solar power financial supports
		Regulation of solar power integration pilot projects
	2010	Measures of wind power integrations
		Standards of wind power infrastructures
		Regulations of solar power subsidy applications
		Management of off-shore wind development funding
12th FYP	2011	Regulation of wind farm safety issues
		Guidance of wind resource predictions
		Suggestions of wind power integration
		Requirement of implementing wind power tariff
		Guidance of hydropower power pricing structure
		Requirement of finalizing feed-in tariff for solar power
	2012	Announcement of off-shore wind power coordination

		Planning of strategic industries development (renewable energy chapter)
		Requirement of new energy urban-rural development regions
		Funding allocation measures of energy conservation policies
	2013	Policies of coordinating wind power predictions and power grid integrations
		Regulations of wind and solar power project development
		Regulations of solar power integration requirements
		Announcement of wind power development in Yunnan province
		Announcement of wind and solar power development in Xinjiang province
		New guidance of renewable energy subsidy policies
	2014	Announcement of mandatory closure of small size coal power plants
		Measures of green dispatch policies
		Regulations of air pollution reduction measures through power sector
		Measures of distributed generation management policies
		Announcement of regulating wind power industries
		Announcement of sustainable development of solar power industry
		Guidance of financial support of distributed solar power development
	2015	New guidance of solar power project management policies
		Adjustment of solar power tax polices
		Announcement of NEA funding support of distributed generations
		Guidance of solar power distributed generation policies
		Requirement of establishing the carbon trading system
		New guidance of accelerating the development plan of renewable energy industries
		Opinions of enhancing quality monitoring system of renewable energy products
		Guidance of utilizing market mechanism on accelerating solar power development
		Announcement of establishing power system reform policies