The Hong Kong Polytechnic University

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A POLICY FRAMEWORK FOR SUSTAINABLE ELECTRICITY MARKET DEVELOPMENT

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CERTIFICATE OF ORIGINALITY

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ABSTRACT

This thesis points out that Electricity market development (EMD) emerges to be a significant concern following a shift of paradigm from the design of EMD aiming for considering energy as key commodity and service to deliver a sustainable low-carbon generation future. Hence, a feasible regulatory regime is needed to shape and constrain the decisions related to prices, returns and other variables in order to promote credibility with investors in the meantime of delivering greater efficiency for the economy as a whole. Improved policies and more effective investment framework are required in sustainable EMD for attracting private capitals. By means of deep investigation into China's electricity transmission and distribution section, its technical and economic characteristics are identified. The findings indicate that the hasty separation of the transmission and distribution segments is technically applicable but not economically viable for realizing a competitive distribution market which would be premature when the country's distribution networks, especially those in rural areas, are still underdeveloped. With this in mind, the political issues concerning China's power industry are studied in this project. Scheme of Control in Hong Kong is further discussed. A roadmap shows how the interest of different stakeholders can be balanced by instituting appropriate regulatory authorities and associated legal framework.

The feasible options of EMD are set to illustrate the interaction of the policy instruments, the market regulation and the sustainable investment environment. EMD requires setting up appropriate policies and building a more effective investment environment to attract

continuous provision of supporting resources. The economic benefits and costs have to be realized systematically and in a wide perspective including technical, operational and financial dimensions. A macroscopic analysis on the prevailing policy and potential of wind power development in China is then employed. It starts by analyzing the characteristics of wind power resources and pin-pointing the relationship between the regulatory policies and various economic, taxation, legal and grid integration attributes of wind power development. Then it follows by analyzing the status quo and capabilities of the wind power manufacturing industry in China including its operational efficiency and grid integration standards. The economic and environmental benefits are estimated by referring to the associated costing analysis in respect of the major contributing factors such as manufacturing, operational and financial factors. Results of the benefits analysis indicate that the use of the wind power generation helps to save a significant equivalent amount of standard coal consumption and effectively reduce the emission.

Subsequently, the thesis suggests that the energy policy of a sustainable electricity market development (SEMD) is set to ensure the energy needs of the community be met; to maintain the safe, reliable, efficient energy at reasonable prices; to minimize the environmental impact of energy production and use; and to promote the efficient use and conservation of energy. It involves a wide range of complex and interrelated technical, economic and regulatory issues. A dynamic decision making model has been developed to cope with the requirements of the multimarket trading policy framework. Fuzzy Differential Evolution (FDE) algorithm is employed to solve the multi-period stochastic optimization problem and obtain the optimum results for each time interval. Comparisons between different market scenarios demonstrate the economic and environmental positive influences of the policy framework to the society. Policies defining the three interactive markets can accurately reflect the intended goals such as decreasing emissions, promoting renewables, and keeping electricity cost at a reasonable level.

Considering all the goals and requirements, it is necessary for China to refine its blueprint of electricity market development by fine tuning the originally market-oriented reform momentum in China's 12^{th} five-year plan. This policy framework aims at designing appropriate policy instruments which caters for this purpose. Referring to this framework it discusses how China pinpoints her policies and strategies of reform to meet these requirements and achieve these goals of the 12th five-year plan. Comments drawn from corresponding international experiences are provided to illustrate how China is going to secure a sustainable energy future.

In summary, the following original contributions of this thesis are achieved:

- Establish a SEMD-SRRM policy framework and validate it as an effective decision making platform for electricity market reform;
- Derive and implement a sustainable electricity market scenario by optimizing wind power investment in China; and
- Derive and implement feasible policy options for sustaining electricity market development.

PUBLICATIONS

1. **Yang Wu**, H.W. Ngan, Zhongfu Tan, Xuran Ivan Li, and Songdan Guo, "Developing a SRRM-ISEMD Policy Making Framework for Sustainable Electricity Market Development", submitted to *Energy Policy*, 2012.

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6. Zichao Yu, H.W. Ngan, **Yang Wu**, "Restructuring China's Power Sector: The Technical, Economic and Political Foundations of Unbundling Transmission and Distribution Segments in China's Electricity supply industry", *The 9th IET International Conference on Advances in Power System Control, Operation and Management*, Hong Kong, Nov. 2012.

7. X.R. Li, C.W. Yu, F.J. Luo, S.R. Ren, Z.Y. Dong, **Y. Wu**, M. K. Meng, and K.P. Wong, "Decision Making Model for GENCO under the Emission Trading Scheme", *IEEE Power & Energy Society General Meeting*, San Diego, California, U.S., Jul. 2012.

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11. Y. Xu, X.R. Li, **Y. Wu**, and S.S. Shen, "Design of an Advanced Real-Time Dynamic Security Assessment Tool for Blackout Prevention in Modern Power Systems", *The IET Young Members Exhibition and Conference*, Hong Kong, Jul. 2010.

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LIST OF ABBREVIATIONS

ACE	Agent-based Computational Economics
BEP	Bureau of Electric Power
CDM	Clean Development Mechanism
CM	Carbon Market
CMA	China Meteorological Administration
DSR	Driving force-State-Response framework
EM	Electricity Market
EMD	Electricity Market Development
ESI	Electricity Supply Industry
ETS	Emission Trading Scheme
FDE	Fuzzy Differential Evolution
FIT	Feed-in Tariff
FM	Fuel Market
FYP	Five-year Plan
GENCOs	Generation Companies
GHG	Greenhouse Gas
IRR	Internal Rate of Return
ISED	Indicators for Sustainable Energy Development
ISEMD	Indicators of Sustainable Electricity Market Development
ISO	Independent System Operator
LMP	Locational Marginal Pricing

MEPI	Ministry of Electric Power Industry
NDRC	National Development and Reform Committee
NETA	New Electricity Trading Arrangement
NPV	Net Present Value
NWC	Net Working Capital
OCF	Operating Cash Flow
OPF	Optimal Power Flow
PCF	Project Cash Flow
PSR	Pressure-State-Response framework
QL	Q-Learning algorithm
RL	Reinforcement Learning
ROR	Rate of Return
SDPC	State Development Planning Commission
SD	Sustainable Development
SEMD	Sustainable Electricity Market Development
SERC	State Electricity Regulatory Commission
SGCC	State Grid Corporation of China
SOC	Scheme of Control
SOE	State Owned Enterprise
SRRM	State-Response-Regulatory Market framework
T&D	Transmission and Distribution
UHV	Ultra High Voltage

CHAPTER 1

INTRODUCTION

Electricity market development has been on-going worldwide for various reasons including one for chasing sustainable investment and development. It appears that an efficient and market-oriented investment regulatory is necessary for installing investment incentives [1] by which investment liberalization of electricity market will support their reforms to meet energy policy objectives [2] such as sustainability and safety, environmental protection, universal service and consumer protection [3].

1.1 Research Background

The electricity supply industry, which has long been considered by China as a foundation of the national industry [4] and of strategic importance for the country's socialist market economy [5], has undergone a series of reforms in the last decade. In 2002 the State Council [6] has released its "Annual Scheme Number 5", titled as "Scheme of Reforms in China's Electricity System". On one hand, it set the goal of reforms as to breach the originally monopolistic operation [7] and to introduce market competition into a restructured electricity supply industry [8]. On the other hand, the major measures to be taken in the reforms were determined as to separate electricity generation from power grids [9], to detach the ancillary services from the industry's core business, to unbundle electricity transmission and distribution segments and to foster market mechanism throughout the chain of power industry. During the past ten years the laws and policies to promote reforms and remarkable achievements have been enacted [10]. Five state-owned independent power producers were founded by reallocating national assets in power segment, thus realizing the separation of generation from grids [11]. Collective and private investments were also absorbed to boost the country's power generation [12]. At the same time, ancillary services were detached from different regional and provincial grid operators and reunited as two independent [13], state-owned corporations dedicated to the nation's electricity construction. The liberalization of distribution and sales of electricity was also attempted through a pilot run of direct contracts between power generators and high capacity consumers.

The above achievements are commonly seen and recognized by Chinese society. Despite those, growing concerns have recently been raised as reforms proceeded to the unbundling of power transmission and distribution segments [14]. For years the country has been discussing and preparing for liberalizing the sales side of electricity supply industry while little progress has been made [15].

1.2 Thesis Outline and Objective

Chapter 2 argues that professionals representing different stakeholders [16] spoke contradictorily about whether to break the integrated operation from transmission to sales. Most social scientists [17] insisted on continuous reforms through segmenting electricity transmission, distribution and sales and introducing market mechanism to each part separately [18]. They also challenged the financial and administrative power still held by state-owned grid operators and appealed for stronger supervision on their business [19]. On the contrary, people from grid operators stated that an integrated pattern is important [20] and should be carried on. They emphasized the economic and security significance [21] of a united nation-wide power grid. Section 2.2 points out that some researchers believed that monopoly rather than competition is the ultimate solution to electricity market for it can actually reduce the overall social costs [22] and thus the price of power supply. Consequently, it has been broadly realized that China's electricity market developments have come to a critical point where further policies and instruments are to determine future development and sustainability of the country's power industry.

In order to identify the present deficiencies in China's electricity supply industry, there is a need to sort out the causes and consequences and present a roadmap [23] of facilitating further reforms, including the technical, economic and political background of electricity supply industry and determines the foundations on [24] which unbundling of transmission and distribution segments can be realized.

Also, innovative design for a different mix of energy generation is desirable. It requires review on the current status of sustainable energy development [25], and justification on the different means of energy utilization [26]. According to International Energy Agency (IEA) statistics, total global carbon dioxide emission was 29 billion tons in 2007 [27], while China's emission was 6 billion tons, exceeding 1/5 of the worldwide total, and 50% of China's total carbon dioxide emissions came from the electricity sector [28]. Therefore, optimizing China's power generation structure and supporting renewable-energy power generation become important ways to ease the energy crisis and environmental pressures. Due to the abundant wind resources and advantages of wind power, such as lower cost, more mature technology and higher reliability, wind power becames China's first choice for developing renewable energy, shows great potential and significant achievements of development. The newly installed wind power capacity in China is roughly doubled every year during the last decade.

In the electricity market restructuring process, electricity utility is no longer confined by geographical area because deregulation offers expansion opportunities [29] for power holding companies to acquire both generation and network assets all around [30]. Thus, it is desirable to work out how attractive a fixed feed-in-tariff wind power project is. It could be considered as a stable investment because the tariff is fixed for a pro prolong period of time and apparently [31], annual average wind energy production is constant. Hence both price and quantity of wind energy can be assumed fixed.

In Chapter 2.4, a two-part approach is proposed, namely, designing a policy framework and devising feasible market instruments for securing sustainable investment in the EMD process. The policy framework is to be established and justified via a range of interrelated technical, economic and regulatory issues. The feasible options of EMD are set to illustrate the interaction of the policy instruments [32] with request to the market regulation and the sustainable investment environment. Analysis on sustainability of investment incentives for EMD in Britain and Australia [33] is performed and based on which a balance way of making decision among the key issues of reform, development and investment, as well as stability and sustainability is envisaged. Findings also suggest that an extremely market oriented approach is not a perfect solution for attracting investment in EMD and neither is desirable for an approach under an extreme of planned economy.

In Chapter 3, some critical concepts of sustainable development (SD) [34] are discussed. It points out that power demand is increasing continuously in the foreseeable future and the demand surge is not going to be not only simply expanding the current generation capacity structure because large numbers of tiny, uneconomical and coal-fired generating units are adversely affecting the performance of the electric power supply system. Furthermore, power generation is causing increasing environmental damages that require promotion of energy efficiency and sustainable growth of the electric power industry [35]. Section 3.2 suggests that utility de-integration and market competition represents an attractive alternative to policy makers, but little is concrete on the reform roadmap. A critical review on this fluid process is of particular interest to sustainable electricity market development (SEMD) when its policy framework has to be formulated under the open competitive market environment in the near future.

The main aim of Chapter 3.3 is to develop a policy framework in which feasible options for future development of the electricity market are justified. In approaching the issue of regulatory reform, governments therefore need to make clear the nature of their objectives, to take care of the potential conflicts, and to devise optimal tools or methods for achieving them. It is understood that many of the challenges in developing the market-oriented reform are not confined to the electricity supply industry alone, but require policies affecting the national energy economy as a whole and should not be developed in isolation from the rest of the energy system and economy. Also, there is little doubt that the driver in the current wave of regulatory reform is economic efficiency. Not only must reform achieve this key objective, but it must also achieve — or continue to achieve — others such as environmental performance and social stability. Hence in designing the regulatory framework, policy-makers need to pay very close attention to the long-term need of a robust and competitive society.

Chapter 3.4 suggests that in the electricity market, the market participants have to make strategic decisions independently with little or even in-complete information, and learn how to interact with each others. Also, they tend to exercise market power through strategic methods for gaining more profit [36]. Obviously, the same as other economic systems, the human's peculiarities such as learning, risk attribute, fuzzy thoughts are playing some key roles in the electricity market. Hence, modeling the behavior of the electricity market has been always a challenging task. On the other hand, designing an efficient electricity market requires a deep understanding of the marketing policies before implementation.

In Chapter 3.5 the main issues of China's wind power development including policies and economic benefits are analyzed. The approach is to explore the current status of power development [37] from a macroscopic point of view covering the electricity supply industry resources [38], policy and legal issues [39], various capabilities and benefits and finally the prospective potential development concerns. It proposes an evaluation process to investigate capital structuring decision [40] as an optimization problem in rate of return

(ROR) framework. The findings suggest that from both the economic and policy point of views, it is a healthier, more sustainable and efficient means to provide clean power for the energy market in China. In this respect, findings indicate that the appropriate investment model in wind power can help to achieve its economic and social goals. From the social-economic point of view, the findings are also regarded as a sustainable and efficient energy portfolio. Finally, the contribution comes from the results of analysis for justifying development of wind power in China as a cleaner and more efficient option.

In Chapter 3.6, it points out that since the introduction of the renewable energy legal framework, the use of renewable energy for electricity generation in China has grown rapidly [41]. The newly installed wind power capacity in China has roughly doubled every year since 2005 [42]. Wind power has been deemed as a potential clean energy source world-wide [43], and China is no exception, but its use links to some social engagement with support of appropriate policy set to achieve specific targets [44]. The approach is to explore the current status of wind power development from a macroscopic point of view covering the wind power resources, policy and legal issues, various capabilities and benefits and finally the prospective potential development concerns [45]. This section also includes comprehensive discussion on various aspects for justifying the regulatory measures and policy framework for supporting the sustainable energy development in China [46]. A notable feature in the adopted approach lies on the analysis framework based on which the value of the relevant energy policies is presented. The comments are in line and supplement the policy options suggested by [7] which says that wind power development in China would meet its environmental objectives realistically. Following suggestions from [47], analysis on the potential of China's wind power manufacturing industry is presented. Development of the wind power industry will also open up new areas in the manufacturing industry of both onshore and offshore wind power technologies which shall enable China to become a major player in the growing domestic and international markets. In this respect, findings indicate that the appropriate energy policy framework of wind power in China can help her to achieve her economic and environmental goals. From the social-economic point of view, the findings also support that China regards wind power as a practical means to achieve a more sustainable and efficient energy portfolio. Finally, the contribution comes from the results of analysis for justifying development of wind power in China as a cleaner and more efficient option.

In Chapter 4, it is argued that a price change in the wholesale electricity market occurs due to several socio-economic and engineering factors [48]. Electricity auctions are like repeated games, in which we need to take into account the learning behavior in order to analyze the possible solutions of the game. In Chapter 4.2, a fuzzy reinforcement QL method is developed to model the power supplier's strategic bidding behavior [49] in a computational electricity market. In the simulation framework, the QL algorithm selects power supplier's bidding strategy according to the past experiences and the values of the parameters, which show the human's risk characteristic [50]. The application of the proposed methodology for the power supplier in an IEEE 39 bus power system shows the performance difference in comparison of two bidding strategies. China began a step-by-step restructuring of the power sector more than ten years ago. In February 2002, the State Council issued its notice on the "Program for Electricity System Reform", setting forth the basic elements of the plan which remains in effect today [51]. The early significant reforms included the separation of generation assets from the grid companies, the dismantling of state-owned assets into diverse generation companies, and the establishment of an independent regulatory authority in the State Electricity Regulatory Commission [52]. After these initial reforms, however, the process was stagnated, in part due to the uncertainty inspired by the electric crises in California and elsewhere. The slowdown of the pace of reforms has, though, provided China with an opportunity to pause and reflect, and to adjust its plans for the industry.

Chapter 4.3 suggests that the use of agent-based simulation will enable the researchers to develop models of the electricity supply industry that are more realistic than current ones [53]. The suppliers used a reinforcement learning algorithm to simultaneously maximize their profits and reach a target utilization rate of their own power plant portfolio. The demand side model as presented by Bower and Bunn [54] in the year 2000 had a static price-responsive load. An alternative to the game theoretic approach, used to study the behavior of market participants, is agent-based simulation (ABS). In the implementation of ABS, the market participants develop their profit-maximizing strategy through the repetition of the game and reinforcement learning.

In Chapter 5, with respect to the 12th five-year plan [55], analysis over the technical, economic, environmental and social aspects of China’s electricity market development (EMD) is performed. Findings indicate that China has endeavored on new trends to further promote its EMD. Section 6.2 briefly describes the goals to achieve China’s 12th five-year plan [56] in respect of its power sector. Findings on the multi-dimensional aspects of the reforms and electricity regulation about clean energy and energy efficiency are provided in Chapter 5.3. Chapter 5.4 investigates how China defines a new strong smart grid and what could be promoted at this stage. Finally, our integrated policy framework and prospective electricity market strategies with numerical analysis are discussed in Chapter 5.5.

Chapter 5 also concludes that during the just completed 11th five-year plan period (2006-2010), rapid power industry growth met the needs of economic and social development, but this growth was disorganized [57]. Rapidly growing demand and price pressures will continue to confront the country, and the dominant long-term challenges will be energy efficiency, environmental protection, and climate change [58]. It appears that these problems were not addressed seriously in the early stage of electricity market reform. As a result, different jurisdictions are now thinking of ways to either redesign their earlier power sector reforms or superimpose new mechanisms on them to meet their environmental challenges [59]. China has the advantage of building the needed reforms into its power sector at the outset.

Chapter 6 provides a serial of feasible policy options and aggressive goals for expanding the case of renewable and other clean energy resources including hydro-electric, nuclear, advanced coal and most recently, high efficiency natural gas [55]. Although coal-fired facilities have the lowest nominal costs, explicit policies are need to be formulated so as to ensure investments for clean energy are favorable. The critical question for China is to find ways for formulating policies that would provide a trade-off between market force and planned economy type of platform.

CHAPTER 2

SUSTAINABLE ELECTRICITY MARKET DEVELOPMENT

Electricity Market Development (EMD) emerges to be a current concern following a shift of paradigm from EMD design with focuses upon energy as the key commodity to a need to deliver a sustainable low-carbon generation future. EMD has been on-going worldwide for various reasons including one for chasing sustainable investment and development.

2.1 Why Electricity Market Reform

It appears that an efficient and market-oriented investment regulatory is necessary for installing investment incentives by which investment liberalization of electricity market will support their reforms to meet energy policy objectives such as sustainability and safety, environmental protection, universal service and consumer protection [3]. For instance, Britain has marginally successively experimented two typical market designs [60], which are the Pool Market with capacity payment from 1990-2001 and the New Electricity Trading Arrangement (NETA) markets without capacity payment after the year of 2001 [61]. However, it was suggested [62] that one of the major criticisms of the Pool market was that it was designedly difficult to change the Pool rules, hence hard to heal with anomalies. Although the market oriented framework has the capability to introduce competition in electricity market development [63], existence of strong market power could not only benefit the investment in electricity reform but may obstruct an effective direction of investment [64]. It is expected that the investment for electricity market will be more sustainable in the reform process, and hence investment regulatory needs to match up with the reform policies respectively for more effective and sustainable outcomes. Furthermore, electric power developers have to consider how a regulatory regime will shape and constrain decisions related to prices, returns and other variables so as to promote credibility with investors in the meantime of delivering greater efficiency for the economy as a whole. EMD requires improved policies and more effective investment framework for attracting private capital. In the section, we propose a two part approach, namely designing a policy framework and devising feasible market instruments for securing sustainable investment in the EMD process. The feasible options of EMD are set to illustrate the interaction of the policy instruments, the market regulation and resultant sustainable investment environment.

2.2 Electricity Supply Industry Restructuring in China

The electricity supply industry of China has been in a process of reforms since the 1980s [65]. This section demonstrates a review on the four main stages of reforms in China so as to trace out the key features of various reform measures including those for power investment financing, the separation between government and power enterprises, and the division between power generation firms and power grids. The findings suggest that further regulatory change in China's electricity market development is necessary when integration of the electricity markets and increased competition are paving the way ahead for a market-oriented structure. Prospective electricity regulation in the form of a strong legal system and effective institutions that protect market competition and promote appropriate incentives for efficiency are suggested in the section.

The electricity supply industry in China has gone through the four main stages of reform starting from economic reform to fund its expansion by open capital investment, followed by a market oriented institutional reform on its State-Control-Enterprises, and coming to the third stage of reform by unbundling its generation from the grid so that competition can be introduced. Worldwide experience [66] points out that an efficient and market-oriented regulatory environment is needed for China to install incentives by which investment liberalization of the electricity supply industry will support her reforms to meet the national energy policy objectives such as health and safety, environmental protection, universal service and consumer protection. Market access barriers, however, remain in the partially liberalized markets in China, where only a segment of the energy supply chain is opened to competition [67]. It is expected that the energy sector will be more open to competition in the long run, and hence electricity regulation needs to match up with the competition rules for more effective competitive outcomes. This section provides a summary of analysis on recent changes to electricity market regulation in China. The analysis includes an overview of trends on the electricity market developments and suggests that a regulatory framework for China's power sector is a tool to bring China's energy process in line with the market value of energy.

Since 2002 China has been engaging a vast amount of resources in restructuring its power industry. China has so far achieved the separation of generation and auxiliary from the former vertically integrated entity. What remains unsettled and even grew into a tougher bottleneck is that without obvious efforts, in unbundling the transmission and distribution

(T&D) segments, there was actually a trend of reintegration and recentralization of power grid assets. The State Grid Corporation of China (SGCC), China's giant national grid operator, currently runs over 70 percent of the country's business in electricity transmission, distribution and sales, and its monopolistic market power continues to expand through pursuing national goals, like rural electric network renovation and strong smart grid construction. Despite SGCC's great contribution to the overall development of China's power sector, its operational efficiency has long been questioned and little public openness been challenged. The chaos in recent years in which interest controversies between local electric companies and SGCC evolved into armed conflicts exposed the structural deficiencies in a unified T&D configuration. It is consequently appealed that an approach to dismantle China's electricity distribution from transmission should be urgently dedicated to.

This section aims at designing an approach to unbundle China's electricity transmission and distribution segments. Such an approach should be effective in solving present problems and paving ways for further reforms. At the same time, it should avoid affecting the achievement of the nation's long-term goals. It is therefore suggested that a gradual approach with modest, step-by-step adjustments should be taken. Through deep investigation into China's electricity transmission and distribution section, its technical and economic characteristics are identified. The findings indicate that the hasty separation of the transmission and distribution segments is technically applicable but not economically feasible, for a competitive distribution market would be premature when the country's distribution networks, especially those in rural areas are still underdeveloped. Based on this conclusion the political issues concerning China's power industry are studied. A roadmap is presented which intends to balance the interests of different stakeholders and the administrative power of different authorities. A stronger legal system is also suggested to confine the market power of state-owned grid operators and foster a healthy market in the future.

2.2.1 Present Defect in China's Electricity supply industry

Professionals representing different stakeholders spoke contradictorily about whether to break the integrated operation from transmission to sales. Most social scientists insisted on continuous reforms through segmenting electricity transmission, distribution and sales and introducing market mechanism to each part separately. They also challenged the financial and administrative power still held by state-owned grid operators and appealed for stronger supervision on their business. On the contrary, people from grid operators stated that an integrated pattern is important and should be carried on. They emphasized on the economic and security significance of a united nation-wide power grid. Some believed that monopoly rather than competition is the ultimate solution to electricity market for it can actually reduce the overall social costs and thus the price of power supply. Consequently, it has been broadly realized that China's electricity market developments have come to a critical point where further policies and instruments are required to determine the future development and sustainability of the country's power industry.

In order to identify the present deficiencies in China's electricity supply industry, sort out the causes and consequences and present a roadmap of facilitating further reforms, an approach is employed to study the technical, economic and political background of electricity supply industry and determines the foundations on which unbundling of transmission and distribution segments can be realized.

Market reforms in electricity supply industry have proceeded for a decade. Did the process really evolve as originally designed? Recent studies indicated that reforms have been digressed from the initial purpose since 2005. People's persistent expression of their dissatisfaction over China's power sector reveals the deficiencies embedded in the industry. By studying reports of the State Electricity Regulatory Commission (SERC) and relative publications by social scientists, I identify the deficiencies and summarized them as in the following aspects.

The disaccord between coal price and electricity feed-in tariff" means a structural contradiction of benefits between thermal coal suppliers and thermal power plants. On the one hand, like all other market suppliers electricity producers earn their profits by making revenues larger than costs. Thus their profitability relies on the price of coal. Since 2000 coal prices keep climbing up, but feed-in electricity tariffs are not adjusted accordingly. Taking the case in Shanxi Province as an example, from 2008 to 2012 the price of thermal coal has increased by an average of ￥320/ton, meaning that a corresponding increase of ￥0.107/kWh in electricity feed-in tariff would be enough to cover the rise of costs of thermal power plants. However, the actual increase was only ￥0.081/kWh, leaving thermal power producers an involuntary loss of ￥0.026 for every kWh of electricity they sold. On the other hand, in most China's provinces the electricity feed-in tariffs and volume of production are still determined by annual plans of local governments. Little real competition has been introduced into power generation market and consequently neither price nor quantity can be decided by market mechanism. Generators are commonly not allocated an economical volume of production and they are forced to accept an even lower price if they want to produce more. As a result, the profitability of electricity producers is generally squeezed.

The original plan, according to "Annual Scheme Number 5" was to dismantle electricity transmission and distribution segments and bring competition into the sales side. However, so far little progress has been made in the related fields. The State-owned grid operators currently control electricity transmission, distribution and sales and take charge of all grid-related jobs including grid assets management, grid investment and construction, power grid operation and financial settlement of electricity tariff. By taking advantage of their inherited administrative power to counteract governments' interference and technological barriers to escape the public's supervision, power grid companies have greatly strengthened their market power and become the major impedance to further restructuration and liberalization.

The monopolistic expansion of state-owned grid operators has paralyzed further reforms and devastated the formation of a competitive electricity market. The State Grid Corporation of China (SGCC) owns five regional grid operators and all corresponding provincial electric power companies. In other words, this state-owned enterprise runs over 70 percent of the nation's grid-related business. Generally there is only one electric power company in one province and it sells electricity to all consumers, leaving them neither comparison nor alternatives. This situation is similar with power producers who have to trade with corresponding provincial companies. As a result, voices from consumers and generators are usually overwhelmed by power grid companies' opinion and fairness in trades is thus not guaranteed. Expansion of grid operators is not confined within grid-related areas. In 2011 SGCC bought XJ Group Corporation and PingGao Electric, which are China's two leading manufacturers of transformers, relays, high-voltage switches and electric meters. Such re-integration of ancillary services means the internalized production and purchases are likely to harm market competition and other producers' interests.

The key to a fair, healthy and sustainable market is the presence of powerful, responsive and effective regulation. In an electricity market, power generation and sales are two segments generally treated as competitive markets while transmission and distribution are still considered as natural monopolies. Therefore supervision should have two concerns: to maintain free competition and functioning of the market mechanisms; to limit the operational costs of power grid companies and to prevent their abuse of monopolistic market power. However, things in China are differently designed. Feed-in and sales tariffs are usually subjective to government plans. Price loses its elasticity of supply and demand thus can barely be used to guide market behavior. Grid operators are under loose regulation and their operational costs are seldom investigated or revealed. Some may bargain with governments and regulators, make collusive or corruptive contracts that harm the benefits of other market participants.

Electric power companies are in nature public utilities which should shoulder high social responsibilities with low rate of profits. However, grid operators in China are more devoted to capital expansion. SGCC has issued billions of dollars in overseas investments and currently holds Brazil Electric Company and Philippine National Grid Corporation. Such investments have unpredictable profitability and actually place extra burden on the country's financial budget But they are still valued as of strategic significance by the Chinese central government. The country's assessment tools for state-owned enterprises are in need for reconsideration and redesign.

2.2.2 Technical and Economical Foundations of Unbundling Electricity Transmission and Distribution Segments

Based on the "Scheme of Reforms in China's Electricity System" the next step in reforms is to unbundle the electricity transmission and distribution segments. By categorizing high-voltage transmission networks as "transmission assets" and low-voltage distribution networks as "distribution assets" [68], segmentation of original power grid assets is realized. These two classes of assets are then regrouped, respectively, as "power grid companies" and "power supply companies", which are managerially and financially independent. "Power grid companies" are in nature regional grid operators whose work includes high-voltage electricity transmission and inter-provincial trades. "Power supply companies" run inner-provincial business including the distribution and sales of electricity. More than one power supply company serve the consumers in one province, giving them more alternatives.

Through competition among electricity suppliers, price can be rationalized and upgrade in customer services can be achieved.

In China there are generally 13 levels of power transmission voltage, namely (Alternating Current) 1000kV, 750kV, 500kV, 330kV, 220kV, 110kV, 66kV, 35kVand 10kV and (Direct Current) ±800kV, ±600kV, ±500kV and ±400kV. When categorizing power grid assets, networks at voltage level 330kV and above should be assigned as "transmission assets", while networks at voltage level 220kV and below should be assigned as "distribution assets". Apart from places with poorly developed power grids or clients with special requirements, this principle can be applied to most regions and provinces. The key to such design is to guarantee the integrity of transmission networks and to preserve the scale effect of distribution networks. Since the majority of China's power grids are newly-built and well-structured, categorization of grid assets is physically applicable. In other words, China has the required technical foundations in dismantling its power transmission and distribution assets.

Business in electricity transmission has similar economic characteristics as those in electricity distribution. Both segments enjoy economies of scale, scope and network and present a certain level of cost sub-additivity. Therefore power grid operators, no matter in transmission or distribution, are natural monopolies. If transmission and distribution are unbundled, a single regional transmission company will be in charge of the entire region. Corresponding provincial distribution companies will also be setup but have no overlap in their business. That is, no actual competition or market mechanism is introduced by merely restructuring power grid business. At the meantime, there are places in China where electricity distribution networks are still underdeveloped. The gap between urban and rural areas is severe in terms of availability and quality of electricity services. Poor regions especially those in northwest China need central government financial support for rural electricity network renovation. Once the construction of distribution networks is liberalized, few investments will be guided towards those areas thus development of local electric infrastructure will be affected. In this sense measures taken to dismantle the transmission and distribution networks should be properly adjusted to local conditions so as to balance development between different regions and guarantee the long-term stability of the Chinese society.

2.2.3 Status Quo in China

Analysis on the technical, economic and legal aspects of the electricity market developments in China is performed and results of the findings indicate that the reform of the electricity supply industry in China has taken place not just in the way foreseen by theorists. China regards the reform firstly as a social contract committed to achieve the basic needs of energy, and then as a measure to support her long-term development plan for transitioning into a market-oriented economic system by 2020. It aims to maintain a balance among reform, development and stability. Findings also suggest that building autonomous regulators to oversee increasingly competitive electricity sectors is necessary if China is to benefit from world-class services. Although China has introduced limited competition in generation, the rest of the supply chain remains heavily regulated. Market regimes composing economy wide policies such as competition law and sector-specific electricity law are crucially in need of scrutiny. To ensure that prices reasonably reflect the costs of operating electricity networks, the electricity sector is subject to some form of environmental regulation. These regulations tend to affect the production of electricity as more than just energy goods but preferred services like those in transport and quality aspects of transmission and distribution.

The electricity supply industry in China was nationalised since its government assumed power in 1949. During those days, the relevant nationalized assets were fully controlled by the State- Owned-Enterprises (SOEs) under the administrative supervision of the Ministry of Electric Power Industry (MEPI). The State Development Planning Commission (SDPC) was the chief economic planning and tariff-setting agency responsible to project the demand for power, plan new projects to meet the future needs, and set tariffs for new plants. As the energy sector in China is growing rapidly to match the country's economic transformation, the rapid rise in production and consumption of energy has taken place largely as a consequence of the economic reforms introduced in the late 1970s. Various reform measures – such as power investment financing, the separation between government and power enterprises, and the division between power generation firms and power grids – have been adopted since the 1980s. In1985 State Council issued the ''Provisional Regulation on Encouraging Fund-Raising for Power Construction'', and the power sector has successfully raised investment from both domestic and foreign sources. However, the national demand for electrical power during the first years of the new century has led to a mismatch between supply and demand. In2005, a power supply deficit existed resulting in the emergence of power shortages across the country. Households and industries continue to experience planned power outages on a regular basis. This appears to be a direct result of the drive for economic growth being pursued without sufficient regard for the energy requirements involved or enough lead time to build the necessary generation, transmission and distribution infrastructure. Recognising the need to respond to these challenges, the government decided to implement far- reaching reforms in the electric power industry of which the main stages of development are outlined.

Under the centrally-planned system, the electricity supply industry was structured as one strip. Industrial governance at that time could be roughly divided into three levels: central, local, and enterprise. At the central level, the State Council had sole power to legislate detailed economic rules for the implementation of laws passed by the People’s Congress. The Ministry of Electric Power (MEP) was the functional governmental organ under the State Council which managed all national electric assets. At the provincial level, the Bureau of Electric Power (BEP) was the local agent of MEP and supervised generation and distribution SOEs in designated geographical areas. Provincial bureaus proposed industrial development and operational plans and had authority to directly control electricity generation, transmission, and distribution in designated regions.

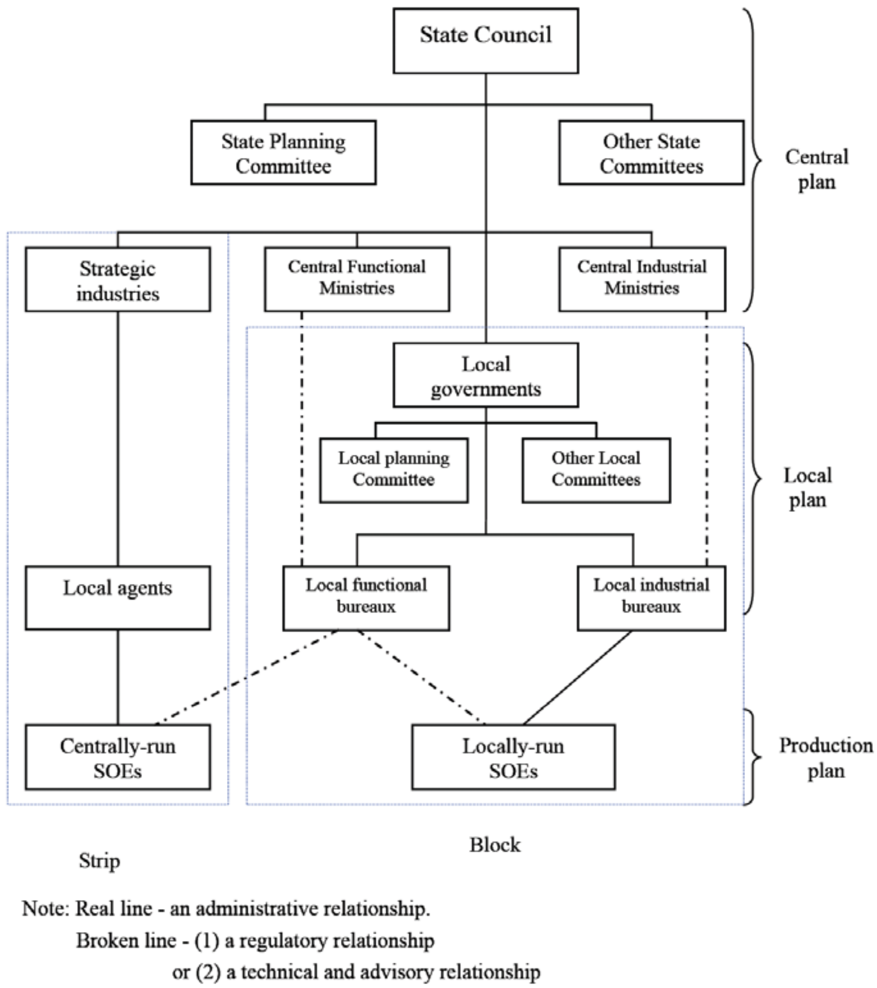
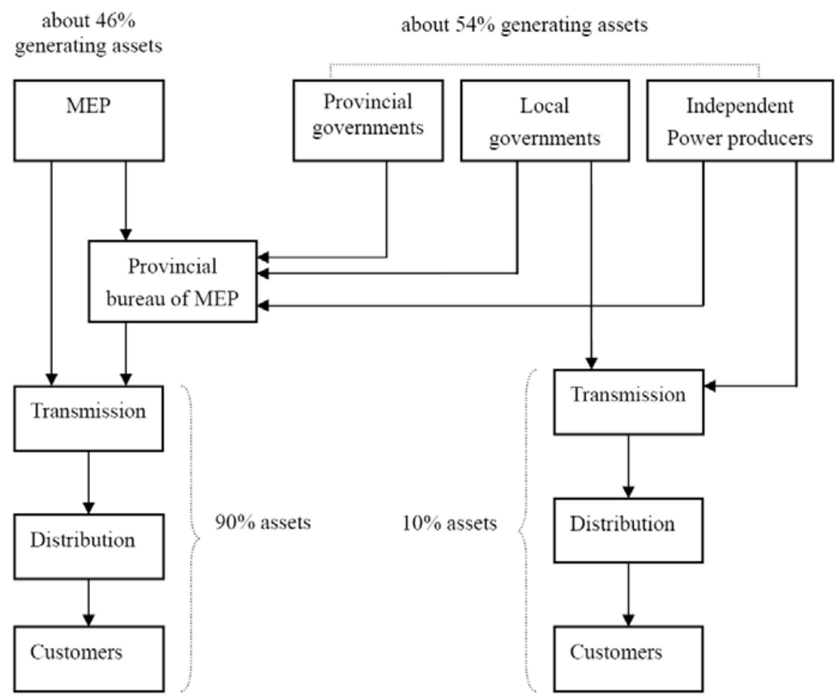


Figure 2-1 Hierarchy of the centrally planned economy

During early years of electricity market developments when electricity generation were faced with the problem of insufficient investments, the Chinese central government started to allow capital from local governments, private enterprises and foreign companies to enter the power sector. Firstly, the central government adopted a policy called 'anyone who invests wins preferences and profits'. Higher prices and long-term buying contracts for electricity were permitted. Typically, a 15% rate of return was guaranteed to investors. At the same time the central government changed the rules for investment approval. Much of the decision-making authority for electricity projects with 50MW generating capacity or less was assigned to local governments. Since local governments had inherent incentives to develop local economy and infrastructure, these reforms yielded a rapid expansion of the Chinese electricity supply industry. By the end of the 1990s, the proportion of generating capacity controlled by central government decreased to less than 50%, although transmission and distribution remained under unified central control [69]. Secondly, the government allowed selected firms to raise funds, initially from the international stock market and later from domestic stock markets. Statistics showed that by 2002 at least three generation companies floated on foreign stock markets and another 39 on domestic stock markets [70]. To some extant these measures relieved financial pressure on central government. For example, between 1996 and 2000 the proportion of investment funds from central government was reduced to about 44.6% of total construction capital. However, the fact that public assets play a major role in power investments remains unchanged, with 64% of the total investments coming from government resources.

Reform of industrial governance should inevitably go hand in hand with adjustments in investment mechanisms. The central government recognized from early reforms that a bundled structure of administrative authority and business functions could no longer effectively implement electricity policies or benefit the development of the industry, therefore decisions were made to separate administrative functions from corporation management. Provincial electric power companies were constructed alongside provincial electricity bureaus. Attempts to separate resources, responsibilities and personnel in local electric companies were also made but little progress was achieved.



Note: 1. This figure is modified from Figure 8: Electricity System After Early Reforms (Zhang and Heller, 2005).

2. Percentages represent shares of assets.

Figure 2-2 Power system after earlier reforms

In tandem with the 2002 restructuration, an independent electricity regulator, the State Electricity Regulatory Commission (SERC) was established by the State Council in 2003, which was the first supervisory entity in China's infrastructure industries. SERC is expected to carry on electricity reforms, speed up the construction of laws and regulations, and most importantly, develop a successful electricity wholesale market. In the same year, China started trial operation of regional electricity markets [52]. Electricity price in regional markets is set by a two-tier mechanism – about 80% of the demand is covered by the long-term annual bilateral contracts and the remaining is traded in monthly and daily markets. The goal of restructuring the electricity supply industry, by SERC, is to build six competitive regional markets across provinces. However, at present provincial electricity markets are temporarily allowed in some 31 cases as an interim measure. Electricity reform in China is still ongoing. Many plans about the wholesale market are still on blueprints, and the future has not yet been foreseeable.

Between 2000 and 2006, the Chinese government experimented with limited electricity markets in some areas. In 2003 a partially competitive wholesale electricity market was introduced in some eastern and southern places in China on a trial basis. Electricity prices were determined through a competitive bidding process. Participating power plants were limited to selling a maximum of 10 to 20 percent of their electricity through the bidding. Unfortunately all trials were terminated by 2006 and SERC did not report any consequential conclusions about the application of wholesale electricity markets in China.

2.2.4 Summary

This section studies the third phase of China's electricity market developments in which unbundling of electricity transmission and distribution (T&D) segments should be achieved. By identifying the deficiencies in China's power sector it is concluded that further reforms should focus on breaking the integrated pattern from transmission to sales. The technical and economic characteristics of T&D sections are investigated. Findings indicate that dividing power grid assets is currently not feasible but liberalization of sales is a necessary condition for a healthy and sustainable power market. Independent trading institutions are therefore suggested to manage electricity transactions and introduce diversified contracts into power markets. This measure needs to be accompanied with adjustments in electricity market regulation. Administrative power presently held by grid operators should be transferred to the State Electricity Regulatory Commission. A stronger legal system is also required to guide market regulation and guarantee fair competition.

With all the above description a summary of the development of China's power industry and electricity market is provided as follows. This summary is based on a pattern which identifies the EMD process in China as three consecutive while distinct phases.

The 1st phase (1986-1995) of China's power industrial development includes 7th and 8th five year plans and its milestones can be summarized as:

- Multi-channel financing capital expansion project
- Allow foreign investment since 1995
- Aroused the enthusiasm of the society to generate power and rapidly changed the serious power shortage all around the country
- Multiple investment bodies gradually formed in the power market

The 2nd phase (1996-2000) refers to the 9th five year plan here:

- State Power Corporation was founded in January 1997
- Four-step reform strategy in August 1998: Separation of administration from enterprise operation, Separation of generation from grid and bidding for grid access

The 3rd phase (2001-2010) covers the 10th and 11th five year plans:

- Plans of power regime reform was formally approved by the State Council in March 2002

- State Electricity Regulatory Commission (SERC) was set up in October 2002
- The former SPC was restructured into two grid corporations, five large generation companies and four subsidy groups in December 2002
- Separation of generation from grid

2.3 Scheme of Control Agreement in Hong Kong

Reform of electricity supply industry (ESI) has been a major concern in the energy sector throughout the world in the past two decades. It leads to changes in structure, ownership and market operation of power enterprises in different forms [71] such as unbundling privatization, deregulation and the introduction of direct competition into the industry. A motive of the changes is to move away from the paradigm in which regulation may have been too responsive to protect benefits of certain interest groups and inherent information asymmetry between regulators [72] and those that are to be regulated may also lead to distortions such as under or over investment.

2.3.1 Overview

In Hong Kong, electricity needs are served by privately owned utilities with vertically integrated operation and financially regulated through a Scheme of Control (SOC) Agreement [73]. The SOC Agreement was designed in the 1960s and is now considered insufficient to cope with the changing environment when investment is no longer the only main concern. One allegation is that the present SOC Agreement (expiring by 2018) cannot provide sufficient motivation for better performance. It is further postulated that the simple rate-of-return regulation is a cause of uneconomical deployment of resources due to lack of market arbitration and competition mechanisms, and insufficient incentive to optimize the use of scarce infra-structure resources.

Introducing market competition is poised to be a typical feature of Electricity Supply Industry (ESI) reform worldwide including in our vicinity, Chinese mainland. Any possible reform of the ESI in Hong Kong is more than likely to follow the worldwide trend and, in fact, it aligns with one of the Government's principal policies in enhancing economic efficiency and free flow of trade. The Government considers it be best nurtured and sustained by allowing a free play of market forces and by keeping intervention to a minimum.

The present regulatory system relies heavily on the SOC agreements which were made between the Government and the utilities in the 1960s when Hong Kong at that time required huge demand of electricity. The intention of the agreements is to provide a stable framework to encourage investment through a guaranteed return derived as a function of the fixed assets installed. Under the present regulatory system, the utilities have to submit proposal of their expansion to the Government for approval. However, the incentive for each individual utility to maximize its own fixed assets is an inherent feature of the present framework. In this case, there is little incentive for the two utilities to go for options involving asymmetric incremental asset additions though they are at least-cost for the HEC-CLP overall. Virtually, the present system does not fit well with the pursuit of economic synergy of having more market driven incentives. Hence, the Government has indicated clearly a wish to see a certain degree of competition to the electricity supply industry upon expiration of the SOC Agreement by 2018.

2.3.2 Recent performance

Since electric utilities in Hong Kong have been privatized right from their inception, the regulatory reform of the ESI in Hong Kong aims more specifically to correct inefficiencies caused by the SOC Agreement rather than on relaxation of ownership. It is viewed as complementary to the success of existing operation in terms of incentives for investment and system reliability. The proposed reform of any sort is to broaden trade and to facilitate competition. Establishing a credible regulatory framework is an essential element of the overall reform because it has to create a stable and predictable operating environment that is conducive for long-term participation and investment. In this section, a framework is proposed which ensures sufficient rules and regulations be set in place in such a way that reform of the regulation not only improves the status quo but also leads the way to an even more competitive future.

The SOC was first proposed by CLP in 1964. HEC did not join in the SOC Agreement until 1979, the year CLP renewed its Scheme with the Government. It lays down rules for governing financial affairs of their electricity-related activities and consists of the following main points including that the duration of the regulatory contract is fixed at 15 years, with a 5-year review clause.

The Scheme requires each company to set up a development fund. The main purpose of the fund is to assist the company in financing its acquisition of fixed assets. In addition, any difference between the actual profit after taxation and the permitted return will be transferred to or from the fund. In other words, the company is not allowed to keep any excess profits above the permitted level. Any excess profits have to be put into the fund. The development fund does not form part of distributable shareholders' funds and is, in effect, a liability owing to customers carried in the company's books. The permitted rate of return on equity-financed asset is 15%, while the permitted rate on asset financed by debt or the development fund is 13.5%. That extra 1.5% is aimed at "encouraging shareholders to increase investment".

From the permitted return, interest deductions must be made in order to obtain the figure of net return. These interest deductions are:

- interest payable on long-term financing up to a maximum of 8% per annum; and
- a charge of 8% per annum on the average balance of the development fund, which is to be credited to the rate reduction reserve. The purpose of the rate reduction reserve is to give rebates to consumers.

2.3.3 Regulation targets

By nature, the SOC agreement can be regarded as a sort of ESI regulation which works on a guaranteed rate of return on investment type of model. It has proven to be a successful model particularly during the early stages of development in Hong Kong, for the power utilities in securing investment for expanding their infrastructure. When referring to evaluation on its effectiveness as a regulatory scheme, Littlechild in 1983 proposed a number of criteria which can mainly be grouped into the following aspects:

- Protection against monopoly
- Encouragement of efficiency and innovation
- Minimization of the burden of regulation
- Promotion of competition
- Proceeds and prospects of the firm

2.4 Sustainable Investment in Electricity Market Development

Sustainable electricity market development (EMD) requires setting up appropriate policies and a more effective investment environment for attracting continuous provision of supporting resource. The economic benefits and costs have to be realized systematically and in a wide perspective including technical, operational and financial dimensions. Wind power is a potential renewable generation source having a number of basic concerns on development of clean energy technology, structural reform of power markets and risk portfolio analysis. In this section, an optimization approach is proposed to maximize the wind power investment evaluation based on using the Rate of Return (ROR) as a decision variable subject to capital constraint. Results from a case study suggest that wind power contribute to achieve a low carbon electricity market and the proposed evaluation approach is practically feasible.

In this section, a two-part approach is proposed, namely, designing a policy framework and devising feasible market instruments for securing sustainable investment in the EMD process. The policy framework is to be established and justified via a range of interrelated technical, economic and regulatory issues. The feasible options of EMD are set to illustrate the interaction of the policy instruments, and market regulation and resultant sustainable investment environment. Analysis on sustainability of investment incentives for EMD in Britain and Australia is performed and based on which a balance among the key issues of reform, development and investment, as well as stability and sustainability is envisaged. Findings also suggest that an extremely market oriented approach is not a perfect solution for devising investment in EMD and neither is desirable for an approach under the framework of planned economy.

2.4.1 Policy Instruments

As the EMD process has to be intertwined with a multitude of political, legal and economical dimension of support, effective promotion of sustainable development require use of appropriate social and environmental policy instruments to be discussed in the following context. So far the sustainable investment problem is concerned which arises from the fact that the current electricity market focuses mainly on energy as the key commodity and the market is not designed to deliver a sustainable or low-carbon generation future, a feasible solution is envisaged based on a new market design for implementing policy instruments such as carbon price support mechanism, defining appropriate emission performance standard, devising a capacity mechanism and setup up long-term feed-in tariff for low carbon generators. By analyzing their different economic attributes, the risk-reward balance approach is extended to include mechanisms for pricing of capacity, increasing flexibility and firmer pricing of carbon.

2.4.1.1 Carbon Price Support Mechanism

The abatement cost of carbon emission is usually calculated using the following expression [74]:

$$c_i = \frac{c_m - c_b}{E_{mb} - E_{mm}} \tag{2-1}$$

Where

c_i is the abatement cost of the energy-saving retrofit project *i* ($/ton),

c_m is unit power generation cost for the energy-saving retrofit project ($/kWh),

c_b is unit power generation cost for the base line project ($/kWh),

E_{mb} is carbon emission factor for the base line project (tCO_2/MWh),

E_{mm} is carbon emission factor for the energy-saving retrofit project (tCO_2/MWh).

The candidate unit for retrofit is taken as the baseline project. Because the implementation of the energy-saving retrofit project is in the pulverized coal power plant, the emission factors can be converted to the net coal consumption rate, which is shown as follows:

$$E_{mb} = b_{mb}\gamma \tag{2-2}$$

$$E_{mm} = b_{mm}\gamma \tag{2-3}$$

Where

b_{mb} is the net coal consumption rate of the baseline project,

b_{mm} is the net coal consumption of the retrofit project,

γ is carbon emission of for standard coal.

To make $\Delta b = b_{mb} - b_{mm}$, the abatement cost formula can be written as:

$$c_i = \frac{1}{\gamma \Delta b}(c_m - c_b) \tag{2-4}$$

However, the formula for the reduction quantity of carbon emission is:

$$ER_y = BE_y - PE_y \tag{2-5}$$

Where

ER_y is the emission reduction for the retrofit project in year *y* ($MtCO_2$/yr),

BE_y is baseline emission in year *y* ($MtCO_2$/yr),

PE_y is the emission of the retrofit project in year *y* ($MtCO_2$/yr).

It is assumed that the annual quantity of electricity generation is at the same level, equation (2-5) could be then turned into:

$$ER = \gamma \Delta b G \tag{2-6}$$

Where

ER is annual emission reduction for the retrofit project ($MtCO_2$/yr),

G is the annual quantity of electricity generation (kWh).

2.4.1.2 An Emission Performance Standard

Numerous resources and polices have been devoted to controlling greenhouse gas emissions from the power supply industry and other energy-intensive sectors. Greenhouse gas emissions trading, green pricing programs and renewable portfolio standard are three concurrent policies that are expected to be implemented to reduce our reliance on fossil-fueled or coal-based power generations. However, greenhouse gas trading aims at reducing greenhouse gas, green pricing and renewable energy portfolio directly target to promote renewables on a voluntary and mandatory basis, respectively.

In some countries, green pricing programs providers are allowed to bundle power generated from coal-based plants with renewable energy credits and sell as green power [75]. This provides a direct arbitrage opportunity between renewable energy credits and green power. However, there is not much theoretical or empirical study examining the prices between renewable energy credits and green premium.

2*.4.1.3 A Capacity Mechanism*

Britain has adopted two types of electricity market framework, one is the Pool Market, and the other is New Electricity Trading Arrangement (NETA) market. Basically, the NETA is designed as a kind of energy-only market. In an “energy-only” market, there is no separate payment for energy and capacity and the primary income source for recovery of capital costs is the difference between the market clearing price or the contract price in a pay-as-bid system and the generators' marginal costs. In the former Pool Market framework, Britain adopted a capacity payment mechanism based on the peak load pricing concept. According to that theory, generation of electricity requires two factors of production: capacity and energy, where the amount of energy that can be produced in any given time period is constrained by the available capacity [60]. Hence, the energy is efficiently priced at marginal cost and an adequate charge is imposed on the peak-period users.

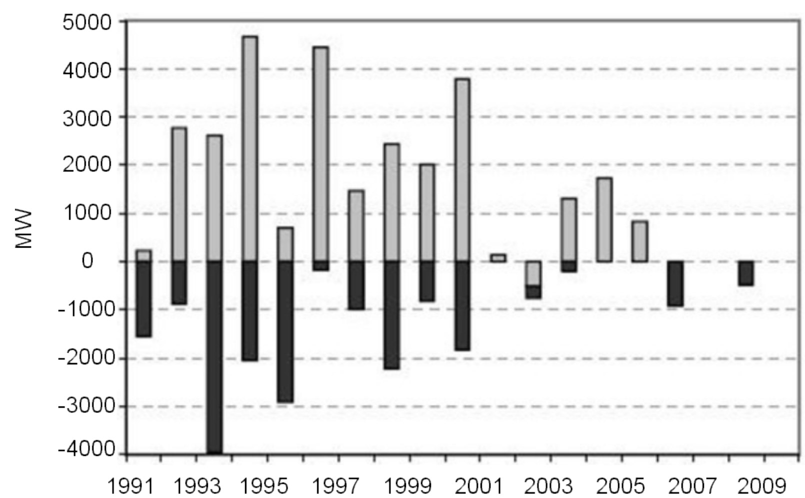


Figure 2-3 Past and declared future generation capacity

The Electricity Pool of England and Wales was a mandatory auction spot market, which was established in the year 1990 and operated in a day-ahead mode. The Pool operated as a uniform single-price auction for buying and selling power whilst the balancing mechanism is run as a discriminatory auction, which is on pay-as-bid basis. After which, the capacity payments have been abandoned and the NETA becomes an energy-only market. It is argued that capacity payments and the mechanisms that attempt to mitigate price volatility can be thought of as targeting the symptoms rather than the cause of electricity mechanism deficiencies [60]. However, Fleten suggested that the lack of demand response in electricity markets is the root of the problem [76]. A bidding price cap coupled with a capacity mechanism may also further reduce demand responsiveness, as consumers no longer face high prices. Any regulatory intervention requires caution, since it may introduce secondary side effects or perverse bidding incentives making further regulatory intervention self-perpetuating. It can be observed that since privatization in 1990, generation connections and disconnections have remained at high levels during the Pool but decreased dramatically since that implementation of the NETA, which is shown in Figure 2-3.

The fundamental issue is whether the burden of providing – and paying – for reserve capacity should be decentralised and be borne individually by the players of the market, or centrally optimised by the system operator, and paid collectively by the market players through the balancing mechanism costs. A consensual starting point is that the costs of balancing the system and providing for reserve should be minimized. However, capacity payments and relatively high wholesale electricity prices resulted in large investments in generation during the second half of the 1990s, leading to excess capacity and, after 2000, falling wholesale prices under the Pool, which contributed to the postponement of construction on a number new power station which had received planning permission [77]. The ideal balancing mechanism designs are somewhere in-between the two extreme cases of central dispatch of reserves and individual balancing. It would optimise incentives for market players to balance their positions.

Meanwhile, there are no capacity payments in the NEM and operating decisions remain the responsibility of the participant concerned. Projections are broadcast of how the half-hourly prices are expected to solve for the following day and these projections are updated on a three-hourly basis to reflect changes in bids and offers, unit availability and forecast demand. The combination of spot market design simplicity and price volatility has encouraged active trading in derivatives linked to spot price for risk management and market discovery purposes. Effective commercial management of risk is essential to the operation of a competitive electricity supply industry.

2.4.1.4 Long-term Feed-in Tariffs for Low Carbon Generators

Regulators that offer a feed-in tariffs (FIT) program guarantee a set price for energy to private investors for feeding power into the electricity market. This alleviates the concerns of private investor who would otherwise avoid investments because of the risk from higher than expected program costs. Since FIT is set based on technology, incentives can be placed on both established and emerging generation technologies. Advanced FIT may differentiate prices based on time-of-use and may offer more detailed contract terms to the investor [78]. Governments, attempting to reduce carbon emission, may introduce penalties through carbon taxes. With a carbon tax mechanism, a tax would be imposed on a dollar per tonne of emission basis, for carbon emissions accrued by the emitter or end user.

In jurisdictions where significant electricity generations are from thermal plants or coal based generation, such as in Hong Kong, the impact of FIT and related policy issues are expected to be different.

2.4.2 EMD Main Steps

It is known that market fundamentals dictate that electricity prices should rise to the marginal cost of generation required to meet demand during times of shortage. That, therefore, provided balancing mechanism mutes scarcity signals by paying generators their bid price and not the marginal price, in order to mitigate market power and possibly reduce volatility. The current arrangements result in imbalance prices which can be significantly lower than the marginal energy balancing price, particularly at shortage times.

Figure 2-4 shows a comparison of the current price and price calculated by the marginal methodologies weekly, across the year 2003-2004. Using average rather than marginal prices gives incorrect imbalance signals, as the imbalance charge depends on the relative contracting position of the generator – short or long – as compared to the market global imbalance [60]. And they also concluded that a marginal methodology for the calculation of imbalance prices would provide more appropriate signals to the forward markets than the current methodology, especially at times of scarcity. Therefore, the only workable solution seems to come back to marginal pricing with a single imbalance price. Given the change of market structure since the creation of the NETA, the concerns about market-gaming that led OFGEM to advocate pay-as-bid dual imbalance pricing could be appropriately relaxed.

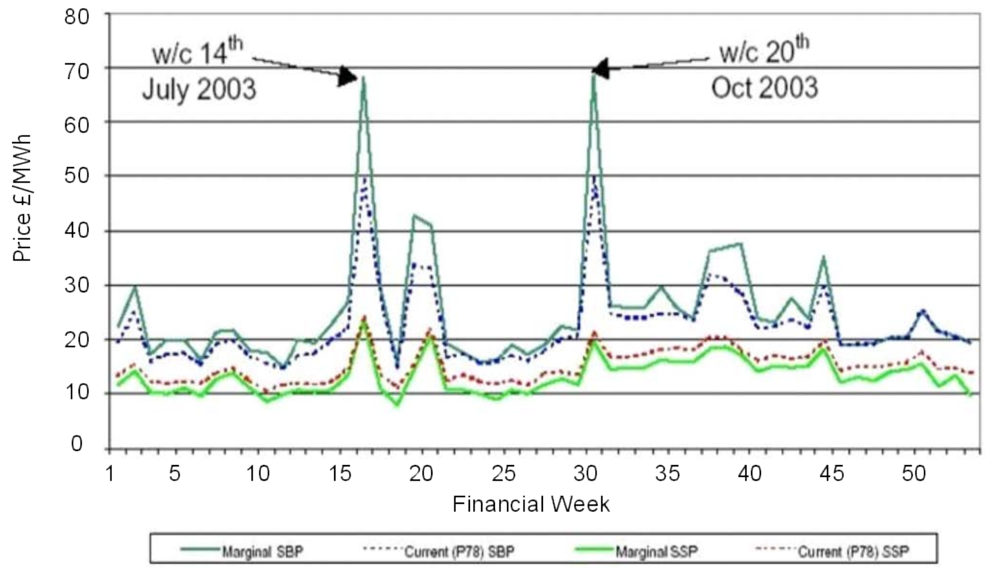


Figure 2-4 Comparison of average and marginal pricing methodologies 2003-2004

How market forces are reshaping the roles of investors and governments – Electricity markets have in general encouraged adequate investment while governments remain concerned about the performance of electricity markets and the reliance on volatile electricity prices to bring forward that investment. Market liberalization intends to limit government intervention in the electricity market but volatile electricity prices have put pressure on governments to intervene and to limit variation of such prices.

While market prices are a necessary incentive for new investment in peak capacity, government intervention into the market to limit prices may undermine such investment. For investment to thrive, the government's role in electricity reform needs to be more carefully defined. Its role should include monitoring the level of investment, and being able to respond effectively to threats of market manipulation. Table 2-1 shows the generic outlines of an EMD process in most countries all over the world. In practice, the actual frameworks need to take into account both the specific characteristics of the national electricity supply industry and the generic features of the liberalization framework.

However, how investors have responded to the need to internalize investment risk in power generation still has to be considered. While capital and total costs remain the parameters shaping investment choices, the value of technologies, which can be installed quickly and operated flexibly, is increasingly appreciated. Investors are also managing risk by greater use of contracting, by acquiring retail businesses.

Table 2-1 Main steps in EMD

Phases	Features
Restructuring	- Vertical unbundling of generation, transmission, distribution, and supply activities - Horizontal splitting of generation and supply
Competition and Markets	- Whole market and retail competition - Allowing new entry into generation and supply
Regulation	- Establishing an independent regulator - Provision of third party network access - Incentive regulation of transmission and distribution networks
Ownership	- Allowing new private actors - Privatising the exsiting publicly owned businesses

While price fluctuations are intrinsic to well-functioning markets, these can be reduced by encouraging greater response of demand to prices – providing electricity users both the incentive and the ability to vary their demand for electricity in response to changes in electricity prices.

By increasing demand response, price and demand peaks can be clipped and reliability improved. The "response" involves voluntary changes in consumer behaviour – deferring power demands around the house such as hot water heating, clothes washing and drying, dish-washing, for instance, or by reducing demands through installing more efficient air conditioners, heating or lighting systems.

The power to choose shows that the economic benefits of demand response are large. Given the additional benefits of improved reliability of electricity markets, reduced investments in peak capacity, more efficient energy use and associated reductions in greenhouse gas emission, the incentive for governments to act to encourage demand response in strong. An electricity market with active demand response is a more efficient market.

2.4.3 Summary

In this section, it has been reviewed that electric power developers would consider global investment opportunities and how a regulatory regime will shape and constrain decisions related to prices, returns, and other variables. It shows that successful regulators seek to promote credibility with investors and a sense of fairness in the eyes of the public, while delivering greater efficiency for the economy as a whole.

The features of the EMD are highlighted as to increase efficiency through better investment decisions, better use of existing plant, better management, and better choices for customers. From the analysis of the concerns of various stake-holders, it is concluded that the key issue for customers is market conduct (price, availability, and quality) whilst the market regulators would assess options for competition, decide on setting up the fair entry rules, rule on pricing flexibility, monitor outcomes, and deal with compensation issues (stranded assess).

From the different electricity frameworks as reviewed in the section, it concludes that their choice depends on the degree of competition and extent of vertical integration desired. Each model has its pros and cons and so the choice of the policy framework depends on the characteristics of each country. In the discussion on the energy market reforms in Australia over the last decade, the EMD has delivered significant benefits from lower prices, better investments and the flow-on benefits of these to the competitiveness of Australian industries.

Although investment incentives tend to be market oriented and the market signal is functioning effectively, the EMD process remains an ongoing process. The case discussion on the NEM confirms that successful development of the markets lies on the effectiveness of the energy policy instruments which have to be interactively linked to a number of important areas such as demand-side participation. Reforms to address those issues are meant to provide better signals for investment to be sustainable.

CHAPTER 3

ISEMD-SRRM POLICY FRAMEWORK FOR SUSTAINABLE ELECTRICITY MARKET DEVELOPMENT

Sustainable electricity market development (SEMD) requires setting up appropriate policies and a more effective investment environment for attracting continuous provision of supporting resource. The economic benefits and costs have to be realized systematically and in a wide perspective including technical, operational and financial dimensions. With electricity market restructuring, electricity utility is no longer confined by geographical area because deregulation offers expansion opportunities for power holding companies to acquire both generation and network assets all around. Thus, it is reasonable to work out how attractive a fixed feed-in-tariff wind power project is. It could be considered as a stable investment because the tariff is fixed for a long period of time and apparently, annual average wind energy production is constant.

3.1 Overview of Past Energy Policy Frameworks

United Nations (UN) employed the concept of Sustainable Development (SD) with the definition of a dynamic pattern of social, technological and environmental policies and indicators that make the countries to move toward a better wellbeing. There is no final fix sustainable state or circumstance [79]. Based on the SD concept, several frameworks have been provided by the international organizations such as UN, World Health Organization (WHO) and the Organization of Economic Cooperation Development (OECD) [80]. A

Driving force-State-Response (DSR) framework has been developed by the United Nations Commission on SD based on the Pressure-State-Response (PSR) framework [81]. In addition, PSR model has been modified by the European Environment Agency for analyzing environmental problems [82]. Those two frameworks have been used world-widely to prepare sets of environment and other indicators.

SD has played a significant role as a foundation of several policy making frameworks developed mainly by international organizations. In this section, some critical points regarding the origination and formulation of the SD concept are discussed specifically in request of the electricity market development. It is argued that as consumers need rapid capacity expansion and power imports in the foreseeable future to meet the continued demand surge, the structural configuration for providing the generation capacity is highly inadequate because large numbers of tiny, uneconomical and coal-fired generating units are adversely affecting the performance of electric power supply system. Furthermore, power generation is causing increasing environmental damages that require promotion of energy efficient and sustainable growth of the electric power industry. Utility de-integration and market competition represents an attractive alternative to policy makers, but little is concrete on the reform roadmap. A critical review on this fluid process is of particular interest to sustainable electricity market development (SEMD) when its policy framework has to be formulated as an integral part of that in China under the open competitive market environment in the near future.

Based on rational and logical structures, policy frameworks provide a platform in which indicators can be identified and classified, for every purpose [79]. The drawbacks of Pressure–State–Response (PSR) framework in modeling complex and causal relationships of system behavior are presented [83]. A review of the methodologies is given and an operational framework is proposed to support policymakers and analysts for formulating sustainable energy policies [43].

Several SD policy making frameworks have been developed in various fields, including energy, environment and health mainly by international organizations. Their main differences come from their subjects of policy making and assessment and the inter-linkages between their components [84].

The PSR framework consists of three components, i.e. Pressure, State and Response as shown in Figure 3-1. Pressures on environment are due to human activities such as exploration, exploitation and especially consumption of energy resources in different sectors [79]. States describe the conditions of natural resources, ecosystems and human health. Responses comprise the preventing, precautionary and awareness activities in environmental, economical and social sectors [84]. PSR has been used mainly for sustainability assessment of environment.

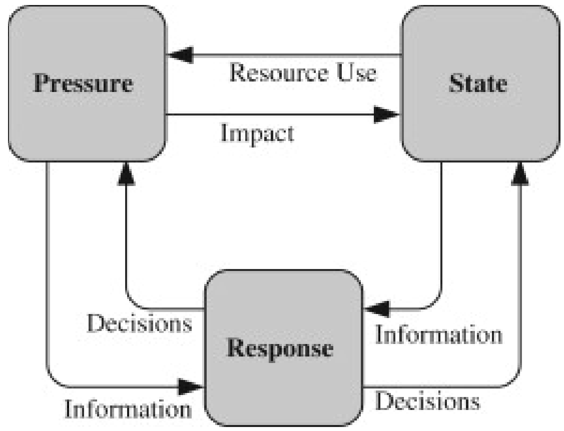


Figure 3-1 PSR framework

DSR framework is developed by the United Nations Commission on SD (UNCSD) to provide a consistent set of indicators and to assess progress towards a sustainable energy future [85]. Therefore, it has three major components: Driving Force, State and Response, as shown in Figure 3-2.

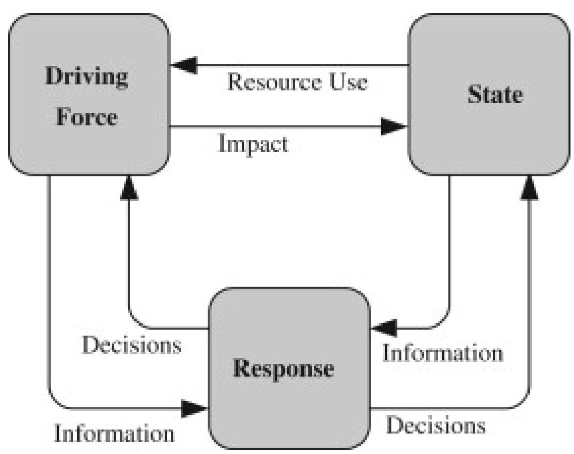


Figure 3-2 DSR framework

The Driving Forces include human activities that have an impact on the sustainability of a system State like the conditions of the environmental and natural resources. The Responses include the legislation, regulation and so on. In addition, using the IESDs not DSR framework, other countries have been trying to monitor their energy systems and to develop new strategies. The objectives to be achieved in the industrialized countries like European ones and European Union (EU), energy policy is used for improving the security and efficiency of energy supply because the economy in these countries is threatened by high dependency on import energy [84]. The effort is reinforced by the International Atomic Energy Agency (IAEA) during 1999–2005 by developing an original set of Indicators for Sustainable Energy Development (ISED) [86], and then implementing and testing in 15 countries as shown in Figure 3-3.

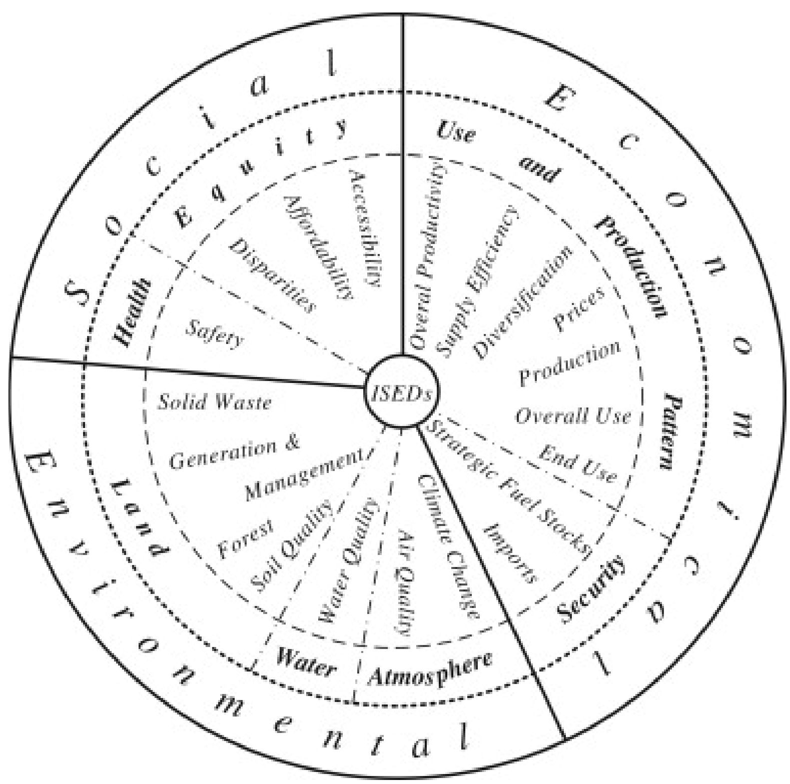


Figure 3-3 IESD by IAEA

3.2 Origination of a Sustainable Policy Framework

The energy policy of a sustainable electricity market development (SEMD) should be set to ensure energy needs of the community are met safely, reliably, efficiently and at reasonable prices; to minimize the environmental impact of energy production and use; and to promote the efficient use and conservation of energy. It bounds to involve a wide range of complex and interrelated technical, economic and regulatory issues. Wind power being one of the most appealing renewable energy resources has gained widespread concerns as an effective way to mitigate energy source deficiency, control GHGs emissions, and achieve smart grid vision. A dynamic decision making model is proposed to cope with the multimarket trading type of policy applications of the policy framework. Comparisons between different market scenarios are used to demonstrate the economic and environmental influences of the policy framework. Policies defining the three interactive markets can accurately reflect the intended goals such as decreasing emissions, promoting renewables, and keeping electricity cost at a reasonable level.

A policy framework is a set of boundaries and principles based on which policies and strategies can be formulated and assessed. The policy framework can be designed for developing China's electricity market in a way which ensures policy strategies are capable of achieving the economic and environmental targets as set in the China's 12th five year plan. The framework would outline the specific goals of China's EMD and suggest how these goals can be achieved through appropriate measures taken in the electricity market development process. It suggests that the development of a national strong and smart power grid for integrating a variety of distributed energy resources and providing intelligent control and energy management for better demand side response. The graphical representation of the policy framework is depicted as shown in Figure 3-4:

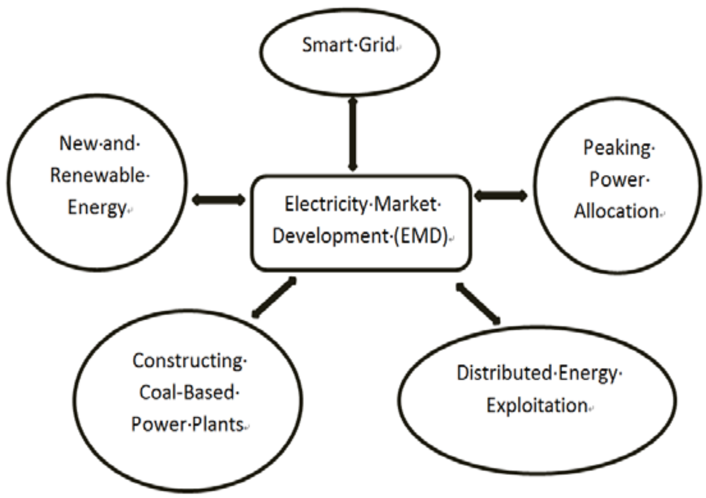


Figure 3-4 Integrated policy framework of EMD in respect of the China's 12th five-year plan

The above graphical representation shows how each one of the five goals is related to China's EMD and subsequently how the EMD can help to achieve each goal without compromising the core intention of any one of them. The subtle concept achieved points to a trade-off value show that there exists a value concept of balance between market force and regulation power governing the operation of the five relationships. In other words, instead of going into extreme cases of overemphasizing free market or controlled regime, a balance way is to align the contribution of market force and regulation power of which its diversion is a continuous trimming process

Development of REs and increasing the efficiency, diversification of energy supply and reducing the CO_2 emission, and investment incentives are the main goals of sustainable policy framework of electricity market development.

3.3 ISEMD Policy Framework

The main aim of the proposed model is to develop a policy framework in which feasible options for future development of the electricity market are justified. In addressing the issue of regulatory reform, governments therefore need to make clear its objectives, potential conflicts, and feasible methods of implementation. It is understood that many of the challenges in developing the market-oriented reform are not confined to the electricity supply industry alone, but require consideration of policies affecting the national energy economy as a whole. There is no doubt that the driver in the current wave of regulatory reform is economic efficiency. Not only must reform achieve the key objective, it must also achieve — or continue to achieve — others such as better environmental performance and social stability. Hence in designing the regulatory framework, policy-makers need to pay very close attention to the long-term need of a robust and competitive society.

A dissection of the economical, environmental and regulatory aspects of the SEMD, illustrated below in Figure 3-5, is performed to formulate a policy framework to cover area of concerns on efficient use of energy, renewable energy, energy pricing, and regulation imperative. Technically, it refers to those aspects utilities would like to pursue cost-effective operation, improve in plant investments, operations and maintenance, and fuel efficiency. Economically, government would continue to undertake developing the electricity supply industry for cost effectiveness. The legal aspects pertaining to the electricity market development refer mainly to the set up of the regulatory and institutional establishment.

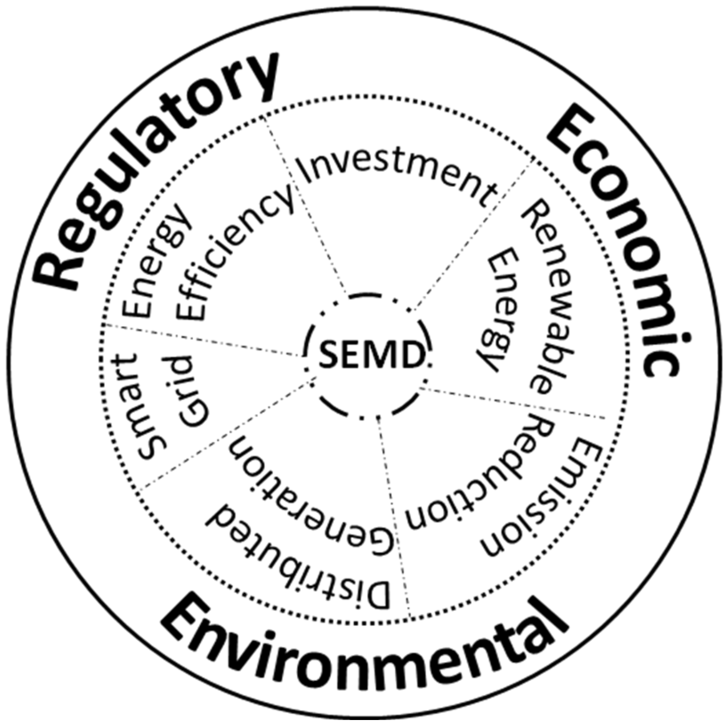


Figure 3-5 ISEMD policy framework

Indicators of sustainable electricity market development (ISEMD) highlight a need for further changes in energy regulation to ensure reliable cost effective supply in the face of increasing demand and environmental regulation. The main impacts of regulation on competition, pricing and consumption are highly technical and highly variable depending on the policy mix, the regulatory regimes and enforcement mechanisms. The hierarchical structure of my policy framework can be demonstrated as below in Figure 3-6.

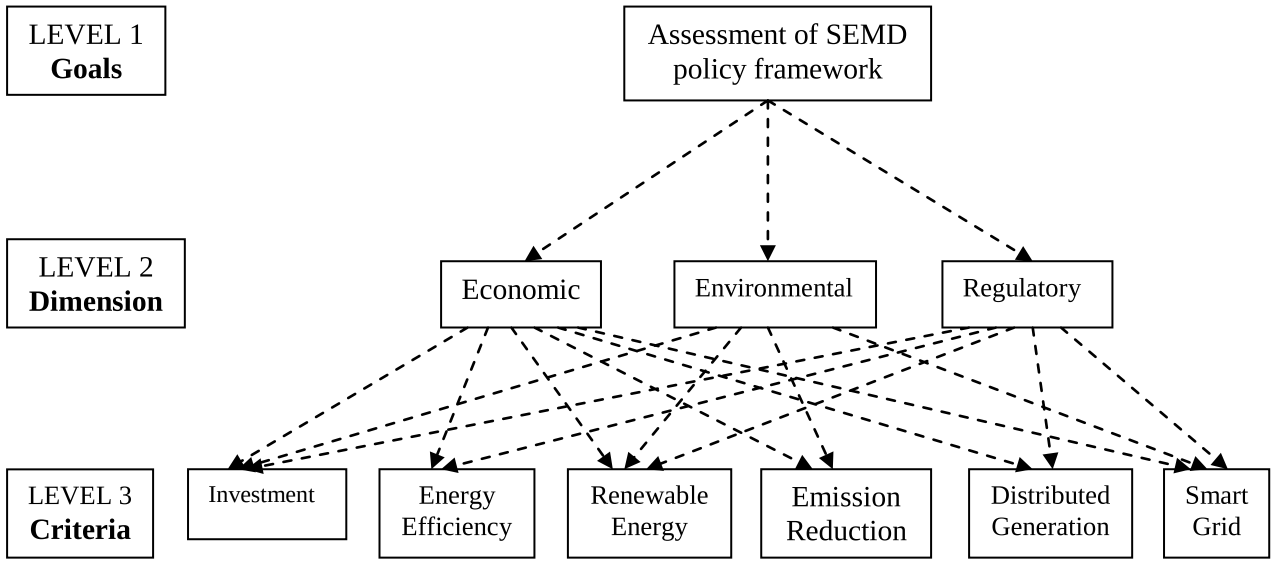


Figure 3-6 Hierarchical structure of SEMD policy framework

3.3.1 Efficient Use of Energy - Clean Coal Policy

The use of coal as an energy source has been constrained mainly due to its environmental impact. Coal cleaning technologies can increase efficiency and decrease pollution in the course of the mining, processing, transforming and use of coal. Examples of measures to promote investment in use of cleaner coal or use of renewable sources of energy as a substitute for coal include:

- direct subsidies from the national government to encourage the development and uptake of renewable technology
- new funding for renewable energy technology under the State Science and Technology Commission
- local government support for renewable technologies
- tax reduction incentives.

3.3.2 Renewable Energy Policy

China is faced with a separate challenge of reducing its reliance on coal. China's government has just passed a Renewable Energy Law which seeks to increase investment and set the target of usage of solar and wind power to 10 per cent of China's total energy consumption within five years.

3.3.3 Energy Pricing Policy

Energy pricing policy seems to provide signals both to the power industry for making investment decisions and to consumers for motivating their choices for better using and conversing energy. It includes:

- to establish an appropriate on-grid price-setting mechanism to accommodate a reasonable level of competition in power generation;
- to establish a preliminary pricing mechanism for transmission and distribution to facilitate the healthy development of the power grids;
- to establish an appropriate pricing mechanism for ancillary services to safeguard operation of the power system and improve the electricity trade;
- to link the coal prices and retail prices with the on-grid prices;
- to optimize the energy price chains including coal, generation, transmission, distribution and power supply;

- to pilot-run the practice for high voltage users to directly make purchases from the power generation companies based on a reasonable price for transmission and distribution.

3.3.4 The Regulation Imperative

Regulation is commonly used as tool to quickly bring China's energy process in line with the market value of energy. Regulation is also used as an engine drving for energy efficiency. Energy consumption per unit of GDP in China is 5 times and 12 times greater than those in the United States and Japan respectively. This level of inefficiency may due to higher wastage which may deter China's energy and economy development.

3.4 SRRM Decision Making Model

By referring to the philosophy of sustainable electricity market development, a modified decision making model is constructed to illustrate and execute the policy framework of SEMD. The interrelations between investment incentives, promotion and development of renewable energy, energy efficiency, and distributed power generation, etc provide a platform for an overall criteria of SEMD policy framework design and monitoring. The general elements of the modified framework are illustrated in Figure 3-7, i.e. state, response and the regulatory market.

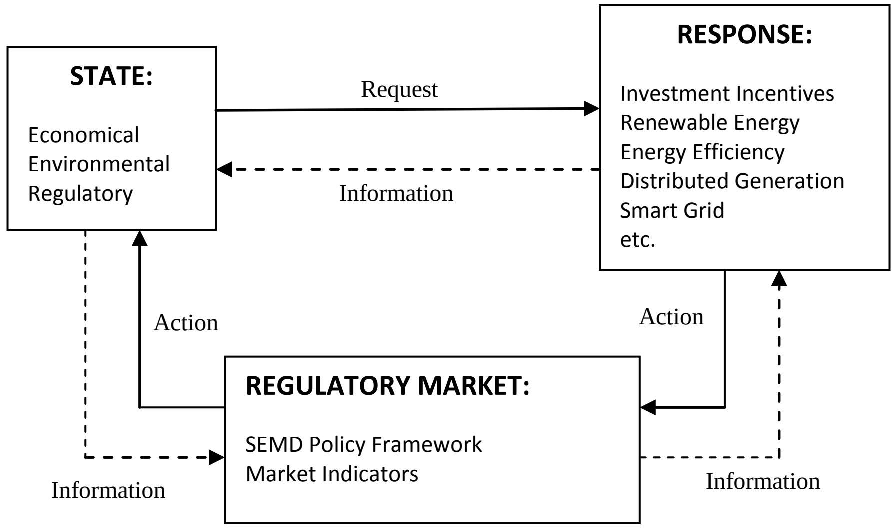


Figure 3-7 SRRM decision-making Model

The open-economy policy adopted in SRRM sustains the market-oriented economic reform of the electric industry including that in Hong Kong. In this project, it envisages to justify an appropriate reform set-up including a fair and competitive power market, independent regulation and new electricity pricing system by considering its economic performance such as improvement of economic efficiency, lowering costs, providing incentives for using renewable energy.

It has been argued that the two electric utilities under the SOC Agreements are running efficiently and have served the community well, providing Hong Kong with adequate and reliable electricity supply at a competitive price. The infrastructure developed by the two companies has also strengthened Hong Kong's competitive power and helped Hong Kong develop over the past few decades. But if one takes a closer look at the prices charged by the local electric utilities and their equity returns, there is evidence that the SOC Agreement tends to protect the producers rather than the consumers; it may also fail to achieve efficient production decisions and reduce the incentive of the regulated companies to reduce costs.

Hence, by applying the framework to the Hong Kong context, the starting point is to review the economic performance of the two electricity companies under the SOC Agreement by analyzing their returns, supply reliability, economic efficiency and tariff level and volatility, energy efficiency and environmental impacts.

In China, the government has recognized weaknesses in its legal and regulatory systems and has set a target to establish an appropriate framework to match up with the development towards a market economy. The current WTO-inspired wave of reform, which will probably continue for five to ten more years, has resulted in intense efforts to revise laws and regulations on trade, technology transfer, investments, banking, insurance, securities, taxation, customs, intellectual property, telecommunications, health, professional services and other subjects to bring them into compliance with the WTO regime and to make the adjustments required by market access commitments. In this phase, the government places more attention on improving the quality, efficiency, and implementation of law-making and administration, including enforcement and the State Owned Enterprise (SOE) reforms will proceed in parallel. The public sector remains dominant, but diverse sectors of the economy are developing side-by-side, so that the national economy is gradually becoming more market-oriented.

Having accepted that an electricity market has been built on the policy platform identified in the previous section, the feasible options for the initial stage of electricity market development are proposed with due regard to the relevant experience overseas market development and the unique local situation.

3.5 A Policy Framework for SEMD with Consideration on Wind Energy Investment

This section presents a macroscopic analysis on the prevailing policy and potential of wind power development in China. It starts by analyzing the characteristics of wind power resources and pin-pointing the relationship between the regulatory policies and various economic, taxation, legal and grid integration attributes of wind power development. Then it follows by analyzing the status quo and capabilities of the wind power manufacturing industry in China including its operational efficiency and grid integration standards. The economic and environmental benefits are estimated by relating to the associated costing analysis in respect of the major contributing factors like manufacturing, operational and financial factors. Results of the benefits analysis indicate that the use of the wind power generation helps to save significant equivalent amount of standard coal consumption and effectively reduce emission. Finally, from the prospective analysis on the wind power development in China, the potential is affirmed to be tremendous and the wind power development contributes to the effective implementation of sustainable energy policy in China.

China is facing various energy related challenges due to her fast-growing energy demand coupled with increasing environmental toll for securing the required energy. Innovative design for different mix of energy generation is desirable. It requires review on the current status of sustainable energy development, and justification on the different means of energy utilization. Since introducing the Renewable Energy Law in 2005, use of renewable energy for generating electricity in China has been growing rapidly. The newly installed wind power capacity in China is roughly doubled every year since 2005 [42]. Wind power has been reckoned as a potential clean energy source world-wide which has no exception in China [87] but its use links to some social engagement with support of appropriate policy set to achieve specific targets [44]. In this section, the approach is to explore the current status of wind power development from a macroscopic point of view covering the wind power resources, policy and legal issues, various capabilities and benefits and finally the prospective potential development concerns. I also include comprehensive discussion on various aspects for justifying the regulatory measures and policy framework for supporting the sustainable energy development in China. The findings suggest that from both the economic and technical point of views wind power is a healthier, more sustainable and efficient means to provide the clean power for the energy market in China. A notable feature in the adopted approach lies on the analysis framework based on which the value of the relevant energy policies is presented. The comments are in line and supplement the policy options suggested by [47] which says that wind power development in China would meet its environmental objectives realistically. Following suggestions from [47], analysis on the potential of China's wind power manufacturing industry is presented in the section which show that development of wind power industry will also open up new areas in manufacturing of both onshore and offshore wind power technologies which enable China to become a major player in the growing domestic and international markets [88]. In this respect, findings indicate that the appropriate energy policy framework of wind power in China can help her to achieve its economic and environmental goals. In the social-economic point of view, the findings also support that China to regard wind power as a practical means to achieve a more sustainable and efficient energy portfolio. Finally, the contribution come from the results of analysis for justifying development of wind power in China as a cleaner and more efficient option.

3.5.1 Analysis on China's Status of Wind Power Resources

Since the 1970s, China has conducted four nationwide wind resource surveys. The first three were mainly resource investigations, while the fourth, undertaken since 2007, is a detailed investigation and assessment of national wind resources. According to this detailed survey, the China Meteorological Administration (CMA) erected 400 wind towers with heights of 70 m, 100 m and 120 m, and established a national wind measurement network. Based on the analysis of the data from the exploitable areas, development potentials of wind power density grades 2, 3, 4 at heights of 50 m, 70 m, and 100 m are obtained as shown in Table 3-1. If wind resource regions with wind power density of grade 3 and above are considered exploitable, wind resource development potentials will be between 2 TW and 3.4 TW.

Table 3-1 Exploitable potential of land-based wind resources (GW)

Height above ground	Grade 4 or higher (wind power density ≥400 w/m^2)	Grade 3 or higher (wind power density ≥300 w/m^2)	Grade 2 or higher (wind power density ≥200 w/m^2)
50 m	800	2000	2900
70 m	1000	2600	3600
100 m	1500	3400	4000

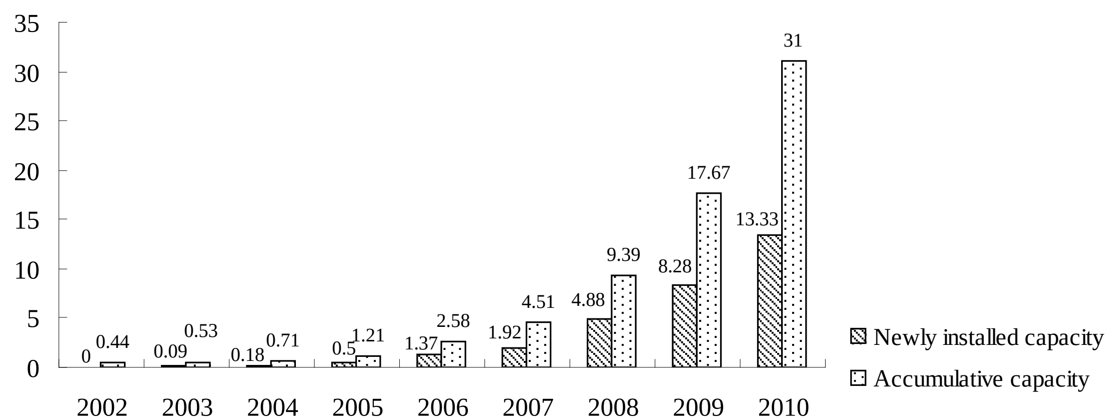


Figure 3-8 Wind power capacity in China

Over the recent years, China has conducted a number of surveys on the potential and capacity of wind power resources. In one of the reports released in 2006, the National Climate Centre of China estimated that over 2,000 GW of wind power can be exploited in her 10 m wind zone not counting that from the Qinghai-Tibet Plateau. That wind power capacity is more than double of the total China's wind power installed capacity in 2010. When comparing to the five largest wind power countries, China’s wind power capacity is comparable to that of USA and much above those from countries of India, Germany and

Spain. Judging from the current exploitation of wind energy in China, about 2% [89] developed only, plus her rich off-shore wind energy, China has in fact a great potential of developing her wind power.

As shown in Figure 3-8, the wind resources in China mainly come from the north, northeast, northwest and eastern regions along the Pacific Ocean regions. It embraces regions along Hebei, Western Inner Mongolia, Jilin, Jiangsu coastal areas, Gansu Jiuquan and Xinjiang Hami forming the seven wind energy bases. Their annual average wind energy generation intensity is in the order above 150 W/m^2, and can be as high as 300 W/m^2 in other regions such as the Western Inner Mongolia whilst the annual production hours are around five thousands to six thousands.

From the seasonal point of view, China's wind energy mainly concentrated in spring and winter which is just a good complement to the hydro power for the shortage in these two seasons. However, from the load distribution point of view, wind energy resources are not matching well with the electricity load demand. Only those wind bases in Jiangsu and northeast are located within the loading zone, other wind resources are geographically far away from the load centre making limited local consumption of the wind energy and hence the wind energy has to be transmitted to the loading centres via transmission network.

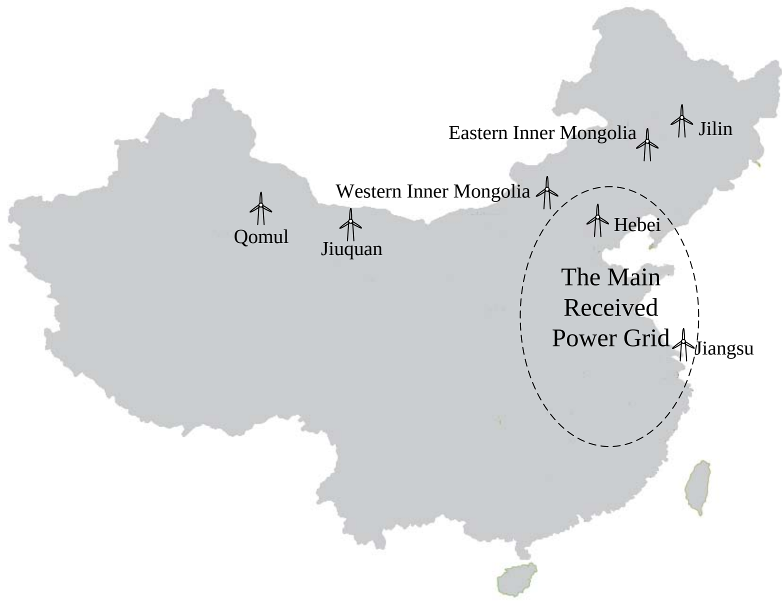


Figure 3-9 Locations of the seven major wind-base and load centre in China

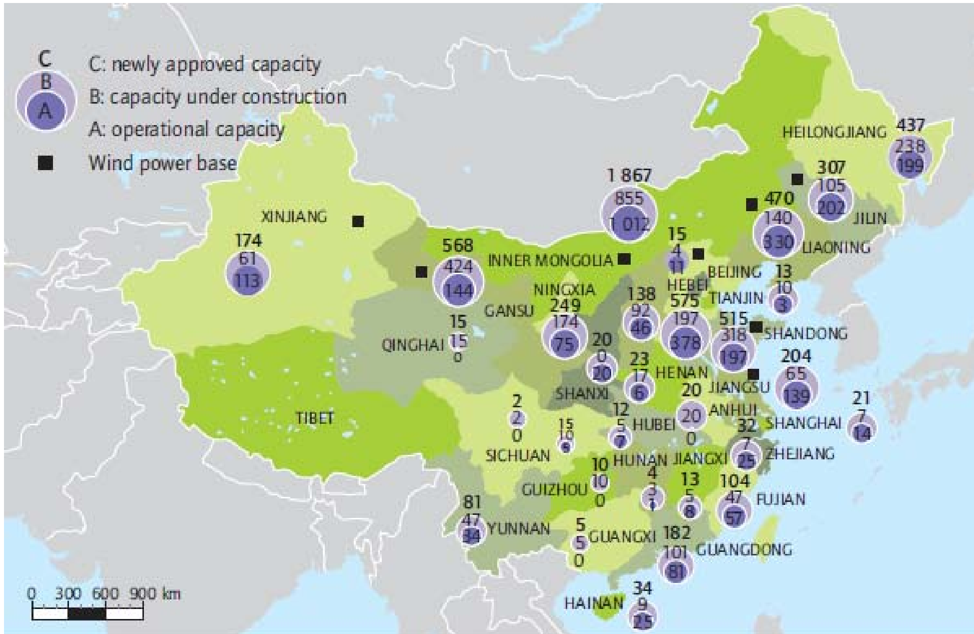
Since the early stage of implementation of the 11th Five-Year Plan, China had set out the regulatory paper - ″Mid-long-term Plan of Renewable Energy Development″ to provide guidelines for development of the Renewable Energy. It led to consequent release of the ″Renewable Energy Law″ in 2005, and based on which a series of incentive based regulatory policies were devised. They serve to provide a legal regulatory framework for setting feed-in tariff and its associated cost allocation, making us of financial subsidy and taxation rebate as the policy instruments, designing technical guidelines to facilitate grid connection of wind power and standards of practices and inducing incentive of investment. Initial success is proven by results showing that the wind power installed capacity is doubled over the recent years. Details of analysis on the cause and effect attributing to various aspects are summarized as listed in Table 3-2.

Table 3-2 Comments on the various attributes of wind power regulatory framework.

Attributes	Comments
Legal regulatory policy on electricity pricing	In this respect, the National Development and Reform Commission (NDRC) issued a regulatory policy for setting Wind Power Feed-in Tariff and dividing China's territory into four categories so that different feed-in tariffs are set for the new installed wind power plants in the order of 0.51, 0.54, 0.58 and 0.61 RMB per kW.
Regulatory policy on cost allocation	**1.** In line with the ″Renewable Energy Law 2005″: the following arrangement are worth to be noted: • Feed-in tariff should be set according to the conditions of different areas for the benefit of promoting, utilizing and justifying economic value of renewable energy. In case if power company purchases renewable energy at a price higher than the average feed-in price of conventional generation, the difference in cost can be offset from the supplementary charge on the renewable energy tariff as a financial subsidy. • Details regarding the cost allocation and regulatory measures are provided in the documents: "Regulation on Renewable Energy Generation", "Trial run on tariff management and cost allocation for renewable energy generation" and "Temporary methods for allocation of supplementary tariff of renewable energy".
Legal Policy on Finance	In accordance with the ″Renewable Energy Law 2005″, set up of Renewable Energy Foundation Funds for supporting research and development of renewable energy is allowed. For those qualified manufacturing industry on renewable power generator and major components, they are entitled to obtain ¥600/kW subsidy for the first 50 MW level renewable generators with details as provided in the document "Temporary methods for financing Renewable Power Generator Manufacturing Industrial Project".
Legal Policy on Taxation	In accordance with the ″Renewable Energy Law 2005″, technological development and related research of wind power manufacturing are considered as high technology industry. Together with the Profit Taxation Law of Enterprise, investment in the renewable energy related industry enjoys 15% of

	their profit tax as tax rebate. Furthermore, the Ministry of Finance and the State Administration of Taxation announces a policy to reduce the capital gain on renewable energy investment by 50%, i.e. from 17% to 8.5%.
Legal Policy on grid connection	The "Renewable Energy Law 2005" has suggested production and grid connection standards for renewable energy. Two reports, one on framework of standardization of renewable energy and another one on entry standard to the manufacturing industry of renewable energy are inviting comments. In effect, it requires regulatory control on the renewable energy industry in its technological development, equipment and installation, quality assurance, and after sale services etc.

Wind power in China has entered the large-scale development phase. From 2006 to 2009, China's total wind power installed capacity doubled. The location of those wind farms in China is shown in Figure 3-9. When compared to the five largest wind power countries, China's wind power capacity is comparable to that of the USA and much above countries such as India, Germany and Spain. Judging from the current exploitation of wind energy in China, about 2% [90] developed only, plus her rich off-shore wind energy [91], China has a great potential to develop her wind power with the overall wind power distribution pattern shown in Figure 3-10. Hence, the wind power development in China is characterized as large-scale, centralized with long-distance transmission support. In the future, this large-scale development of wind farms will be continued in the northern China. At the same time, wind resource development in the east will take advantage of a good power grid infrastructure and a high potential wind power consumption capacity. Offshore wind power in China is in the early demonstration phase. In the near term, a gigawatt-scale offshore project will be started in order to gain experience in offshore technologies.



Source: Hydro China

Figure 3-10 Locations of wind power bases in China

From the seasonal point of view, China's wind energy is mainly concentrated in spring and winter which is a good complement to the hydro power for the shortage in these two seasons. However, from the load distribution point of view, wind energy resources do not match well with the electricity load demand. Only those wind bases in Jiangsu and northeast are located within the loading zone; other wind resources are geographically far away from the load centre making limited local consumption of the wind energy and hence the wind energy has to be transmitted to the loading centers via transmission network. However, since the early stage of implementation of the 11th Five-Year Plan for National Economic and Social Development (2006-2010), China had set out the regulatory paper - ″Mid-long-term Plan of Renewable Energy Development″ to provide guidelines for development of the Renewable Energy. It led to the release of the ″Renewable Energy

Law″ in 2005, and based on which a series of incentive based regulatory policies were devised. In the 12th Five-Year Plan (2011-15), published in March 2011, it further reckons that a modern energy industry in China will be based on energy conservation, domestic development, diversity and environment protection, to strengthen international co-operation and mutual benefit, adjust and optimise the energy structure, and build a safe, stable, economical and clean modern energy industry system. Although the Renewable Energy Law provides the legal framework to set out appropriate policy instruments, such as financial subsidy and taxation rebate, and technical guidelines to facilitate grid connection of wind power, the grid integration and consumption of wind power are still the critical factors for future wind power deployment. If not handled properly, grid connection bottlenecks and excess local power supply become the major problems for wind power programmes in China, leading to large-scale wind power curtailment.

Apart from the above legal policy and regulation as established, some local governments further refine them by setting their strategic measures and direction of development such as pushing out more concrete guidelines on grid connection subject to their local requirements. Obviously, there is room of improvement of the legal and regulatory framework so as to further harmonize the development between the renewable energy and the electricity market.

3.5.2 Analysis on the Capability of Wind Power Development in China

As China is encouraging development of new energy technology, it brings along rapid development on the manufacturing industry on the wind power generators. In 2005, the National Development and Reform Committee (NDRC) set a target of 70% of the market share of the wind power generator equipment had to come from the domestic manufacturers and those wind farms not meeting the target were not allowed to be constructed (the policy was cancelled in 2010). It provided competitive advantages for the domestic invested wind power generator manufacturing companies. As shown in Figure 3-11, foreign invested companies took lead on the market share of more than 70% before 2005. Due to introduction of the protection policy and the obvious pricing advantages of the local production, the domestic market share in the new wind power generators was increased drastically to 87% in the year 2009.

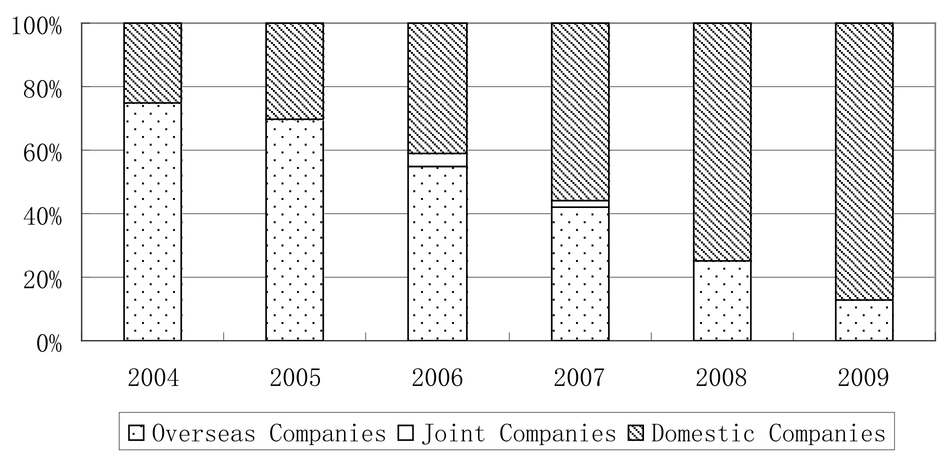


Figure 3-11 Trend of market-share of newly installed wind power generators in China

China’s continued economic development depends on a sustainable and clean energy supply. By taking advantage of the 21st century’s energy revolution and innovation, wind energy is the most promising as it has almost reached the mature technology development stage and has the greatest potential to be deployed commercially [78]. China has set it a clear target in the current Five-Year Plan to transform its energy structure, with wind energy being the central element of that transformation. In the coming 20 to 30 years, as energy demand increases, the government has no choice but to cope with the challenge of securing supply by increasing the scale of wind power deployment while reducing fossil fuel consumption. Inevitably, various problems may emerge with regard to the pattern of development, such as grid access, consumption and subsidies, resulting in deeper institutional and mechanism issues. Appropriate policy measures are necessary to cope with such problems and support the development. Policies should be transparent, stable and predictable so that investors face minimal uncertainty, and also flexibly adapted to different stages of technology maturity. Currently, China’s power system is not keeping up with the demand for wind power development and needs to evolve to a state capable to manage greater shares of variable wind power. Future power systems will need to feature more flexibility on the demand side as well as on the supply side if they are to benefit from the full range of non-polluting, low-carbon energy sources, while maintaining security and reliability. As the wind power technology progresses through the stages of research, design, testing and demonstration to large-scale market deployment, a stable and gradually expanding wind power market including the production and manufacturing of the viable commercial units are essential.

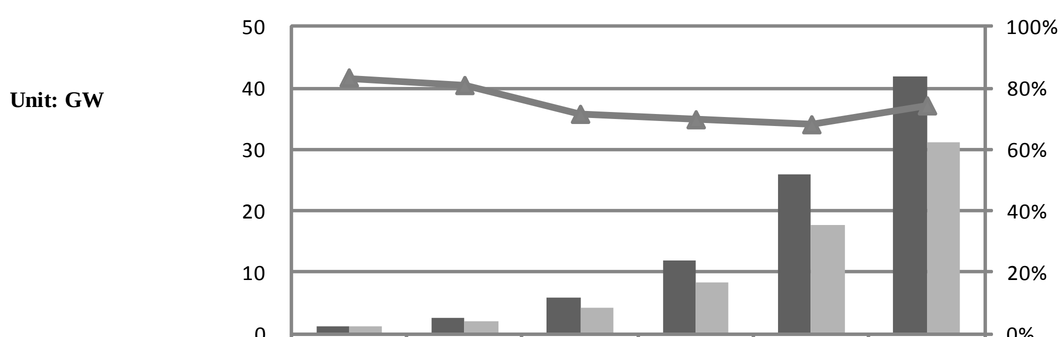
The huge demand of wind power generators in China provides a great opportunity for domestic manufacturing companies to expand their business. There were three domestic wind power generator enterprises ranking top 10 in the world in 2009 indicating that wind power generator manufacturing industry in China has been strived into the world-class level. In terms of the manufacturing state-of-the-art of technology, MW level of wind power generators is the manufacturing norm and its market share in the newly installed generators was increased to 86.8 % in the year 2009. Manufacturing of multiple MW wind power generators is coming out in stages with domestic manufacturing capability of 3 MW wind power generator and followed by 5 MW level unit on its way to be put into production soon in China.

The huge demand of wind turbines in China provides a great opportunity for the development of domestic manufacturing companies. According to BTM statistic, there were four Chinese wind turbine manufacturers in global top 10 largest wind turbine manufacturers in 2010, which indicates that wind turbine manufacturing industry in China has been strived into the world-class level. With the increase of wind turbine sales, the technology of wind power in China also gets improved. Stimulated by the development of offshore wind power, leading manufacturers of wind turbine and component begin to develop large-scale turbines, Chinese manufacturers, such as Sinovel and Goldwind, also begin to develop large-scale wind turbines, and many enterprises succeed in developing wind turbines with and above 3 MW capacity. Wind turbines with three blades, horizontal axis, upwind, doubly-fed, variable pitch, variable speed, and constant frequency take the initiative in Chinese wind turbine market, which is also the main technique in global wind turbine market. Besides, Chinese manufacturers also focus on the development of MW-class wind turbines with vertical axis, consistent with foreign leading manufacturers.

The components manufacturing industry in China has also been emerging as a fast growing business following the rapid pace of wind power development. The well-known international wind power generator manufacturers chase after their products. It has to be noted that flourishing of the component manufacturing industry help solve the shortage of components for the wind power generator manufacturing but just because of the unlevel profit making opportunity, the whole machine manufacturing companies would like to go into the components manufacturing business as well.

Great prospects of the wind power industry in China stimulate the developers to consolidate their asset and get ready to raise their capital through the stock mark for increasing their investment with some have already earmarked tens of MW wind power projects. However, the problem following the rapid development of the installed wind power generation capacity is on the increasing wastage of wind energy due to incapability of connecting the generators to the grid for the energy transfer. The more wind power generators built, the more serious is the problem of having more wind power generators leaving idle and the grid connection appears to be a bottle-neck problem for expanding the generation capacity of wind farm. It can hardly be resolved in a short-time.

According to the Medium- and Long-term Plan for Renewable Energy Development and 12th 5-year Renewable Energy Development Plan, wind power will further be developed and so will stimulate expansion of the wind turbine manufacturing sectors in turn. From 2010 to 2015, China's annual installed capacity is expected to reach about 15 GW, including about 14 GW of land-based wind power and about 1 GW of offshore wind power. Between 2015 and 2020, large-scale offshore wind power will begin to be developed rapidly, and the demand of wind turbine will reach 18 GW of installed capacity per year, which includes 13 GW of land-based wind turbines and 5 GW of offshore wind turbines, while about 500 MW of older wind turbines will need to be retired or transformed. From 2020 to 2030, 24 GW of wind turbines will be needed annually, 19 GW land-based and 5 GW offshore, with 39 GW of older wind turbines needing to be retired or transformed. Between 2030 and 2050, average annual wind turbine demand will be about 50 GW, including 44 GW land-based and 6 GW offshore, with about 400 GW of older wind turbines being retired or reconstructed [90].



	2005	2006	2007	2008	2009	2010
Total Capacity (GW)	1.3	2.6	5.9	12.0	25.8	41.8
Integration Capacity (GW)	1.1	2.1	4.2	8.4	17.6	31.1
Integration Rate	83%	81%	72%	70%	68%	74%

Figure 3-12 Status of recent increase of wind generation installed capacity in China

As shown in Figure 3-12, the wind power installed capacity was expanding in the order of multiples since 2006 but the grid in-feed ratio was decreasing year by year. In 2007, it was the year record of highest annual growth rate up to 129% but in the same year there was the record of sharp decrease of energy in-feed to the grid. These facts clearly indicated that the wind power consumption capacity of the power company could not match with the rapid expansion of the wind power installed capacity. Further along the line in 2010, the rate of installed capacity of wind power generators slowed down and so the wind power installation and grid in-feed ratio appeared to increase but the capacity of wind power not able to in-feed to the grid was still enlarging. In effect, the relationship between the growth rate of wind power installed capacity and the change of wind power in-feed ratio to the grid can be summarized as shown in Figure 3-13.

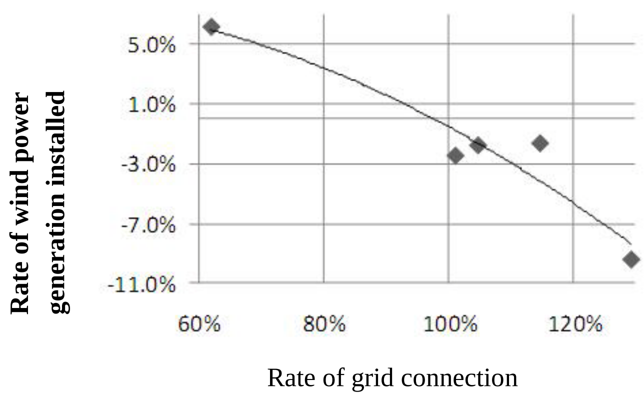


Figure 3-13 Relationship between rates of wind generation installed capacity and rate of grid connection

On one hand, there are a number of factors to be considered for explaining the low ratio of power in-feed to the grid such as lack of an overall wind power consumption plan, insufficient support of transmission networks for the wind power generation, lag behind on the construction of the transmission infrastructure, tedious procedure to fulfill the grid connection requirements and uncertain benefits to the grid after connection, etc. All and all, power companies are not eager to invest for expanding the wind consumption capacity. On the other hand, the distribution of the wind power is too centralized to the extent that the wind power consumption is beyond the grid's capability to handle. As shown in Table 3-3, those not yet purchased wind power in the year 2009 were all found in the provinces where wind power installed capacity was in the top of the list with more than 70% coming from the inner Mongolia where the wind power installed capacity is 35.6% of that of the whole China. Most of the provinces having wind power development on the frontier relatively suffer more seriously on the wind energy wastage aspects due to lacking of wind power consumption capacity for matching the increase of installed wind power capacity. Whilst for those provinces whose wind power capacity is lower, they have relatively smaller share of the generation source of the province. The power company has a better control and dispatch of their wind energy output and in effect achieves higher wind energy efficiency.

Table 3-3 Provincial wind generation installed capacity in 2009

Province	Rank	Wind Capacity		Non-purchased Power	
		Capacity	Proportion	Power	Proportion
Inner Mongolia	1	9.2	35.6%	19.86	72.0%
He-bei	2	2.8	10.8%	2.64	9.6%
Liao-ning	3	2.4	9.4%	0.23	0.8%
Ji-lin	4	2.1	8.0%	1.94	7.0%
Hei Long-jiang	5	1.7	6.4%	1.13	4.1%
Shan-dong	6	1.2	4.7%	0	0
Gan-su	7	1.2	4.6%	1.81	6.6%
others	--	5.3	20.5%	0	0

(Unit: GW, 10^8 kWh) Data from "China Wind & Solar Power Supervision Report 2010"

Being the session connecting the wind farm and the end-users, the power companies have to ensure the transmission network has no congestion on the electricity flow path, its operation reliable, safe and the wind power generation process is optimized. In this connection, the State Grid of China has set up the associated standards governing integration of the wind power to the grid since February 2009. The standards serve to specify the technical requirements in the following six areas covering voltage level, frequency, power, reactive power, contingency handling and power quality. By considering these standards in relation to the corresponding international practices, the analyzing remarks are summarized and listed in Table 3-4. It serves to review the level of integration of the wind power to the grid derived in its context.

Table 3-4 Analysis of the domestic grid connection practices

Standards	Domestic practices	Remark
Voltage	In order to keep the wind farm operation in order, the voltage variation has to fall within the limit of -10% ~ +10%,	The voltage requirements are similar to those from international standards. The cut-off threshold in terms of timing and procedural requirements is not specified clearly.
Frequency	• Range of normal frequency operation is set at : 49.5~50.5 Hz • At least 10 minutes of continuous operation is allowed when the frequency falls within the range of 48~49.5 Hz • At least 2 minutes of	• Arrangement for the normal range of frequency operation is the same as that in Germany and Denmark. • In Denmark, for out of frequency range, at least 30 minutes is allowed and hence the requirement is less stringent in China.

	continuous operation is allowed when the frequency falls within the range of 50.5~51 Hz	• In Germany, wind power generators are not allowed to be switched off for frequency within the range of 47.5~51.5 Hz
Active Power	Specifies that the wind farm should be equipped with the real power controllability to cater for the largest fluctuation of real power up to 2/3 of system installed wind farm capacity within every 10-minute block.. For minute to minute interval, the corresponding magnitude of change is 20% of the installed wind farm capacity.	In Denmark, Germany and UK, their wind farms are all required to contribute to control the system frequency. In Germany, all wind power generators are required to offer a constant rate of 1% change per minute of power from the least to the nominal power output range. In Canada, it requires the rate of changes be kept within 10% of the installed capacity per minute of which its standard is higher than that in China.
Reactive Power	In all operational modes, wind farm should be equipped with sufficient reactive power control capability. Generally speaking, the level of compensation on the wind farms is designed with power factor within the range of 0.98 leading and 0.98 lagging.	It appears the reactive power capacity requirement in China's wind farm is relatively not high. In UK, corresponding power factor compensation is within the range of 0.95 leading and 0.95; for Canada, the range is 0.985 leading and 0.95 lagging implying less compensation requirement. In the case of Canada, it also requests wind farms to specify the details of timing control for their continuous dynamic compensation.
Through Fault	In case of through fault, wind power generators have the capacity to keep on grid connection for 0.625 s during	Germany has a higher through fault capability (Guan et al., 2007), with fault duration of 1.5 s; keeping on grid connection for 0.15 s during the high

	which the voltage may drop by 20% at the point of common coupling (PCC). If the voltage at the PCC can regain to 90% of the nominal voltage level within 3 s of the voltage drop commencement, the wind farm generators have the capability to maintain on grid connection. For all those not disconnected wind farm generators, they should have the capability to restore their power output at least at a rate of 10% constant power up to the operational level before faulty.	short circuit state when the system voltage drops to zero; keeping on grid connection for 0.15 s during the low short circuit current state when the system voltage drops to 45% level; those not disconnected wind farm generators, they have the capability to restore their power output at least at a rate of 10% constant power up to the operational level before faulty. In Canada, the standards are similar to those in China except that the voltage drop through to a lower level which is set at 15% of the nominal voltage. Besides, since the domestic regulation on this respect has no specification on the required reactive power compensation during the through fault period, it bounds to cause the grid voltage to drop to a too low level resulting to slower restoration pace after removal of the through fault.
Power Quality	The regulations address on the four common categories of power quality problems including voltage unbalance, voltage fluctuation, flicker and harmonic distortion. They also require the wind farm generators equipped with long term energy quality monitoring facilities and committed to qualified quality	IEC 6100 is commonly adopted in both domestic and international practices to devise their own regulations. They need to be adaptive and hence may vary in accordance with different situations.

	assurance agency to perform periodic monitoring checking.	

In general, the grid integration standards for wind power in China have yet to be refined but they fulfill the needs of the wind power industry basically. Judging from the above analysis and comments derived, China has the potential to further mature on the wind power industry, which is picking up fast and moving on the right track.

To meet the needs of the wind power supply chain and ensure wind turbine quality and reliability, advanced large-capacity turbine system R&D capabilities should be improved further. The support policy and financial fund should pay more attention on basic technology research.

3.5.3 Grid Integration

China's geographical imbalance of electric load and energy resources results in the key characteristics of transmission from west to east and mutual support between north and south grids. After sustained reforms of power infrastructure and the power market, China has established an interconnected grid network of regional grid infrastructures, with provincial grids as the major operators in practice. As China's greatest wind resources are in the north, far from load centres and the power grid framework, it will develop several large wind power bases, with capacities in the tens of gigawatts scale of wind base groups by 2050 developed in west Inner Mongolia and other regions [92]. Integration and accommodation of wind power in the power network have to face with many constraints, however, such as wind power output, system load, power source structure, regulation capability, power transmission scale and operation methods. These factors, which will continue to change, pose major challenges to the integration and accommodation of wind power. Seeing that China's power system is mainly based on coal generation, there is little scope for system balance dispatching. Integration and accommodation of a large volume of wind power from northern wind bases will be a challenge due to insufficient peak adjustment capacity and limited transmission capabilities to handle the overabundance of wind power.

Existing support policies for large-scale wind power integration are inadequate. They focus mainly on wind farm tariffs, grid access subsidies and cost sharing, rather than on obligations and conflicts of interest. Accommodating wind power in the national power system requires not only technical solutions but also reforms in management, policies and regulations. The National Energy Administration initiated a wind power grid integration and accommodation study in 2010, which shows that China could achieve a wind energy economic potential of 160 GW to 200 GW by 2020, by optimising systematic power development plans, encouraging appropriate deployment of pump storage capacity and gas power peak adjustment, as well as rational development of inter-province power transmission. To achieve this potential, administrative co-ordination needs to be strengthened to increase the provincial capacity of wind power accommodation and promote long-distance inter-provincial and inter-regional transmission of wind power.

As suggested in Section 3.2.2, the management of wind power projects needs to be strengthened and the speed of wind power development controlled so that it keeps pace with overall power system development. Dispatching capacity should be increased by: accelerating hydropower development in western China; expanding large-capacity pump storage systems and natural gas power stations for peak adjustment; balancing distribution of coal-fired power plants; and increasing dispatching capability of thermal power plants. Wind power development should be incorporated into grid construction programmes with wind farm connection projects optimised and coordinated, and backbone grid construction well planned ahead of time for better provincial and regional interconnections, including ultra-high-voltage DC transmission from northern China wind bases to power load regions. Studies should be carried out on wind power transmission from northern to eastern regions. A cost return mechanism should be established for transmission system operation.

Further policy supports, such as establishing pricing policies to encourage to encourage grid-friendly wind power projects, could include performance-based incentives or ancillary service cost-sharing. National directives should be strengthened on inter-provincial/inter-regional power exchange. Intra-province wind power transmission cost could be shared through local power tariffs. Inter-provincial and inter-regional UHV transmission costs should be covered by purchase prices and sale prices in the target province or region. In addition, mutually agreed quota systems and liberalised market mechanisms should be explored and implemented to promote inter-regional power exchange.

In short, wind power and power system development plans need to be co-ordinated, along with technology roadmaps, system standards and arrangements for power grid scheduling, dispatch and operation strategy. The implementation of flexible, well-developed electricity market mechanisms and incentives is required in order to optimise system operation and eliminate institutional barriers in the near and midterm. In the long term, the power system should be comprehensively transformed by technical and institutional innovation.

3.5.4 Benefit Analysis on the Wind Power Development in China

Analysis of a project investment has to concern at least two points. Firstly, the evaluation itself should comply with finance theories. Secondly, the project technical characteristics have to be addressed in financial sense. The wind power investment project is not different from others in terms that its evaluation also needs to involve initial cost, operating cost, future revenue, etc. And its technical characteristics such as generation capacity, power efficiency, tariff structure, dispatch principles, etc. should be concerned as well.

In practice, earnings are measured by cash flows. The change in cash flows to be contributed by the project is referred as incremental cash flows, in which ROR method is based on.

While incremental cash flows are the actual money created by the project, other indirect consequences of adopting this project may also count. Among them are sunk costs, opportunity costs, erosion and net working capital (NWC) [93]. NWC is conveniently assumed as the difference between accounts receivable and accounts payable. Practically, sunk cost, opportunity cost and erosion are difficult to be quantified and thus they are not considered in a simple model. Finance cost, interests, dividend and principal paid has to be deducted from the cash flow in this section. A project generates a stream of periodic cash flows. At each period, the project cash flow (PCF) is composed of three components: operating cash flow (OCF), capital spending *I* and change in NWC.

$$PCF = OCF - \Delta NWC - I \tag{3-1}$$

Change in NWC is the annual fluctuation in NWC that could affect the periodic project cash flow. And capital spending is taken only at the beginning. Any major upgrade of the project that needs substantial capital spending is ignored.

Rate of return (ROR), in finance, is the ratio of money gained or lost (whether realized or not) on an investment relative to the amount of money invested. The amount of money gained or lost may be referred to as interest, profit/loss, gain/loss, or net income/loss. The money invested may be referred to as the asset, capital, principal, or the cost basis of the investment. ROR is usually expressed as a percentage based on capital investment.

The internal rate of return, also known as the dollar-weighted rate of return or the money-weighted rate of return, is defined as the value that satisfies the following equation:

$$NPV = \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} = 0 \tag{3-2}$$

Where

NPV is net present value of the investment,

C_t is the cash flow at time *t*.

When the cost of capital is smaller than the IRR rate, the investment is profitable, i.e., NPV > 0. Otherwise, the investment is not profitable.

It is the rate that a company is expected to pay on average to all its security holders to finance its assets. And WACC is the minimum return that a company must earn on an existing asset base to satisfy its creditors, owners, and other providers of capital, or they will invest elsewhere. Companies raise money from a number of sources: common equity, preferred equity, straight debt, convertible debt, exchangeable debt, warrants, and options, pension liabilities, executive stock options, governmental subsidies, and so on. Different securities, which represent different sources of finance, are expected to generate different returns [94]. The WACC is calculated taking into account the relative weights of each component of the capital structure. The more complex the company's capital structure, the more laborious it is to calculate the WACC.

Furthermore, WACC is also a significant signal to see if the investment project is worthwhile to undertake. Generally, it is calculated with the follows formula:

$$WACC = \frac{\sum_{i=1}^{n} r_i \cdot V_i}{\sum_{i=1}^{n} V_i} \tag{3-3}$$

Where

n is the number of sources of capital;

r_i is the required rate of return for item *i*;

V_i is the market value of item *i*.

Feed-in tariff is a policy mechanism designed to accelerate investment in renewable energy technologies. It achieves this by offering long-term contracts to renewable energy producers, typically based on the cost of generation of each technology. The goal of feed-in tariffs is to offer cost-based compensation to renewable energy producers, providing the price certainty and long-term contracts that help finance renewable energy investments [95].

Under a feed-in tariff, eligible renewable electricity generators are paid a cost-based price for the renewable electricity they produce. This enables a diversity of technologies like wind power to be developed, providing investors a reasonable return on their investments. Theoretically a feed-in tariff involves a temporary increase in electric rates for a long term benefit. Increases have been attributed as a result of the fact that electricity generated from renewable energy sources is typically more expensive than electricity generated from conventional sources. In this section, FIT typically includes three key aspects: guaranteed grid access, long-term contracts for the electricity produced, and purchase prices based on the cost of generation.

Determination of the economic benefits of wind power industry mainly depends on a few factors such as original investment, operational cost, equivalent effective hours per annum and on-grid feed-in tariff [96]. The original investment includes those on the wind power generation units, civil engineering, electrical engineering, installation expenses, financing cost and other miscellaneous cost on land acquiring and surveying fees etc. and out of which the wind power generation units have the highest share. For the operational costs, they include maintenance cost and salary etc. out of which the wind power generation units have the highest share. Since the cost, scale and time schedules of wind power development can differ remarkably from region to region, the economically exploitable wind power potential is estimated by using the two price metrics, namely, feed-in tariff (FIT) and Full Cost (FC). By referring to the geographical information of the regions, the FIT is based on the economic evaluation of wind projects, including annual electricity production of a unit area, assumed internal rate of return (IRR) and installation cost. This tariff does not take into account costs of grid connection and transmission as it will be included in the other price metric, FC, which is determined as FIT plus local grid access cost and inter-provincial transmission costs.

Since 2005, the Chinese wind power market has expanded rapidly and the wind power investment costs fell from ¥ 8,000/kW to ¥ 9,000/kW, of which the wind turbine itself generally accounted for nearly half. With continuous improvements in wind power scale and technology, the wind turbine unit cost may fall to match the unit cost of coal-fired thermal power. Within the next 10 years or so, wind power is expected to be able to compete with conventional energy technologies. Wind turbine prices still have room for cost reductions of 10% to 20% in constant prices. By taking the current average onshore wind farm operational cost as about 25% of total wind power cost, the wind power O&M costs on land can reasonably be assumed to be around ¥ 0.10/kWh. At the same time, as decreasing wind turbine prices, wind farm investment costs and O&M costs are lowering the cost of wind power generation in China, higher thermal power prices will be difficult to avoid, because of higher coal mining costs and prices. It is expected that after 2020, even without fossil energy resource taxes or environmental taxes, carbon taxes, etc. Wind power costs and prices will tend to match those of thermal power. After 2020, wind power tariffs will be lower than coal power tariffs without considering wind power consumption and long-distance transmission factors as summarized in Table 3-5.

Table 3-5 Technically exploitable potential of land-based wind resources (GW)

		2010	2020	2030	2050
Unit investment (¥/kW)	Land-based	8000-9000	7500	7200	7000
	Near offshore	14000-19000	14000	12000	10000
	Far offshore	-	50000	40000	20000
O&M cost (¥/kWh)	Land-based	0.10	0.10	0.10	0.10
	Near offshore	0.15	0.15	0.10	0.10
	Far offshore	-	0.30	0.20	0.10
Projected average tariff (¥/kWh)	Land-based	0.57	0.51	0.48	0.45
	Near offshore	0.77-0.98	0.77	0.60	0.54
	Far offshore	-	> 2	2	1

Due to production surplus on wind power generation, there is a global trend of price reduction on the newly installed wind power units which appears staying at the bottom level in the recent years. For that in China, the price level of the wind power generation units are also falling continuously since 2008. Take the 1.5 MW wind power generation unit for example, the asking price dropped from ¥6,200 / kW in 2008 to ¥4,000 / kW in 2010. As a result, it makes the percentage share of the total investment costs lower for the wind power units. However, following the reversing trend on having more demand of wind power generation units, rebound on the asking price is not excluded. Analysis on the economic benefits requires understanding of the investment price model of the wind power generation unit of which its break-even price in the year i is derived as shown in equation (3-4).

$$P_i = \frac{\left[\frac{r(1+r)^n}{(1+r)^n - 1} \times \frac{C*G}{\alpha} + M_i \right](1+\mu)}{G*T_i(1-I)} \tag{3-4}$$

Where the following notations are assumed:

C is per kW manufacturing cost of the wind power unit;

G is total installed capacity of the wind power units;

I is power consumption of the station service in percentage;

α is wind power manufacturing cost in percentage of the original investment;

n is the period of depreciation in years;

r is the discount rate;

T_i is equivalent effective hours in the year i

M_i is operational cost in the year i; and

μ is value-added tax rate.

By assuming that the operational cost is calculated as a faction (ω) of the original investment and all other factors remain steady and constant, the break-even investment price is re-written as in equation (3-5).

$$P = \frac{\frac{r(1+r)^n}{(1+r)^n - 1} \times \frac{C}{\alpha}(1+\omega)(1+\mu)}{T(1-I)} \tag{3-5}$$

It indicates that when the feed-in price exceeds P, wind power generator developers are profit making. On the contrary, they will lose out when the feed-in price is lower than P.

Table 3-6 Major parameters of the wind power configuration

Parameter	Value	Potential Trend
C	4000RMB/KW	±10%，±20%
α	70%	-10%
ω	10%	
μ	8.5%	
r	8%	
n	20 years	
T	2200 hours	±100，±300，±500
I	2%	

By taking the major parameters with typical values as listed in Table 3-6, estimation on the wind power manufacturing cost, its ratio in terms of the original investment, and effective equivalent hours are made and based on which the break-even price (P) is determined. From the results so obtained as shown in Table 3-7, the benchmark feed-in tariff is set in accordance with the four types of wind energy resource areas, i.e. ¥0.51, ¥0.54, ¥0.58 and ¥0.61 per kWh which ensure normal operation of the respective wind farms. Furthermore, individual local government introduces various compensation schemes encourage wind power development making the feed-in price more than ¥0.7/kWh and for those projects supported with CDM [97], the benefit can be more than ¥0.8/kWh. Hence, the prevailing pricing mechanism in China provides the economic benefits, which serve to drive the wind power industry for continuous and sustainable expansion on scale and quality of the wind power development in China.

Table 3-7 Manufacturing cost factors of generation unit

α		60%						
T		+500	+300	+100	2200	-100	-300	-500
G	+20%	0.368	0.397	0.431	0.451	0.473	0.522	0.584
	+10%	0.337	0.364	0.395	0.413	0.433	0.479	0.535
	4000	0.306	0.331	0.360	0.376	0.394	0.435	0.486
	-10%	0.276	0.298	0.324	0.338	0.354	0.392	0.438
	-20%	0.245	0.265	0.288	0.301	0.315	0.348	0.389
α		70%						
T		+500	+300	+100	2200	-100	-300	-500
G	+20%	0.315	0.340	0.370	0.387	0.405	0.448	0.500
	+10%	0.289	0.312	0.339	0.354	0.371	0.410	0.459
	4000	0.263	0.284	0.308	0.161	0.338	0.373	0.417
	-10%	0.236	0.255	0.277	0.290	0.304	0.336	0.375
	-20%	0.210	0.227	0.247	0.258	0.270	0.298	0.334

Taking the case of wind power generation unit with manufacturing cost of ¥4,000/kW and about 60% of the original investment, the profit making level in the four types of wind energy resource areas is calculated as shown in Figure 3-14. Although the feed-in prices are set after taking care of the different type of wind energy resources, those in the resources rich areas still come with advantageous positions of having more effective equivalent hours and obvious better level of profit making capability. From the angle of view of encouraging a balance and fair wind power development on different parts of the whole country, there is a need for relevant regulatory authority to make adjustment on the feed-in tariff based on their type and areas of the wind energy resources by increasing the rate of the incremental tariff so as to reduce the level of difference in profit, Based on the estimated results and set the feed-in price of the different wind resource areas as ¥0.48, ¥0.53, ¥0.60, ¥0.66 per kWh, their level of difference in profit made would be reduced significantly as shown in Figure 3-15.

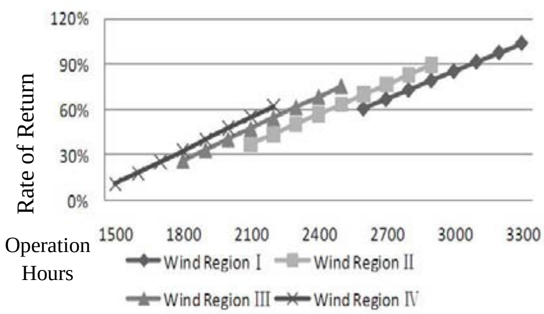


Figure 3-14 ROR of different wind regions

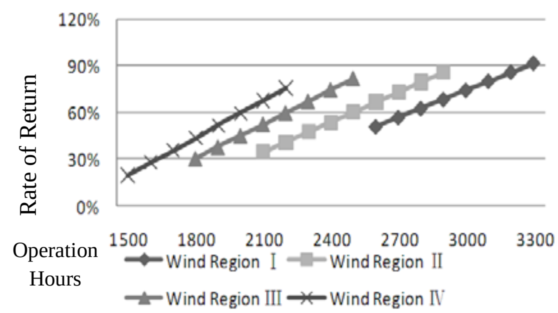


Figure 3-15 ROR after price adjustment

3.6 Analysis on Environment Benefit

Due to tight supply of energy and its obvious environmental problems, the benefits on the energy saving and emission reduction effects of using wind power attract much attention. In effect, every kWh of wind power energy supplied to the grid is equivalent to a saving of 340 g standard coal consumption and, at the same time, a reduction of 0.983 kg of CO_2, 0.698 g of SO_2 0.65 g of N_xO_y and 0.355 g of solid particulate emission [91]. Among the clean energy sources, wind power is the most competitive one and is having the greatest potential of development. As the installed capacity of wind power generators keeps on expanding, the above mentioned benefits and contribution would become more and more obvious and outstanding.

3.6.1 Numerical Modeling and Emission Reduction Analysis

The relative environmental benefits of wind power and coal-fire power can be realized by considering the following five major factors [98] as contained in the equation (3-6) representing the emission reduction capability of the wind power generation:

$$E_{CO_2/SO_2/NO_x/TSP} = \lambda G_T T_{avg} \left(1 - I_{avg}\right) \eta_{CO_2/SO_2/NO_x/TSP} \qquad (3\text{-}6)$$

Where

G_T is total wind power installed capacity;

λ is the percentage of power connected to the grid;

T_{avg} is average equivalent effective hours in use p.a.;

I_{avg} is average power consumption of the station services; and

$\eta_{CO_2/SO_2/NO_x/TSP}$ is respective rate of emission of CO_2, SO_2, NO_x, TSP

By referring to the emission reduction calculation of China in the year 2010, energy saving by the wind power generation is equivalent to around 17 million tons of standard coal consumption and emission reduction of 49 million tons of CO_2, 35 thousand tons of SO_2, 33 thousand tons of NO_x and about 18 thousand ton of TSP. According to the above analysis, it justifies that the wind power installation capacity in China keeps on growing fast in the past decade though its rate may slow down a bit in the coming years. As forecasted by the China Association of Comprehensive Resources Utilization, the wind power installed capacity by 2015 will be around 110-130 GW, average rate of expansion is around 21-25% p.a.; and by 2020, the wind power installed capacity will be around 200-230 GW, average rate of expansion is around 17-19% p.a.. Following maturity on the technical know-how, the ratio of wind power connection to the grid is increasing up to 80~90% which is close to the level of the wind power leading countries in Europe and USA. The annual equivalent effective hours of utilization is mainly affected by the wind quality of the specific wind farm. If the newly installed wind power projects do not cause too much change on the distribution among the wind energy resource areas, the average equivalent effective hours of utilization in the whole country remains more or less equal to the current level. By the same token, the power consumption of the station services, which is regarded as a basic index for maintaining normal operation of the wind farm, can be viewed as a parameter of the stability aspect. Regarding the rate of emission, it is mainly linked to the standard coal consumption of the coal-fired power plant and its environmental protection techniques. Following extension on scale of the coal-fired generation, complete combustion of coal is more likely making consumption of coal for generation decreasing gradually. Improvement of the environmental protection facilities further helps to reduce the rate of emission. A summary of the above analysis is shown in Table 3-8 which provides an estimated effect and benefits of energy saving and emission reduction by using wind power in China.

Table 3-8 Estimated benefits of energy saving and emission reduction of wind power in China

Year		2015	2020
Parameters	Installed Capacity (GW)	110~130	200~230
	Ratio of grid connection	80~85%	85~90%
	Operation Hours (H)	2050~2150	
	Rate of Station Services Power Consumption	2%	
	Coal Consumption for generation (G/KWH)	330	320
Prediction Of Energy Saving and Emission Reduction	Quantity of Coal Substitute (Mtce)	62.5~82.3	117.0~149.4
	CO_2 reduction (10^8 ton)	1.7~2.2	3.2~4.0
	SO_2 reduction (10^4 ton)	12.0~15.8	22.4~28.7
	NO_x reduction (10^4 ton)	11.2~14.7	20.9~26.7
	TSP reduction (10^4 ton)	6.1~8.0	11.4~14.6

Based on figures since 2009, standard coal consumption for 6,000 kW and above power plant in China is about 915 million tons which is increasing at a rate of 6.3% in recent years. By 2015, wind power helps to save more than 5% of the coal consumption in China and the benefits of such energy saving and emission reduction will further be extended. As projected from the analysis results, the benefits of energy saving and emission reduction of wind power continue to be promising. In fact, as an agreement in the Copenhagen 2009 Protocol, China promised to join in the international community effort to reduce 15% of her energy needs by 2020 which is regarded as an important commitment and promise to developing wind power in China.

By considering the lifecycle energy consumption and emission of wind power, the emissions and avoided external costs compared with conventional energy are shown in Table 3-9. Wind power can replace 130 million tce (tones of coal equivalent) by 2020, 260 million tce by 2030, and 660 million tce by 2050 (taking into account improved thermal power technologies and lower coal consumption per kilowatt-hour of power). Annual CO_2 emission reductions are expected to amount to 300 million tones (Mt) by 2020, 600 Mt by 2030 and 1 500 Mt by 2050. In addition, annual SO_2 emission reductions are expected to be 1.1 Mt by 2020, 2.2 Mt by 2030 and 5.6 Mt by 2050. The CO_2 potential reduction of wind power in different areas in future 40 years are shown in Figure 3-16.

Table 3-9 Emissions and benefits of wind vs. coal and natural gas for electricity

	Emissions						Benefits		
	Onshore wind	Offshore wind	Average wind	Hard coal	Lignite	NGCC	Vs. coal	Vs. Lignite	Vs. NGCC
Carbon dioxide (g)	8	8	8	836	1060	400	828	1051	391
Methane (mg)	8	8	8	2554	244	993	2546	236	984
Nitrogen oxides (mg)	31	31	31	1309	1041	353	1278	1010	322
NMVOC (mg)	6	5	6	71	8	129	65	3	123
Particulates (mg)	13	18	15	147	711	12	134	693	-6
Sulphur dioxide (mg)	32	31	32	1548	3808	149	1515	3777	118

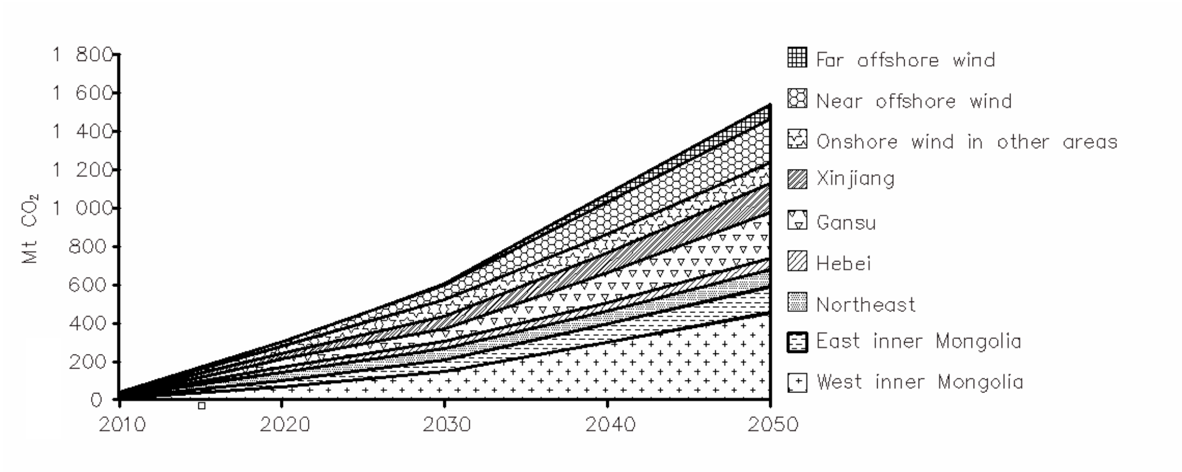


Figure 3-16 Potential CO_2 abatement of major wind farms in China

3.6.2 Prospective Policy Options

By replacing coal power, clean, non-polluting wind power can have significant environmental benefits by emission reduction of the pollutants generated by combustion of fossil fuels. The pollutants are related not only to global warming but also to other environmental impacts such as air pollution, acid precipitation, ozone depletion, forest destruction and emission of radioactive substances [9], which will further cause or exacerbate public health problems, including respiratory problems, skin disease, cancer, and so on. By emission reduction of the pollutants, many major environmental problems and related social health issues will be alleviated.

First, Acid rain caused by the air pollutants, SO_2 and NO_x will be mitigated. As the global largest coal consumer, the acid rain of China is mainly caused by combustion of coal with high sulphur content, and is sulfuric acid type. The damages of acid rain are showed in several aspects, such as impacting the rules of season changes and diurnal changes, causing smog, public health issues via reduction of sun radiation, damaging the ecosystems, destroying the forest, and damaging buildings, etc. Besides, attention is also given to other substances, such as VOCs, chlorides, ozone and trace metals that may participate in a complex set of chemical transformations in the atmosphere, resulting in acid precipitation and impacting human health. The emission of above pollutants will be reduced by substituting wind power for coal power, and then the pollution, acid rain, will also be mitigated.

Second, Ozone layer depletion will slow down. Ozone depletion is caused by the emissions of CFCs, halons (chlorinated and brominated organic compounds) and NO_x, and can lead to increased levels of damaging UV radiation reaching the ground, causing increased rates of skin cancer and eye damaging to humans and is harmful to many biological species. The energy related activities will lead to ozone depletion directly or indirectly by emitting related pollutants, while wind power, as green power, will emit little pollutants leading to ozone depletion.

Besides, global warming and climate changes mainly caused by CO_2 will be mitigated. The greenhouse effect is caused by several greenhouse gasses, such as CO_2, CH_4, CFCs, halons, N_2O, ozone, and has been increasingly associated with the contribution of CO_2, which is estimated to contribute about 50% to the anthropogenic greenhouse effect. Greenhouse effect will result in a rise of the earth's temperature and cause climate changes, which will have a wide range of effects on human activities all over the world. The climate changes include the temperature changes of every season, precipitation fluctuations, extreme weather events, sea level increase, and glaciers melting, which will impact the growth of plants, bring diseases associated with weather, such as influenza, and threaten the existence of coastal cities, etc. CO_2 emissions abatement is a significant contribution in environmental benefit via replacing coal power by wind power, which will mitigate the Global warming and climate changes.

Of course, large-scale development of wind power may have some negative impacts on the environment, such as land use, noise, visual impact, bird migration and electromagnetic radiation, but compared with other conventional energy sources, especially coal-fired electricity generation, wind power's impact in these areas is much lower or even avoidable.

CHAPTER 4

SEMD-SRRM POLICY FRAMEWORK FORMULATION AND SIMULATION

Exploiting renewable energy is an effective way to mitigate energy source deficiency, control GHGs emissions, and achieve smart grid vision. Wind power, as one of the most appealing renewable energy resources, has gained widespread concerns during the last decades. A dynamic decision making model is proposed to deal with the multimarket trading for application of the policy framework. Fuzzy Differential Evolution (FDE) algorithm is employed to solve the multi-period stochastic optimization problem and give the optimum results for each time interval. Comparisons between different market scenarios demonstrate the economic and environmental positive influences of the policy framework. With the proposed model, a GENCO is capable to make a good tradeoff between profit-making and emission reduction under the three interactive markets environment. Policies defining the three interactive markets can accurately reflect the intended goals such as decreasing emissions, promoting renewables, and maintaining electricity cost at a reasonable level.

4.1 Background of Modeling

Electricity supply industry has been deregulated on the generation side and also retail side in some countries and regions, as such there are two major changes: (i) generation companies (GENCOs) are allowed to operate and compete in the market; (ii) GENCOs are subject to competition in the electricity market (EM). The model proposed in this project builds upon the EM consisting of a power pool and bilateral trades. The primary goals of EM are to provide energy securely, reliably and efficiently. Whereas the EM usually meets these goals, other valued outcomes, including conserving finite resources, maintaining stable and reasonable electricity cost, and protecting the environment, are at the stakes. To address these problems, a feasible policy framework has been adopted to mitigate the emission by market-based mechanisms. Under this scheme, specific amounts of emission allowances are allocated to various industrial installations, including generators. These allowances can be used either for producing corresponding amounts of CO_2 or trading in Carbon Market (CM). If the total emission over the emission commitment period, which is the period within which a country/region must remain the national/regional emission level specified by its target, exceeds the allocated allowances, a GENCO has to either purchase allowances on the market or pay a penalty. It is a positive initiative for introducing renewable energy into power sector. implying that EM would be affected by the scheme. Operational decisions of GENCOs on electricity production and related fuel portfolio would be affected significantly. The deregulation of EM and the implementation of CM require each GENCO builds up its own fuel portfolio according to the prices variation in the Fuel Market (FM). In the long run, GENCOs therefore have to contract their fuels in an optimal way that allows them to operate in the multimarket environment without incurring any negative profits. In the daily operation, GENCOs have to decide the usage of their fuel according to the production with consideration of different fuel prices.

When taking uncertainties of EM, CM or FM into account, a few research efforts have been devoted to develop the optimization model. A multi-time period electricity network optimization model is presented in [99] which took gas flows, price and storage problem into account for GENCOs. Incorporating a handling scheme to deal with emission constraints, Guo et al. developed a dynamic economic emission dispatch model of power systems [100]. A typical environmental/economic power dispatch optimization problem is described in [92], which included fuel cost minimization and emission constraints. However, these studies do not take into account the effects of emission trading which play a more important role of increasing the renewable energy output than other policies such as government subsidies [101]. [102] investigated the impacts of both emission trading and renewable energy support schemes on EM operation. However, emission allowance is treated as a fixed cost so that its trading value has been ignored. So far, from literature review, the optimal decision making of GENCOs with the effects of EM, FM and CM have not been tackled fully.

To achieve a better understanding of how a wind based GENCO would react to these three interactive markets, it is proposed that a two-stage stochastic optimization model is created to provide the optimal results in both the production process and trading processes. Different from works that consider only caps on emission, the trading benefits of Emission Trading Scheme (ETS) is incorporated. This is a complex decision making problem in which all units have to be scheduled to satisfy not only the power demand of bilateral trades and power pool but also spinning reserve of the system. Furthermore, the trading in the three interactive markets has to be coordinated with environmental constraints.

4.2 Agent-based Computational Method

One significant subject of interest in the context of reinforcement learning is the balancing between exploration and exploitation with adaptation of the Q-Learning (QL) parameters to the condition of dynamic uncertain environment. The peculiarities of the electricity market have provided such complex dynamic economic environment, and consequently have increased the requirement for advancement of the learning methods. It is prospected that an agent-based model can be used to determine the optimal bidding strategies among generation units in the electricity markets using reinforcement learning. Q-learning offers suppliers the ability to evaluate their actions and to retain the most profitable of them. To achieve it, a Locational Marginal Pricing (LMP) based pricing mechanism is used for setting up the electricity market and determining the generator reward. Formulation of the proposed approach is validated the feasibility of implementation in competitive power markets.

In the electricity market, the market participants make strategic decisions independently with in-complete information, and learn how to interact with each other via repeated games. Also, they have natural incentive to exercise market power through strategic methods for gaining more profit. Obviously, the same as other economic systems, the human's peculiarities such as learning, risk attribute, fuzzy thoughts can play key roles in the electricity market. Hence, modeling the behavior of the electricity market has been always a challenging task. On the other hand, designing an efficient electricity market requires a deep understanding about the effects of market policies before implementation.

Generation units in the electricity market industry are looking for policy guidance on how to determine an appropriate electricity pricing system. A price change in the wholesale electricity market occurs due to several socio-economic and engineering factors [48]. Electricity auctions are like repeated games, in which we need to take into account the learning behavior in order to analyze the possible solutions of the game. The use of agent-based simulation will enable the researchers to develop models of the electricity supply industry that are more realistic than current ones [53]. The suppliers used a reinforcement-learning algorithm to simultaneously maximize their profits and reach a target utilization rate of their own power plant portfolio. The demand side in the presented model of Bower and Bunn in the year 2000 had a static price-responsive load [54]. An alternative to the game theoretic approach, used to study the behavior of market participants, is agent-based simulation (ABS). In the implementation of the ABS, the market participants develop their profit-maximizing strategy through the repetition of the game and reinforcement learning.

Q Learning is among the most popular reinforcement learning algorithms. Agent-based computational economics (ACE) is the computational study of economic processes modeled as dynamic systems of interacting agents, where “agent” refers broadly to a bundle of data and behavioral methods representing an entity constituting part of a computationally constructed world [103]. In recent years, ABS systems have been developed to test electricity markets, for example, EMCAS [104] developed by Argonne National Laboratory in the US and AMES [105] developed by Iowa State University.

In this section, a fuzzy QL method is developed to model the power supplier's strategic bidding behavior in a computational electricity market. In the simulation framework, the QL algorithm selects power supplier's bidding strategy according to the past experiences and the values of the parameters, which show the human's risk characteristic. The application of the proposed methodology for the power supplier in an IEEE 39 bus power system shows the performance difference in comparison of two bidding strategies.

4.2.1 Algorithm of Reinforcement Learning

This section presents a general overview of reinforcement learning theory, the definition and pro-posed algorithm resulted from reinforcement learning respectively.

Reinforcement learning (RL) studies the learning process through interaction between agent and environment, which focuses on effects of rewards and penalties on subjects' decisions in their attempt to catch a goal. In Sutton and Barto's description, RL tries to imitate the learning process or learning what to do, in order to maximize a numerical reward signal. Learning process discovers favorable actions by a try-and-punish/reward method [48]. The common elements of RL theory are:

- Learner, which is called the agent;

- Environment, including everything out-side the border of the learner interacting with it.

The learning process is based on two mechanisms including exploration of the environment and exploitation of the experiences gained by exploration process. The learning process is illustrated in Figure 4-1. At each step, n, the agent (learner):

- Perceives the state s_n of the environment;
- Choose one action a_n according to its per-ception and experience in the past times;
- Is being reinforced by receiving a reward or penalty r_n of its chosen action;
- Implement this reinforcement learning process to maximize its received reward over time.

As it becomes clear from the algorithm described above that the agent explores its environment and be reinforced to learn from the rewards and mistakes.

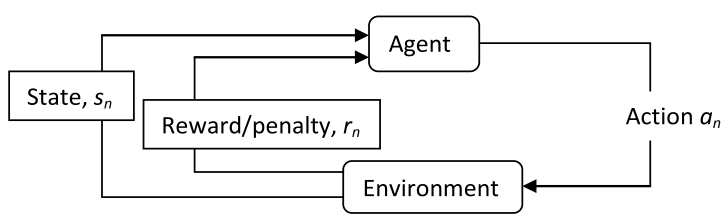


Figure 4-1 Learning mechanism

Q learning provides such advantages that it can be implemented online and requires no explicit model for environment. As shown above in Figure 4-2, a scalar reward r_n occurs as feedback to every step (s_n, a_n); thus, reward r_n is a function of the state perceived by the agent and its chosen action a_n. And the agent in Q-learning continues in memory such a function Q_n (s_n, a_n) which represents the agent's expected reward. The agent believes that it will gain this reward if it takes an action a_n in the state s_n, while the function of the expected reward is represented by a two dimensional matrix which is indexed by state and action as a pair, and the elements of which are defined as Q-values in this Q-learning algorithm as a specific reinforcement method.

The agent's experience, concerning its interaction with the environment, consists of a sequence of distinct stages or episodes [106]. Let S be the set of n possible states of the environment and A be the set of m possible actions which the agent can take. Under the step n, the agent will:

- Perceive its present state s_n, which is an element of set S;
- Choose and implement an action a_n, which is an element of set A, according to its current policy;
- Obtain the subsequent state s_{n+1}, which is an element of set S as well;
- Gain a reward r_n;
- Update its Q-value matrix according to the Q-learning's common formula,

$$Q(s_n, a_n) \leftarrow Q(s_n, a_n) + \alpha_n(s_n, a_n) \times [r_{n+1} + \gamma \max Q(s_{n+1}, a) - Q(s_n, a_t)] \qquad (4\text{-}1)$$

However, we select to not consider the effect of future states to current action's strategy. Hence, the above formula could be written as:

$$Q(s_n, a_n) = Q(s_n, a_n) \cdot (1 - \alpha_n) + r \cdot \alpha_n \qquad (4\text{-}2)$$

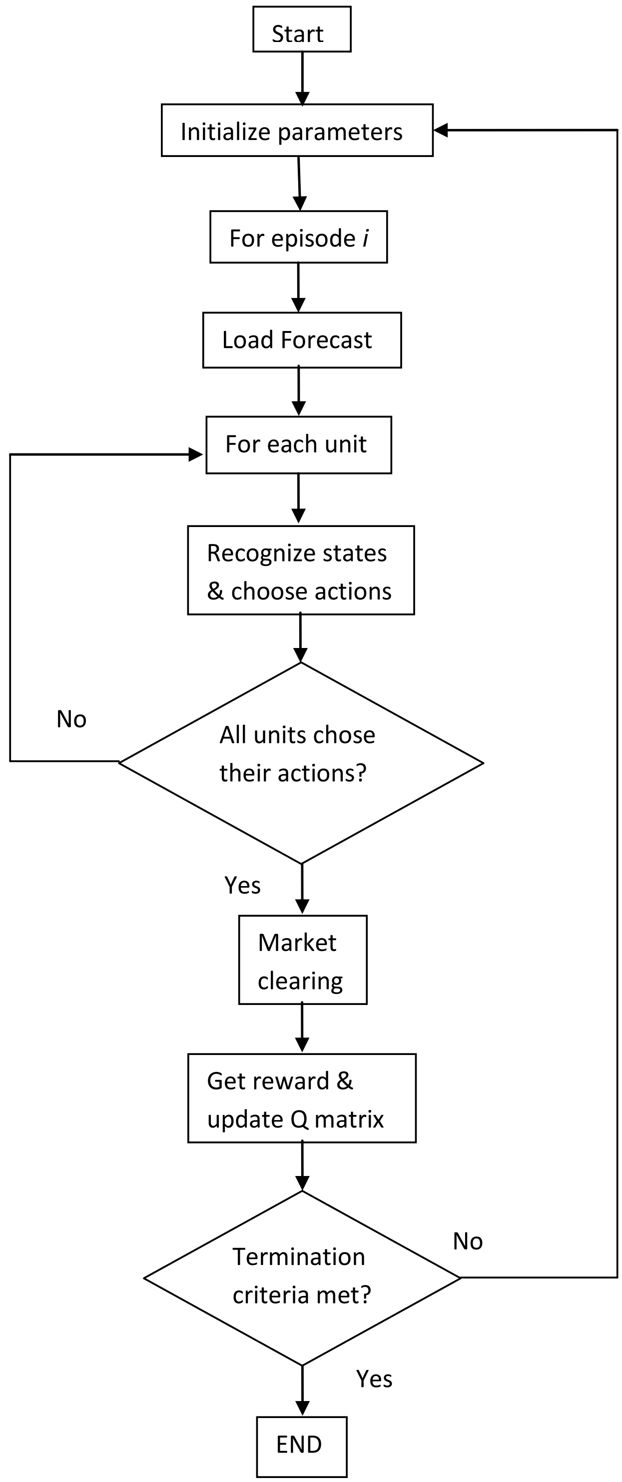


Figure 4-2 How the proposed Q-learning algorithm functions

Equation (4-1) describes the best the agent thinks it can do in state *s* [107]. According to equation (4-2), only Q values corresponding to current state and last action selected are updated. $\alpha_n(s,a)$ is a learning rate in the range $(0,1]$, that reflects the degree to which estimated Q values are updated by new data; it can be different in each step and state-action dependent varying with time.

4.2.2 Methodology

In the agent-based approach, a system is modeled as a collection of autonomous decision-making entities called agents. Each agent individually assesses its situation and makes decisions on the basis of a set of rules. Agents may execute various behaviors appropriate for the system they represent. Repetitive competitive interactions between agents are a feature of agent-based modeling, which relies on the power of computers to explore dynamics out of the reach of pure mathematical methods. At the simplest level, an agent-based model consists of a system of agents and the relationships between them [108]. In this section the behavior of suppliers in a spot market is studied. Suppliers submit bid to the Independent System Operator (ISO), declaring the power they are willing to sell at a specific price.

Each supplier, with active power output, P_i and marginal cost mc_i bids its full generation capacity P_i^{max} at a constant price b_i in \$/MWh, which cannot be higher than a market price cap, *pc*, or lower than the supplier's marginal cost in \$/MWh, $mc_i \le b_i \le pc, \forall i \in [1,10]$.

Hence, the supplier *i* cost function as revealed by his offer in the energy market is $C_i(P_i) = b_i \cdot P_i$, $C_i(P_i) = b_i \cdot P_i$,while the supplier's true cost function is:

$$F_i(P_i) = mc_i \cdot P_i \tag{4-3}$$

4.2.2.1 The ISO Market Clearing Problem

The ISO collects all bids, constructs the supply curve by ordering the suppliers' bids in economic precedence and schedules the system resources for a particular hour, so as to satisfy the load demand by the most economic resources. Equivalently, the ISO market-clearing problem is formulated as a locational marginal pricing (LMP) problem and calculated by matpower, which employ DC optimal power flow (OPF) as an optimal approach to achieve its OPF and LMP.

Each supplier selects its actions in order to maximize his profits from the participation in the spot market. Since, as stated in the previous section, each supplier is assumed to bid his maximum capacity in the spot market, the supplier actions are limited to the selection of the bid prices he submits to the spot market.

The application of Q-Learning algorithm in modeling the supplier bidding behavior requires the definition of the *states* of the agent's environment, the admissible *actions* and the returned *reward*.

4.2.2.2 State

The market, which represents the environment in our simulation, informs each supplier about the market price, which describes the state of the environment. The market price cap, defined by the regulatory authority, only limits the market price; therefore, the state space is divided into a constant number of states, equally distributed between zero and the market price cap.

4.1.2.3 Action

The supplier-agent action is the selection of the bid price. The market price cap, publicly available to all agents, as an upper bound, defines the limits of the agent's bid price and his marginal cost, as a lower bound. Hence, the action space is divided also in a constant number of actions, equally distributed agent's cost and the market price cap.

4.2.2.4 Reward Calculation.

Reward is also the generation source of Q-value of each unit. The reward of each agent is set equal to the profit, in \$, the agent makes by participating in the spot market. Let Q_i be the dispatched power of supplier *i*, then his reward $r_i(x,a)$, for taking an action *a* from state *x*, under the locational marginal pricing rule, is given by the following equation:

$$r_i(x,a) = lmp \cdot Q_i \tag{4-4}$$

The learning ratio here is designed to be 0.65 in horizontal bidding and 0.70 in linear increasing bidding.

4.2.3 Numerical Model

A New England 39-bus test system is employed in this study which is depicted in Figure 4-3. This is a regional power system that serves the six states of Maine, Connecticut, Massachusetts, New Hampshire, Rhode Island, and Vermont. Currently, it includes more than 350 separate generators and more than 8,000 miles of transmission lines. In our case studies, the 10 units of Table 4-1, shown the 10 generation plants in the above 39-bus test system, compete to serve a daily load curve shown as Figure 4-4. Unit 10 is the dominant supplier in the market and it is the cheapest unit.

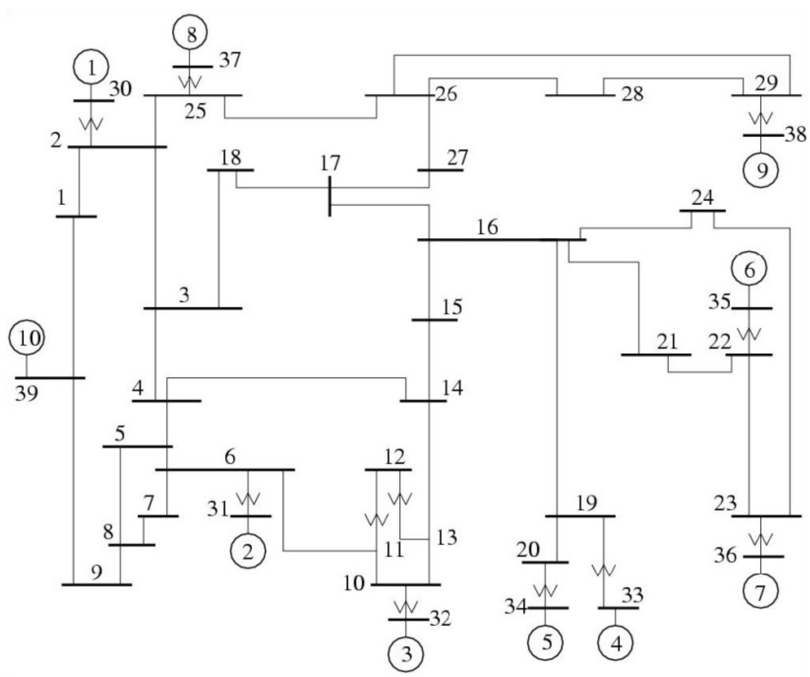


Figure 4-3 39-bus test system with 10 gens

Every generator's bidding behavior is evaluated hourly in a day and the simulation is undertaken in 30 days in horizontal bidding and 60 days in linear increasing bidding. Since the selection of different bidding actions in linear increasing case is more complicated and sensitive to parameters, longer simulation period is needed. Matpower calculates locational marginal price with DCOPF method. And the reward is set directly related with profit of each unit. All suppliers are considered as players in our market and their behavior is modeled through the Q-Learning algorithm. The parameters of the algorithm that need to be defined are experiment period, learning ratio and initial Q matrix. In the subsections that follow, two cases are examined, two for settlement mechanism.

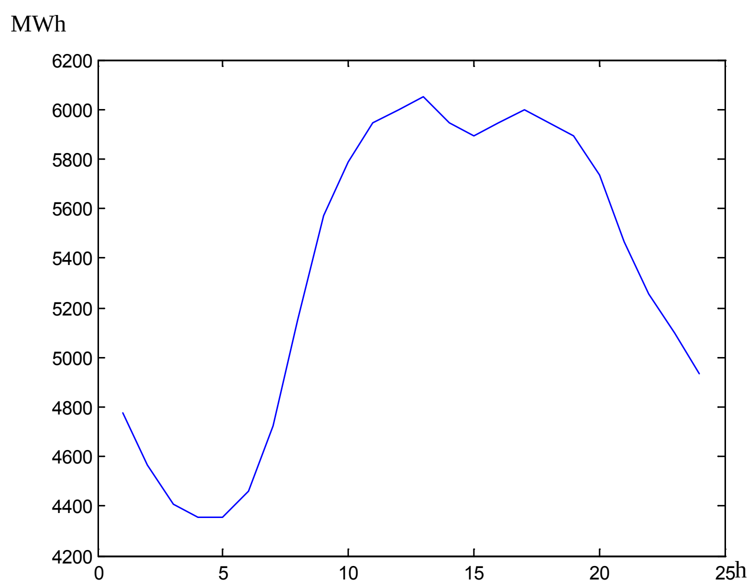


Figure 4-4 Daily Load Curve

In this case, agents are set to bid in a horizontal line but at different values including marginal cost, where locational marginal pricing (LMP) is employed as the market clearing mechanism. According to the definition above, the marginal cost here is actually the lowest bidding price of all the plants, which is 30.0 $/MWh here.

Table 4-1 Unit Data in the Case Studies

Unit No.	P_g^{max}[MW]	mc_g[$/MWh]
1	250	40.0
2	677.871	35.0
3	650	34.5
4	632	36.5
5	508	37.0
6	650	36.2
7	560	38.5
8	540	38.3
9	830	32.5
10	1000	30.0

Following graphs illustrate the market clearing price in this horizontal bidding case and two units' behavior strategies as good subjects to observe and compare.

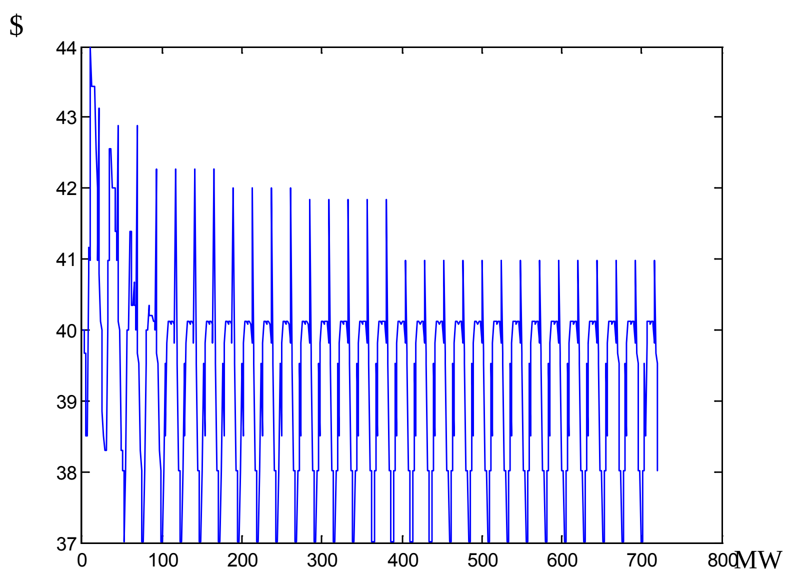


Figure 4-5 Market prices in horizontal bidding

The agents' generation cost c follows equation (4-5):

$$c = aq + b \tag{4-5}$$

Where q is the practical output of each unit and a, b are the parameters of its cost c. While the agents' marginal cost is:

$$mc = a \tag{4-6}$$

Table 4-2 Behavior Strategies of Unit 6 in horizontal bidding

State Sequence	1	2	3	4	5	6
Action No.	E	E	C	C	C	C
State Sequence	7	8	9	10	11	12
Action No.	C	D	A	A	A	A
State Sequence	13	14	15	16	…	50
Action No.	A	A	A	A	A	A

It illustrates Unit 6's bidding behavior in Table 4-2, who firstly selects Action E as its bidding strategy and then tries Action C and D for a short period. Finally it comes to Action A and stays at its convergence action. And Table 4-3 shows Unit 2's bidding behavior, which firstly selects Action E as its bidding strategy, after that, it tries Action D and C and finally comes to Action B as its convergence action.

Table 4-3 Behavior Strategies of Unit 2 in horizontal bidding

State Sequence	1	2	3	4	5	6
Action No.	E	E	E	E	D	D
State Sequence	7	8	9	10	11	12
Action No.	C	C	C	C	C	C
State Sequence	13	14	15	16	…	50
Action No.	B	B	B	B	B	B

While following charts are the marginal case, in which agents all bid at the marginal cost. So their bidding strategy selection is always Action A and all of them are the same.

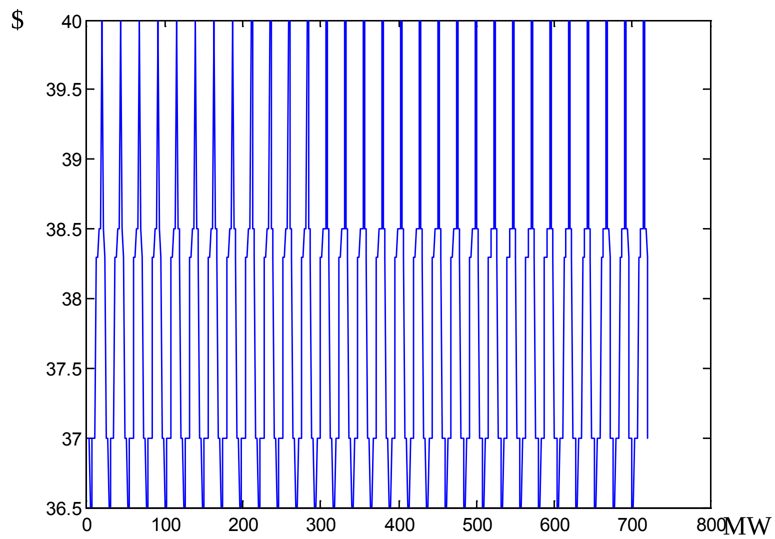


Figure 4-6 Market prices in marginal bidding

Table 4-4 Behavior Strategies of all units in marginal bidding

State Sequence	1	2	3	4	5	6
Action No.	A	A	A	A	A	A
State Sequence	7	8	9	10	11	12
Action No.	A	A	A	A	A	A
State Sequence	13	14	15	16	…	50
Action No.	A	A	A	A	A	A

If bidding in linear increasing line, agents are set to bid in a linear increasing line but at different slopes including marginal cost line. According to the definition above, the slope of marginal cost line here is actually the lowest bidding line of all the plants, which should be $(0.01q + b_i)$ \$/MWh here. 0.01 is the lowest slope of all 10 units in this case and b_i is their intercepts specifically. In increasing bidding, the agents' generation costs are calculated in Equation (4-7):

$$c = aq^2 + bq \tag{4-7}$$

Where q is the practical output of each unit and a, b are the parameters of its cost *c*. While the agents' marginal cost is:

$$mc = aq + b \tag{4-8}$$

Table 4-5 Strategies of Unit 6 in linear increasing bidding

State Sequence	1	2	3	4	5	6
Action No.	B	B	B	B	B	B
State Sequence	7	8	9	10	11	12
Action No.	B	E	E	B	B	B
State Sequence	13	14	15	16	17	18
Action No.	B	B	B	C	C	C
State Sequence	19	20	21	22	23	24
Action No.	B	B	B	E	E	B
State Sequence	25	26	27	28	29	30
Action No.	B	A	A	E	E	A
State Sequence	31	32	33	34	35	36
Action No.	A	A	C	C	A	A
State Sequence	37	38	39	40	…	50
Action No.	A	B	A	A	A	A

Unit 2 and Unit 6 are selected as two subjects to compare their differences of bidding behavior and action strategies in horizontal bidding and horizontal marginal clearing, and increasing bidding and marginal clearing with slope as well, respectively. It obviously shows that Unit 6 selects its bidding actions firstly from Action B to Action E and then jumps between Action E and Action C. Finally, its convergence action comes to Action A and remains it. And Unit 2's bidding actions are from Action E to Action D, then Action C and stays at Action B at last. Their action selection is undertaken based on their learning experience from Q-value matrix and updated rewards of every action in every state.

It could be seen from the above simulation that when the generator units are provided with learning capability, they can report higher-than-true marginal costs that lead to increase in market prices. The LMPs and allocated generations of generators showed that this method leads generators to learn a strategic manner and, thus, increase LMPs and maximize their rewards.

Table 4-6 Strategies of Unit 2 in linear increasing bidding

State Sequence	1	2	3	4	5	6
Action No.	D	D	D	D	D	D
State Sequence	7	8	9	10	11	12
Action No.	D	D	E	E	A	A
State Sequence	13	14	15	16	17	18
Action No.	A	C	C	A	A	A
State Sequence	19	20	21	22	23	24
Action No.	A	A	D	D	A	A
State Sequence	25	26	27	28	…	50
Action No.	A	A	A	A	A	A

According the simulation results, the market clearing price in Case 2 is higher than that in Case 1. And the selection of different bidding strategies in Case 2 is more sensitive than that in Case 1 as well.

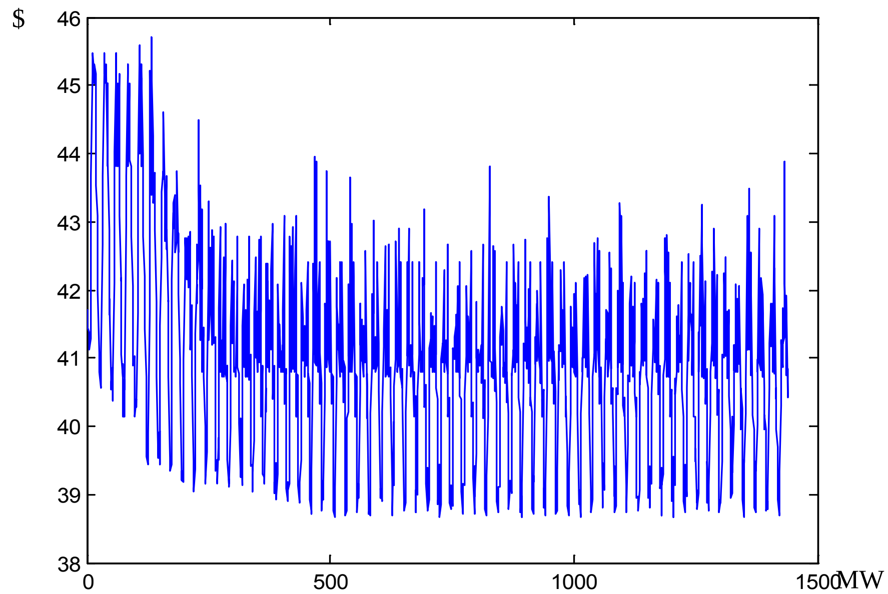


Figure 4-7 Market prices in increasing bidding

The notable effect of simulation on distinguishing bidding strategies which concerns electricity prices is demonstrated and it is worth mentioning that, as the first two cases indicate, market clearing price of horizontal bidding is definitely higher than that of marginal trading, which is similar in increasing bidding market. However, simulation operation in increasing bidding is much more complicated and the results are more sensitive to parameters' evaluation.

4.2.4 Summary

The primary contributions of this section include the formulation of a stochastic game model for the energy market and its reinforcement learning-based solution methodology. To integrate agent-based approach and optimal competitive electricity market structure, this section presents a comparative analysis of the most commonly used pricing systems in electricity markets: uniform and locational marginal pricing. For the needs of the analysis agent-based simulation was employed, where each supplier was modeled as a learning agent, following a Q-Learning bidding behavior. A spot asymmetric market with 10 generation plants was simulated and four experiments were conducted. The analysis of the cases led to useful conclusion. It has been shown that the scalability of the RL-based solution approach still remains a challenge in solving stochastic games involving actual power networks. Nevertheless, the RL-based method, which is proposed here, allows us to tackle the feasibility of agent-based computational approach in sustainably competitive power market. Further research is still needed before the whole issues of convergence, optimality, and scalability are fully addressed.

4.3 Framework Formulation

The proposed framework in this section is built on the electricity market (EM) consisting of power pool and bilateral trades [109]. The primary goals of EM are to provide energy securely, reliably and efficiently. Whereas EM usually meets these goals, other valued outcomes, including conserving finite resources, maintaining stable and reasonable electricity cost, and protecting the environment, are at the stakes.

4.3.1 Energy Production of a Generator

Under the deregulated market environment, a GENCO has to decide the amount of power generation by considering two components. The major income component is for long-term bilateral contracts. Usually, they are confirmed at the high levels. The remaining component of production is for the power pool. Power pool features with fluctuated price and stochastic demand. A GENCO has to make a trade-off between the profit and the risk of fluctuating energy price. Another concern is that a GENCO has to pay more in a balancing market if it cannot obtain the sufficient bidding amount. Based on these two aspects, the proposed model divides a GENCO's output at time interval *t* on day *d* into two parts: one for bilateral contracts $d_{d,t}$ and another one for the stochastic power pool $\omega_{d,t}$. The total production at time interval *t* on day *d* is

$$\sum_{g=1}^{G} q_{d,t,g} = d_{d,t} + \omega_{d,t} \tag{4-9}$$

In the production process, a GENCO needs to decide the optimal $q_{d,t,g}$ for all its units. In a competitive EM, market clearing solves the stochastic output of each GENCO via coordinating all the bids. A GENCO is expected to develop its own optimal bidding strategy to maximize its profit in EM. Firstly, employing the method described in [110], the upper bound of output for stochastic power pool $\lambda_{d,t}$ for each hour is forecasted using historical data. Then the proposed model provides the optimal level of the stochastic output $\omega_{d,t} \in [0, \lambda_{d,t}]$ and the corresponding units' generations through FDE algorithm. In each FDE iteration, economic dispatch (ED) is employed to allocate generation of units at minimal possible cost whereas satisfying all the power units and system constraints. Here, the classical lagrange multiplier method is used to solve the ED problem[111]. FDE selects the best $(\omega_{d,t}, q_{d,t,g})$ among the maximum number of iterations for each hour.

4.3.2 Carbon Allowance Trading

A GENCO must balance its emission allowances with the generated emissions at the end of the emission commitment period. A unit of allowance is the permission to emit one tonne of CO_2 within the emission commitment period (0, *C*). On the last day of the emission commitment period (i.e. compliance day *C*), GENCO must pay a penalty price for excessive emissions without allowance as follows (on day *C*, $c_d^S = c_C^S$, $c_d^B = c_C^B$, $x_d = x_C$, $q_{d,t,g} = q_{C,t,g}$):

$$Penalty_C = p_C^{pp} \max[(x_C + c_C^B) - \sum_{t=1}^{T}\sum_{g=1}^{G} e_g(q_{C,t,g}) + c_C^S \; , 0] \tag{4-10}$$

The penalty price p_C^{pp} is usually determined before the commitment period based on the national/regional emission levels. It is consistent throughout the whole commitment period. To avoid paying penalty on the compliance day *C*, a GENCO can either operate their units under strict environmental constraints according to the initial allowances or reallocate its allowances in CM during the commitment period.

4.3.3 Revenues and Costs in the Market

The profit of a GENCO during the whole planning period $d = (d_0, D)$ is the revenue from EM, FM and CM minus the total production cost and expense. The profit can be expressed as follows:

$$\Gamma_D = (R^{BEM} + R^{PEM} + R^{CM} + R^{FM}) - (C^{CM} + C^{LFM} + C^{FM} + C^{PEM}) \tag{4-11}$$

Where

R^{BEM} is the revenue from long term bilateral energy contracts;

R^{PEM} is the revenue from trading in power pool;

R^{CM} is the revenue from trading in CM;

C^{CM} is the cost of trading in CM;

C^{LFM} is the cost of long term bilateral fuel contracts;

C^{FM} is the cost of trading in FM;

C^{PEM} is the cost of trading in power pool.

Each long-term bilateral energy contract between a GENCO and its customer consists of the capacity part (which reserve the GENCO's capacity to provide power) and the energy part. The revenue from all the bilateral contracts is

$$R^{BEM} = \sum_{d=d_0}^{D} \sum_{t=1}^{T} \left[P_{d,t}^{CC} \sum_{i=1}^{I} Q_{d,t,i} + P_{d,t}^{EC} \sum_{i=1}^{I} \min\left(l_{d,t,i}, Q_{d,t,i}\right) \right] \tag{4-12}$$

The revenue from selling electricity in power pool R^{PEM} is another income of a GENCO. A GENCO plans its own production level $q_{d,t,g}$ and its revenue is

$$R^{PEM} = \sum_{d=d_0}^{D}\sum_{t=1}^{T}\left\{ p_{d,t}^{PEM} \max\left[\sum_{g=1}^{G} q_{d,t,g} - \sum_{i=1}^{I} \min\left(l_{d,t,i}, Q_{d,t,i} \right), 0 \right] \right\} \tag{4-13}$$

Besides balancing the emission, a GENCO aims for profits from the trading of carbon allowances. it optimizes the trading amount of allowance in CM, with the consideration of variation in the emission level and the allowance price. It is computed as:

$$R^{CM} = \sum_{d=d_0}^{D} \left(I_d^{CMS} p_d^{CM} c_d^{S} \right) \tag{4-14}$$

In each trading process, a GENCO, if necessary, can purchase emission allowance when the allowance price in CM p_d^{CM} is relatively low. It this case, the cost of a GENCO in CM is:

$$C^{CM} = \sum_{d=d_0}^{D} \left[I_d^{CMB} p_d^{CM} c_d^{B} \right] \tag{4-15}$$

The allowance buying index I_d^{CMB} suggests purchasing allowances when the current price is lower than the mean value of the future prices at a certain level, which is expressed as follows:

$$I_d^{CMB} = \begin{cases} \beta^{-1}, & if\ \dfrac{\mu(p_{d+1:D}^{CM}) - p_d^{CM}}{p_d^{CM}} > r_1 + r_2 \\ 0, & if\ \dfrac{\mu(p_{d+1:D}^{CM}) - p_d^{CM}}{p_d^{CM}} \le r_1 + r_2 \end{cases} \tag{4-16}$$

Where the risk factor r_2 is used to control excessive purchasing.

The price of the long term fuel contract for generator *g*, which is known before the planning period, is $P_{d,t,g}^{LFM}$. Hence, in FM, the total cost of the long term contracts, C^{LFM}, can be expressed as follows:

$$C^{LFM} = \sum_{d=d_0}^{D} \sum_{t=1}^{T} \sum_{g=1}^{G} \left[P_{d,t,g}^{LFM} Q_{d,t,g}^{FM} \right] \tag{4-17}$$

A GENCO needs to purchase fuel to meet the demand of the generators when the amount of fuel related to the long term contract is not sufficient. The cost of fuel purchasing C^{FM} is expressed as follows:

$$C^{FM} = \sum_{d=d_0}^{D} \sum_{t=1}^{T} \sum_{g}^{G} p_{d,t,g}^{FMB} \left[\max\left(f_g\left(q_{d,t,g}\right) - Q_{d,t,g}^{FM}, 0 \right) \right] \tag{4-18}$$

Where the purchasing price $p_{d,t,g}^{FMB}$ is calculated based on the predicted benchmark price $p_{d,t,g}^{FM}$ in FM:

$$p_{d,t,g}^{FMB} = \beta^{-1} p_{d,t,g}^{FM} \tag{4-19}$$

Power pool features with volatile spot prices and stochastic demand. When the spot price is lower than a certain level, a GENCO is able to fulfill the extra demand by purchasing a part of electricity from the power pool instead of producing. However, a GENCO needs to produce certain amount of electricity due to the physical constrains and the output limitations of generators. At some time intervals, the contract loads cannot be fulfilled because of the physical limits such as ramp up/down rate. In this case a GENCO needs to purchase power from the spot market. The cost of trading in power pool C^{PEM} can be expressed as follows:

$$C^{PEM} = \sum_{d=d_0}^{D} \sum_{t=1}^{T} p_{d,t}^{PEM} \left\{ \begin{array}{l} I_{d,t}^{EM} \max\left[0, \sum_{i}^{I} \min\left(l_{d,t,i}, Q_{d,t,i} \right) - \sum_{g=1}^{G} G_g^{\min} \right] \\ + \max\left[0, \sum_{i=1}^{I} \min\left(l_{d,t,i}, Q_{d,t,i} \right) - \sum_{g=1}^{G} q_{d,t,g} \right] \end{array} \right\} \tag{4-20}$$

Where $I_{d,t}^{EM}$ is an index function, indicating whether a GENCO should buy part of power from the power pool or not.

4.4 Numerical Case Study and Simulation

Emission allowance was treated as a fixed cost so that the trading value had been ignored. This is a complex decision making problem in which all units have to be scheduled to satisfy not only the power demand of bilateral trades and power pool but also spinning reserve of the system. Subsequently, trading of those three interactive markets has to be coordinated with environmental constraints.

4.4.1 Expected Wind Power Output

Wind power, one of the most appealing renewable energy sources, is being widely developed in the recent years. Wind energy has lots of advantages such as no pollution, relatively low capital cost involved, and the short gestation period required. As the wind speed increases, the power generated by turbine will increase approximately as the cube of the wind speed. When wind speed reaches the rated wind speed, the generator would deliver the rated power.

Weibull distribution is the most accepted density function to describe wind speed frequency curve. A review of various probability density functions of wind speed was provided by [112], which indicated that the two-parameter Weibull distribution is the widely accepted model. Using two-parameter Weibull distribution, cumulative distribution function (CDF), $F_V(v)$, and probability density function (PDF), $f_V(v)$, of the wind speed random variable V are as follows:

$$F_V(v) = 1 - \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{4-21}$$

$$f_V(v) = \frac{k}{c}\left(\frac{v}{c}\right)^{k-1} \exp\left[-\left(\frac{v}{c}\right)^k\right] \tag{4-22}$$

Where $k>0$ is the shape parameter, $c>0$ is the scale parameter.

Three portions of the wind power output random variable W can be analyzed and the corresponding probabilities $\Pr(\bullet)$ can be calculated. When the wind speed v is between v_{in} and v_r, the PDF $f_W(w) = \frac{dF_W(w)}{dw} = \frac{dF_W(w)}{du}\frac{du}{dw}$, where $u = \left(\frac{2w}{\rho A}\right)^{\frac{1}{3}}$. Therefore:

$$f_W(w) = \frac{k}{3c^k}\left(\frac{2}{\rho A}\right)^{\frac{k}{3}} w^{\left(\frac{k}{3}-1\right)} \exp\left[-\frac{1}{c^k}\left(\frac{2w}{\rho A}\right)^{\frac{k}{3}}\right] \tag{4-23}$$

$$F_W(w) = \begin{cases} \Pr(W=0) = \Pr(v < v_{in}) + \Pr(v > v_{out}), V < v_{in} \; or \; V > v_{out} \\ \Pr\left\{W = \frac{1}{2}\rho A v^3 \le w\right\} = \Pr\left\{v \le \left(\frac{2w}{\rho A}\right)^{\frac{1}{3}}\right\}, v_{in} \le V \le v_r \\ \Pr(W = w_r) = \Pr(v_r \le v \le v_{out}), \; v_r < V \le v_{out} \end{cases} \tag{4-24}$$

4.4.2 Fuzzy Differential Evolution

Differential Evolution (DE) can be used to solve stochastic problems effectively. Its efficiency is affected significantly by its control parameters *F* and *Cr*. FDE [113] improves the performance of DE by using fuzzy logic to adjust these parameters adaptively. It has the following steps: initialization, fuzzy control, mutation, crossover, and selection.

Each of *N* individuals is a *P* dimensional vector within the whole population Π of dimension *NP*.

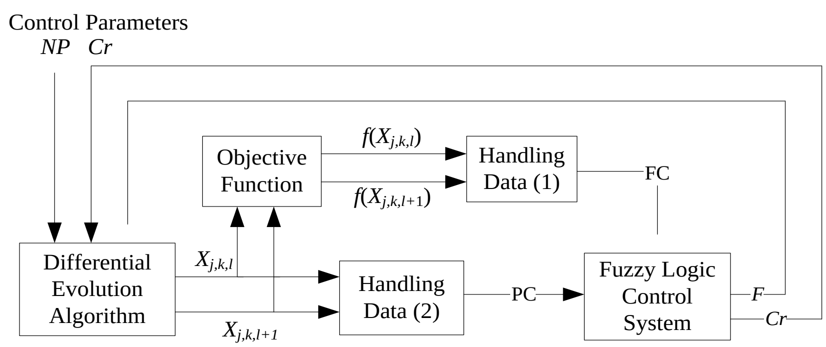


Figure 4-8 Control diagram of fuzzy setting

In a DE process, F is the mutation searching factor whose value is suggested initially chosen as $F \in [0.5,1]$, and Cr is the crossover factor whose value is initially chosen as $Cr \in [0.8,1]$. The purpose of using fuzzy logic is to make the DE's control parameters adaptively adjusted in the evolution process. The work flow of the fuzzy controller can be expressed using the control diagram shown in Figure 4-8. According to [114], an adapting method is obtained by using mean square root concerning the successive generations over the whole population during the optimization process for function values and population members are depressed and used as the inputs of fuzzy logic controls. The fuzzy control is used to map from the given inputs to an output, which mathematically can be expressed as a fuzzy relation $R_{[(FC,PC),(F,Cr)]}$.

$$R_{[(FC,PC),(F,Cr)]} = \int_{(FC,PC)} \int_{(F,Cr)} \mu_R[(FC,PC),(F,Cr)] = \int_{(FC,PC)} \int_{(F,Cr)} \min[\mu_1(FC), \mu_2(PC), \mu_3(F,Cr)] \quad (4\text{-}25)$$

Where

μ_1 and μ_2 are the membership functions of the input parameters,

μ_3 is the membership function of the output parameter.

μ_R is the membership function of the fuzzy relation.

4.4.3 Decision Making Model of Trading Process

During the production process, a GENCO must decide the amount of energy production and aim to maximize the overall profit from the markets [125]. The production model $P_{d^*}(\omega_{d,t}, q_{d,t,g})$ determines the stochastic output $\omega_{d,t}$ and $q_{d,t,g}$ for all the units on the current planning day *d**. The production model is expressed as follows:

$$P_{d^*}(\omega_{d,t}, q_{d,t,g}) = \begin{cases} \max \Gamma_D(\omega_{d,t}, q_{d,t,g}) \\ s.t. \quad q_{d,t,g} \le \min\left(G_g^{\max}, q_{d,t-1,g} + \Delta G_g^U\right) \\ \qquad q_{d,t,g} \ge \max\left(G_g^{\min}, q_{d,t-1,g} - \Delta G_g^D\right) \\ \qquad \sum_{g=1}^{G} G_g^{\max} \ge \sum_{i=1}^{I} \max\left(l_{d,t,i}, Q_{d,t,i}\right) + R_{d,t} \end{cases} \quad (4\text{-}26)$$

To account for the physical constraints of each generator, power productions $q_{d,t,g}$ are subjected to the maximum generation outputs $G_g^{\max}$, minimum generation outputs $G_g^{\min}$, and ramp $\Delta G_g^U, \Delta G_g^D$ constraints. Furthermore, spinning reserve $R_{d,t}$ is required to be fulfilled by a GENCO as a whole whereas all generators are considered available during the whole planning period. Therefore, all generators are assumed to be on run all the time so that start-up and related costs can be ignored.

In the trading process [126], the trading amounts in EM and FM can be calculated based on the optimal decisions obtained in the production process. Furthermore, $T_{d^*}(c_d^B, c_d^S)$ is used to determine the optimum amount of trading in CM on the current planning day *d**. The trading process is expressed as follows:

$$T_{d^*}(c_d^B, c_d^S) = \begin{cases} \max\left\{\Gamma_D(c_d^B, c_d^S) - Penalty_C \times \left[1 - \min\left(C-d, 1\right)\right]\right\} \\ s.t. \quad (x_D + c_D^B - \sum_{t=1}^{24}\sum_{g=1}^{G} e_g(q_{D,t,g}) + c_D^S \geq 0 \\ \quad c_d^B = \max\left[\sum_{d=d^*}^{D}\sum_{t=1}^{24}\sum_{g=1}^{G} e_g(q_{d,t,g}) - x_d, 0\right] \\ \quad c_d^S = \max\left[x_d - \sum_{d=d^*}^{D}\sum_{t=1}^{24}\sum_{g=1}^{G} e_g(q_{d,t,g}), 0\right] \\ \quad c_d^B \times c_d^S = 0 \end{cases} \tag{4-27}$$

where $x_d = x_{d-1} - \sum_{t=1}^{24}\sum_{g=1}^{G} e_g(q_{d-1,t,g}) + c_{d-1}^B - c_{d-1}^S$ is the accumulated allowance level of a GENCO at the beginning of day *d*. At the beginning of the planning period $d=d_0$, an initial allocated allowance is assumed known from the higher level. Furthermore, the constraints $C_d^B \times C_d^S = 0$ disallow buying and selling allowance simultaneously. The penalty has to be calculated on the compliance day *C* if the GENCO cannot balance its allowance with the generated emission. The trading amount in CM is solved based on the forecasting of future uncertainties of price and emission levels. Generally, the trading profit during the whole planning period is maximized through the given current amount of allowance trading on day d^*. This is because for period 1 to period d^*-1, the decision variables and stochastic parameters of the model are considered fixed to their already realized values. Thus, the optimization considers variation in the variables and stochastic parameters only for period d^* to period D.

4.4.4 Simulation Results

In the case study the wind farm is assumed consisting totally of 100 Vestas V90 3.0 MW wind turbines located in a coherent geographic area. The Vestas V90 3.0MW is a pitch regulated upwind wind turbine with active yawing and a three-blade rotor. It has a rotor diameter of 90 m with a generator rated at 3.0 MW. It is widely used in the wind plants and has a proven high efficiency.

The entire scheduling period $d = (d_0, D)$ is assumed to be the week before the compliance day C ($d_0 = C - 6$, $D = C$). Each planning day d is divided into 24 intervals (T = 24). The values of the upper bound of energy output, prices in EM, and prices in FM are forecasted based on the real data provided in the PJM website. The allowance prices are based on the real data provided in the Regional Greenhouse Gas Initiative website. The historical wind speed dataset are obtained from a wind observation station in Tasmania, Australia. The data was provided by the Australian bureau of meteorology. Obviously, predictions with high accuracy can benefit the decision making. process

To demonstrate the effectiveness and performance of the proposed algorithm, case studies are carried out on a typical GENCO which owns one wind farm and six thermal generators, including two coal-fired units, two gas-fired units, and two oil-fired units. The details of the generators are provided in Table 4-7.

Table 4-7 Generation limits, fuel parameters and emission factors

	Unit1	Unit2	Unit3	Unit4	Unit5	Unit6	Unit7
G_g^{min} (MW)	10	20	55	60	100	150	0
G_g^{max} (MW)	100	130	120	180	220	455	90
a_g (MMBtu)	129.97	318.18	126	240	177	480	0
b_g (MMBtu/MW)	3.26	0. 26	8.65	7.74	13.51	7.4	0
c_g (MMBtu/MW^2)	0.0011	0.06	0.0028	0.0032	0.0004	0.0002	0
Ramp up rate(MW/h)	20	40	40	50	50	30	0
Ramp down rate(MW/h)	30	55	60	60	100	55	0
Emission factor (kg/MMBtu)	54.01	95.52	74.54	74.54	54.01	95.52	0
Generation Type	Gas	Coal	Oil	Oil	Gas	Coal	Wind

Table 4-8 Forecasted upper bound of energy output and prices in EM

	Day 1	**Day 2**	**Day 3**	**Day 4**	**Day 5**	**Day 6**	**Day 7**
Upper bound of energy output (MWh)	766	598	501	511	463	442	500
Forecasted prices in EM ($/MWh)	26.7	33.0	36.0	37.2	38.6	37.4	36.3

Note: Owing to limited space, only the data of hour 1 are listed

Results in Table 4-8 are based on the assumption that all units are available in the whole planning period and the spinning reserve is considered to be 10% of the loading at each time interval. Different from DE as reported in [112], the values of the searching parameters[115] F in [116] and Cr in [115] used in the FDE algorithm are not fixed.

With the FDE solution, the proposed model provides the optimal decision of production process according to the interval forecasting of the energy output [117]. In Figure 4-9, the blue dotted line is the predicted upper bound of the energy output whereas the red solid one is the optimum hourly output which the GENCO decides to produce. Based on the forecasted wind speed, the predicted wind power (green solid line) is calculated. Assuming the wind farm is owned by the GENCO, there is little or no incremental cost associated with the wind power generation. Furthermore, the GENCO can save more carbon allowances when producing more energy by the wind unit and less energy by the thermal units. So effectively, the GENCO would wish to use all available wind energy. In terms of the GENCO's operation, it is reluctant to produce more than the thermal units' minimum outputs in some hours because of the relatively low prices in EM.

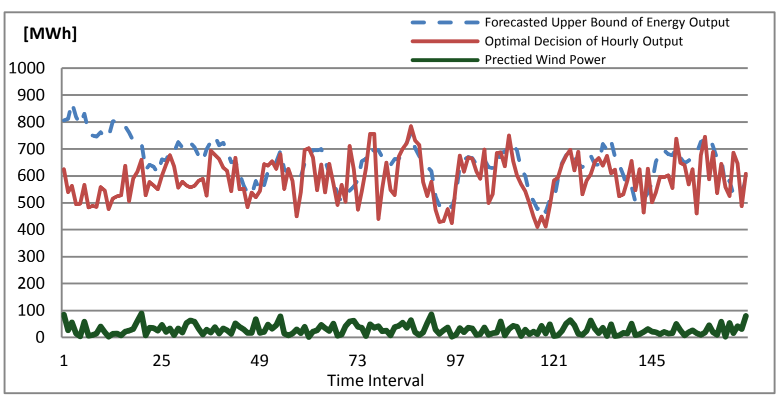


Figure 4-9 Decision of hourly production

The hourly production decisions of the seven units are illustrated in Figure 4-10. Unit 1 is a gas unit which is scheduled least among all the units as it has the highest fuel consumption function. On the contrary, unit 6 is a coal unit which provides the highest percentage of energy although it has the highest emission factor. It can be found that unit 2 and unit 4 are used as the marginal units. During the planning period, the wind farm contributes 4,831MWh energy production in the total production of 83,008 MWh. Although the units are not scheduled freely due to the emission constraints, the proposed model can make a good tradeoff between profit-making and emission reduction under the three interactive markets environment. From the view of EM operation, the reduction of the GENCO's production would lead to increases in EM prices in the short term. On the other hand, the GENCO might consider investing more in wind turbine units according to the price variations in CM and FM.

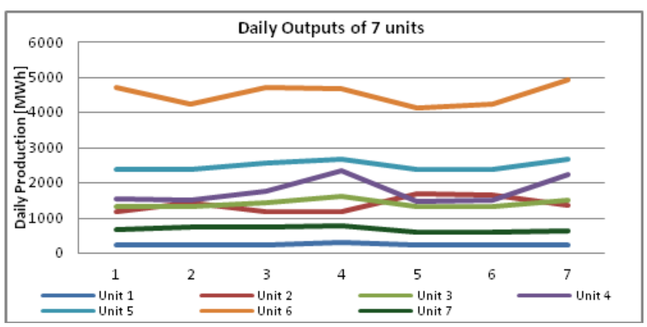


Figure 4-10 Decision of hourly production of the seven units

Figure 4-11 shows the amount of daily emissions of the seven units. Unit 7 is the wind farm, and therefore has no carbon emission at all. Unit 1 and unit 6, corresponding to their energy productions, emit the least and the largest amounts of emission, respectively. During the studied period, unit 2 produces 9,707MWh and unit 3 produces 9,853MWh. However, the total emission amount of unit 2 (9,267 tonne) is more than that of unit 3 (8,056 tonne). This is because the emission factor of unit 2 is higher than that of units 3 and 4. Medium size units 2, 3 and 4 are chosen as the marginal units in the studied period. Furthermore, under the CM environment, the GENCO's emission is directly related to some fundamentals such as carbon prices, amount of emission allowances, emission cap and penalty price [127]. A strict emission constraint and increasing percentage of renewable sources of course would lead to a lower carbon emission level.

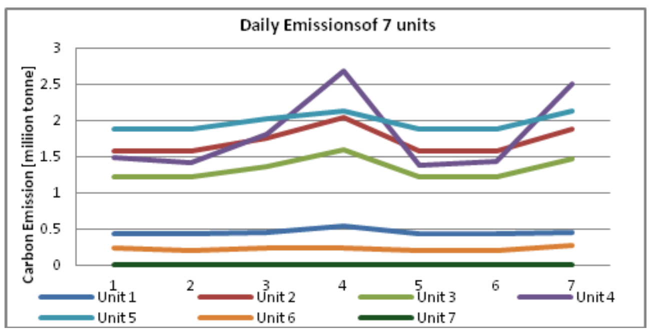


Figure 4-11 Daily emissions of the 7 units

The daily revenues and total profits in the three interactive markets are shown in Figure 4-12. It can be observed that the revenue in EM contribute most in all the planning days. Using the proposed model, the decisions not only ensure considerable amounts of profit in EM, but also enable the GENCO to seek for profits in the other markets. Due to the emission constraint, the GENCO would use all the available wind power. Besides, it has to bring down its energy production so as to reduce the corresponding carbon pollution in the short run. These changes of the operation decision leads to some surplus of fuel from the long term fuel contracts which are decided at the high level. At the low level, the GENCO would sell the surplus to seek for revenue from FM.

Although the GENCO decides to sell some of the fuel in the FM most of the time, it buys a small amount of oil from FM. This is mainly because of the rescheduling of the order of unit production, oil units 3 and 4 are chosen as the marginal units in some hours. At the last day (the emission compliance day), the GENCO has to balance the allowances with the produced emissions by the end of the planning period. Using the proposed model, the GENCO can make a good tradeoff between making profit through power production and emission reduction. It can be seen that the GENCO decides to purchase a certain amount of allowances in day 2 and sell them in days 3, 4, and 7 to make revenue from CM. On the whole, the implementation of environmental policy would lead to a reduction of GENCO's profit. However, the decrease can be alleviated through the trading in the other markets under the multimarket environment.

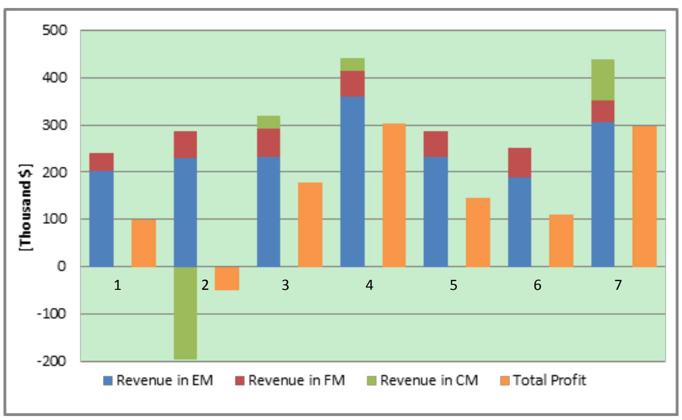


Figure 4-12 Daily revenues and total profits of the GENCO

Besides the profits and emissions in the planning period, it can be conjectured that ETS would adjust the GENCO's portfolios (i.e. investing on renewables) of planning at the high levels in the hierarchical decision making model. The implementation of carbon policies would immediately lead to a drop of the GENCO's profits.

However, the GENCO could accommodate itself to make a good tradeoff between profit-making and emission reduction under the multimarket environment. For the real practice in the long run, the impacts of CM are expected to be larger so that the trades in EM and CM can influence each other. Although this study includes the FM externalities, embodied in fuel price variations, it does not take fuel portfolio building into account. It is an essential problem for a GENCO as it has to account for potential fuel contracts characteristics, transportation contracts, storage/consumption commodity and other services, which can be included in our further studies. It can also be conjectured that the impact of FM on the profit of GENCO would be larger when the above factors in the simulation process are taken into account.

CHAPTER 5

SEMD-SRRM POLICY FRAMEWORK TO SUSTAIN CHINA'S EMD WITH RESPECT TO THE 12TH FIVE YEAR PLAN

China's 12th five-year plan has addressed new challenges and set new goals for the country's power sector. The structure of power generation development will be optimized to properly balance between coal transportation and power transmission. The controversy over the direction of grid transmission and distribution also needs to be reconciled. In the meantime, the plan puts forward specific requirements for energy conservation: developing clean energy, optimizing the production of coal-fired electricity, rationalizing the allocation of peak power, developing distributed energy and constructing a strong smart grid. It also advocates more aggressively on the social and economic aspects of utilization of renewable and other clean energy resources including hydro-electric, nuclear, advanced coal and most recently, high efficiency natural gas. Considering all the above goals and requirements, it is necessary for China to refine its blueprint of electricity market development by fine-tuning the originally market-oriented reform momentum. This chapter aims at designing a policy framework which caters for such purpose. Referring to this framework, it discusses how China should pin point the reform policies and strategies to meet these requirements and achieve these goals with respect to the 12th five-year plan. Comments drawn from compatible international experiences are provided to illustrate how China is going to secure a sustainable energy future.

With respect to the 12th five-year plan, this chapter has conducted the analysis on the technical, economic, environmental, and social aspects of China's electricity market development (EMD) is performed. Findings indicate that China is in need of new trends to further promote its EMD. Section 5.2 briefly describes the deliverables of China's 12th five-year plan in its power sector. Findings on the multi-dimensional aspects of the reforms and electricity regulation about clean energy and energy efficiency are provided in Sections 5.3. Section 5.4 investigates how China defines a new strong smart grid and what could be promoted at this stage. Finally, our integrated policy framework and prospective electricity market strategies with numerical analysis are suggested in Section 5.5.

5.1 Overview of China's 11th and 12th Five-year Plan

The electricity supply industry in China has gone through three main stages of reforms starting from economic reform to fund its expansion by opening capital investments, followed by a market oriented institutional reform on its State-Control-Enterprises, and coming to the latest stage of reform by unbundling its generation from the grid so that competition was introduced [7]. Worldwide experience points out that an integrated and effective market regulator is needed for China to install incentives by which investment liberalization of the electricity supply industry will support its reforms to meet national objectives such as health and safety, environmental protection, universal service and consumer protection [3]. In February 2002, the State Council issued its notice on the "Program for Electricity System Reform", setting forth the basic elements of the plan which remains in effect today [118]. The early significant reforms included the separation of generation assets from grid companies, the dismantling of state-owned assets into diverse generation companies, and the establishment of an independent regulatory authority known as the State Electricity Regulatory Commission [52].

During the just completed the 11th five-year plan period (2006-2010), rapid power industry growth met the needs of economic and social development, but this growth was disorganized [57]. Rapidly growing demand and price pressures will continue to confront the country, and the dominant long-term challenges will be energy efficiency, environmental protection, and climate change [58]. These were not significant considerations when other countries restructured their power sectors or when China first considered restructuring its power sector. As noted above, many jurisdictions are now thinking of ways to either redesign their earlier power sector reforms or superimpose new mechanisms on them to meet their environmental challenges [59]. China has the advantage of building the needed reforms into its power sector at the outset.

Referring to China’s 12th five-year plan there are aggressive goals for renewable and other clean energy resources including hydro-electric, nuclear, advanced coal and most recently, high efficiency natural gas [55]. Liberalized electricity markets of the types adopted in the UK or US will not spontaneously deliver adequate investments in clean power generation technologies. So far as coal-fired facilities have the lowest financial costs, explicit policies will need to be adopted to ensure that investments in cleaner technologies are favorable.

Furthermore, China's power sector continues to confront two longstanding challenges: (1) the need to increase interprovincial and inter-regional trading and (2) the need to improve power plant dispatch. Both provide opportunities to lower costs and reduce emissions. Again, the typical competitive generation market cannot resolve these issues but, fortunately, there are fixes that are effective, simpler, and much less risky. So, the remaining question for China is what policies and what trade-off between market force and competition will deliver the desired outcomes at the lowest cost.

5.2 New Phase of EMD in Respect of China's 12th Five Year Plan

The Five-Year Plans are the most significant government policy documents in China which describe a series of economic development initiatives, map strategies for economic development, set growth targets, and launch reforms. During the just-completed 11th Five-Year Plan period, rapid power industry growth met the needs of economic and social development, but this growth was disorganized. The 12th Five-Year Plan, approved by the Chinese Government on March 14, 2011, established many social and economic goals, including significant expansion of the country's power generation industry in many new directions. As part of the 12th Five-Year Plan, the structure of power generation development will be optimized, including the proper balance of coal transportation and power transmission. The controversy over the direction of grid transmission and distribution must be reconciled. In addition, the plan also puts forward specific requirements for energy conservation measures. While formulating these requirements Chinese central government and major power companies have agreed on certain specifics -

developing clean energy, optimizing the production of coal-fired electricity, rationalizing allocation of peaking power, developing distributed energy and constructing a strong smart power grid. With these goals and requirements in mind, the 4^{th} phase of China's EMD is defined and its main characteristics are identified as follows:

- Focus on optimizing the structure of power generation at a micro level for better economic and sustainable development
- Set out systematic reform strategies for developing clean energies, optimizing production of coal-fired electricity, rationally allocate peaking power, developing distributed energy and constructing a strong and smart grid

Apart from generic opinions including introducing competitive incentives, increasing efficiency, reducing cost, improving pricing mechanisms, optimizing resource allocation, advancing nationwide grid construction, the plan also ensures that further development of the power sector can largely contribute to achieving the nation's boarder economic and environmental goals.

In the meantime, implementation of the "Electricity market development" has slowed down due to uncertainty inspired by the crises in California and elsewhere. Power plant financing is no longer a significant objective, and electricity prices do not depart significantly from marginal cost. The above observation provides an opportunity for China to pause, reflect and adjust its plans for the industry.

5.3 Factors for Sustaining the 12th Five Year Plan

In the next 5 years, China's new energy industries like wind power, solar power, biomass energy and nuclear power will keep on developing rapidly with support from government policies and new technologies. The "New Energy Industry Development Guidelines" submitted to the State Council in 2010 points out how the new trend supersedes the original design in the 11th five-year plan: the new energy industry has expanded from merely utilizing new resources like wind, solar, biomass and nuclear to incorporating new resources and technologies, such as clean coal technology, smart grid and non-conventional gas resources like coal bed methane and natural gas hydrocarbons. The detailed adjustments and preservations of each specific field are given in the following Context.

5.3.1 Renewable Energy and Clean Energy Technology

The 12th Five-Year Plan will change the power generation structure in which new and renewable energy resources figure prominently. According to the plan, non–fossil fuel generation should account for 11.4% of total primary energy consumption by 2015, and renewable energy resources should be 20% by 2020. In order to reach emission reduction targets, the proportion of new and renewable energy in China's overall energy mix will continually increase. Clean energy resources include hydro, biomass, wind, solar, and nuclear power.

In 2010, the total installed electricity production capacity in China was 968.34 GW. Detailed components of this generation capacity are shown in Table 5-1. To meet the Plan's clean energy goals, hydro power will play the most important role in the development of new and renewable energy and contribute considerably to energy saving and emission reductions in the next 10 years.

Table 5-1 Total installed electricity capacity in 2010 and target in 2020 of China

Technology	2010		2020	
	GW	Percentage (%)	GW	Percentage (%)
Coal	646.60	66.77	1030.00	57.68
Gas	26.42	2.73	58.90	3.30
Nuclear	10.82	1.12	80.83	4.53
Hydro	198.21	20.47	340.00	19.04
Pumped Storage	17.84	1.84	50.00	2.80
Wind	29.57	3.05	150.00	8.40
Solar	0.26	0.03	24.00	1.34
Biomass	1.70	0.18	15.00	0.84
Other	36.92	3.81	36.92	2.07
Total	968.34	100	1785.65	100

The National Grid Energy Research Institute (NGERI) has completed a study of several scenarios of coordinated development of clean energy and power systems within the 12^{th} Five-Year Plan period, particularly with regard to energy security and economy. The results of the study showed that China's total installed capacity is expected to soar to 1,786 GW by 2020. The installed capacity of renewable energy will reach 600 GW by 2020, according to the National Development and Reform Commission. Renewable energy will increase in overall percentage from 26.54% in 2010 to 34% in 2020.

Due to intermittency and instability issues, the installed capacity of wind power will be lower than that of hydro power and nuclear power by 2020. During the 12^{th} five-year plan development of wind power will carry on with the high speed growth inherited from the 11^{th} and by its end the 12^{th} five-year plan can potentially see a total installed capacity of 130GW. Wind power equipment manufacturing ability will also be improved significantly. Unlike the 11th Five-year Plan which solely focused on installed capacity, the 12th Five-year Plan focuses on both quality and quantity. Following the past few years of rapid capacity expansion, emphasis on quality is without doubt the necessary path for healthy development of the wind power industry. At the National Energy Work Conference held on January 6th when Zhang Guobao, Director of the National Energy Administration at the time, spoke about the 12th Five-year Plan, he repeatedly used terms like “grid integrated capacity” and “total actual power generation”, clearly surpassing the 11th Five-year Plan’s limited aim on simple capacity installation.

At the same time, the installed capacity of solar photovoltaic will not increase considerably before 2020 because of technology and economic concerns. Nevertheless its industrial scale will continue to grow with focus on simultaneously developing “quality and quantity”.

China’s electricity generation heavily relies on coal. The prevailing coal-fired electricity generating method is now a major source of greenhouse gas (including CO_2), NOx, SO_2 and particulate emissions. On the average, generating 1000 kWh electricity produced approximately 0.21 ton of CO_2, 4.6kg of SO_2 and 2kg of particulate respectively in China. Figure 5-1 below illustrates the condition of CO_2 emission in China [119].

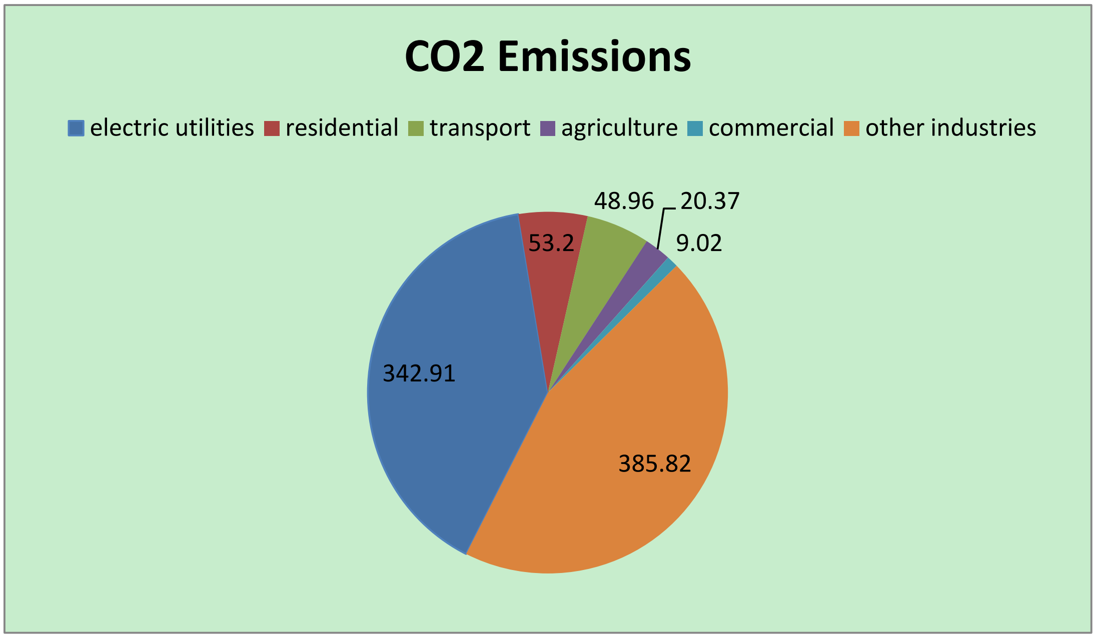


Figure 5-1 CO_2 Emissions (unit: million ton)

With the rapid increase in coal-fired generating capacity, pollution from electricity generation has caused enormous environmental damages and social economic costs. In practice, China has its environmental levies, but their effectiveness in promoting environmental technology popularization is often doubted.

Table 5-2 shows the current impact of emissions charges on sulfur dioxide, nitrogen oxides and dust on the cost per kilowatt-hour of electricity from coal and gas fired power plants. Total environmental charges are less than $0.0016/kWh for coal plants and $0.00004/kWh for gas plants [120]. If the value of RMB were to double, the environmental charges expressed in dollar terms would also double, to $0.0031/kWh for coal plants and nearly $0.0001/kWh for gas plants. While the charges are quite small at present, they might increase in the future.

Table 5-2 Environmental charges on new coal and gas fired power plants in China

Type of Charge and Plant And Other Assumptions	Emissions (kg/kWh)	Emissions Charge ($/kg)	Emission Charge ($/kWh)
SO_x Charge, Coal Plant	0.01737	0.07609	0.001322
NO_x Charge, Coal Plant	0.00030	0.07609	0.000228
NO_x Charge, Gas Plant	0.00005	0.07609	0.000038
Dust Charge, Coal Plant	0.00020	0.01807	0.00004
Dust Charge, Gas Plant	0.00005	0.01807	0.00001
Total Charge, Coal Plant			0.001554
Total Charge, Gas Plant			0.000039

Table 5-3 shows the carbon charges per kWh that would be incurred by coal and gas plants, with and without carbon sequestration, under various assumptions about carbon dioxide emission fees. For coal plants, CO_2 emissions are assumed to be 880 g/kWh without sequestration and 176 g/kWh with 80 percent carbon sequestration technology. For base case gas plants, CO_2 emissions are assumed to be 370 g/kWh without sequestration and 55 g/kWh with 85 percent carbon sequestration. For low-cost, high-efficiency gas plants, CO_2 emissions are assumed to be 319 g/kWh without sequestration and 48 g/kWh with 85 percent carbon sequestration [121].

Table 5-3 Hypothetical charges for power plants carbon emission in China

Plant Type and Cost Assumptions	No Sequestration, CO_2 Fee of			Sequestration, CO_2 Fee of		
	Zero	$20/ton	$100/ton	Zero	$20/ton	$100/ton
Coal Base Case (36% efficiency)	0.0000	0.0176	0.0880	0.0000	0.0035	0.0176
Gas Base Case (50% efficiency)	0.0000	0.0074	0.0370	0.0000	0.0011	0.0055
Gas Low Cost (58% efficiency)	0.0000	0.0064	0.0319	0.0000	0.0010	0.0048

To estimate the abatement attributable to policies that encourage the use of renewable energy, a counterfactual emissions intensity is introduced based on the 'operating margin' reported by the Chinese Government for the purposes of Clean Development Mechanism projects [122]. The Chinese Government has published operating margins for six Chinese electricity grids. The nation's average operating margin is 1.003 t CO_2/MWh of electricity displaced by renewables.

The rate chosen for the sensitivity analysis is the Chinese coal-fired plant 'build margin' specified. This is an estimate of the emissions intensity of the most recently-built 20 per cent of coal-fired plants built in China. This value appears to take into account the increasing efficiency of the Chinese coal-fired generation fleet, and is approximately 20 per cent lower than the 'operating margin' (0.8042 t CO_2/MWh).

5.3.2 New Coal-Based Power Plants in China

One major focus of China's 12th five-year plan is the clean coal technology, which aims at promoting technological innovation especially in polygene ration technology. Within China's energy consumption portfolio about 70% of primary energy relies on coal and 80% of power generation is from thermal power generation. Within the next five years usage of coal is not likely to drop below 60% of primary energy consumption. During the past five years China held clean coal technologies in high regard, mainly focusing on coal processing, high efficiency clean coal burning, coal conversion, pollution control and waste processing [123]. In the 12th Five-year Plan China will continue developing clean coal technologies but it will no longer hang solely on technological R&D and application. Instead it will place gasified coal through polygene ration at the heart of its clean coal application which can increase the overall efficiency by 10-15%. Meanwhile chemical products can be sold to gain extra revenues for power producers, and the balance between chemical production and power generation can be adjusted in accordance with the demand.

The installed capacity of thermal power in China is 710 GW, 54% of which is in the electric load center of east China, and only 19% in the coal-rich regions in central and west China. The 12th five-year plan requires accelerating the optimization of coal-fired power as essential for sustainable development of the power industry, or "local balance." The largest challenge is that China's coal-fired electricity distribution system lacks inter-provincial transmission capability. In addition, coal must be shipped from coal-rich regions to plants in the eastern areas, where air and acid rain pollution are severe. As commonly perceived, coal transport delays and downtimes are frequent, threatening the security and stability of power systems as well as sustainable economic development.

Table 5-4 Estimated fuel costs of new coal and gas fired power plants in China

Plant Type and Cost Assumptions	Fuel Cost Per Unit	Fuel MBtu Per Unit	Fuel Cost ($/MBtu)	Plant Efficiency (%)	Heat Rate (Btu/kWh)	Fuel Cost ($/kWh)
Coal Base Case (Average)	$25.30/ton	21.82MBtu/ton	1.16	36	9.478	0.011
Coal Base Case (High)	$45.00/ton	21.82MBtu/ton	2.06	36	9.478	0.0195
Gas Base Case	$0.1386/m^3$	0.036MBtu/m^3$	3.85	50	6.824	0.0263
Gas Low Fuel Cost	$0.1080/m^3$	0.036MBtu/m^3$	3.00	50	6.824	0.0205
Gas High Plant Efficiency	$0.1386/m^3$	0.036MBtu/m^3$	3.85	58	5.882	0.0226
Gas Low Cost High Efficiency	$0.1080/m^3$	0.036MBtu/m^3$	3.00	58	5.882	0.0176

Labor and other operating costs at power plants are usually fixed. Our analysis are based on the assumptions that annual operating costs per plant is US$1.32 million for coal plants and US$1.02 million for gas plants, both with 1,200 MW of capacity. By operating 6,650 hours per year this amount of capacity will generate 7.98 billion kWh per year. Dividing total cost by the number of kWh, operating costs are found to be $0.0001654/kWh for coal plants and $0.0001278/kWh for gas plants. Those amounts are obviously quite negligible compared with other cost elements.

With growing concerns over global warming, charges might eventually be imposed on carbon dioxide emissions, creating incentives to install carbon sequestration technology, if available. Table 6-4 shows the additional capital costs that would be incurred for the installation of carbon sequestration equipment under various assumptions made earlier for basic capital costs. According to recent technical estimates, technology for carbon sequestration might be made available within the next two decades at an extra cost of US$840 per kW for coal plants and $380 per kW for gas plants.

Accelerating regional optimization of coal-fired power requires cooperation between supply-side and demand-side regions. Eastern areas that lack energy must receive coal, wind, and hydro power from western areas. In order to meet increased electricity demand and environmental protection requirements, it is important to control new coal power installations and focus development on nuclear, hydro, solar, and pumped storage plants. In addition, power development regions and demand-side regions should actively seek government support and establish strategic cooperation mechanisms to ensure an economic and reliable power supply.

5.3.3 Rationalizing Allocation of Peaking Power

Coal-fired power is the foundation of China's power generation structure. Northern plants account for a large portion of coal installation capacity and run-of-water hydropower plants, which makes regulating peak load difficult. With rapid development of wind power, especially given its intermittent nature, power systems must have peaking power. Due to peak-shaving difficulties, the output limits of wind power are very critical in low-load periods. Such situation aggrandizes China's needs of gas-fired power and pumped storage power stations to meet system peaking demand.

Gas-fired power has the advantage of low carbon emission when compared with coal-fired power. More importantly, natural gas generators can start fast and adjust flexibly and are thus better choices for peak shaving. The trends of China's natural gas production and reserve-production ratio are shown in Figure 5-2. At the present time domestic natural gas resources seem limited and supply capacity seems inadequate. However gas supply predictions from companies such as Petro China and Sinopec are optimistic. China should have large growth potential for gas supply (the available reserve of natural gas has been increasing), which meets domestic demand during the 12th Five-Year Plan period and will meet the 13th Five-Year Plan period demand by importing more gas at a higher price.

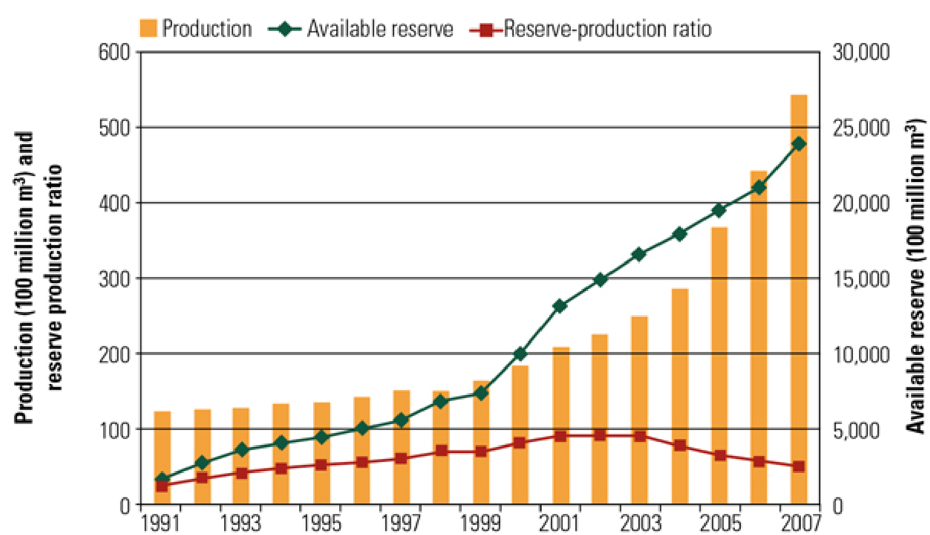


Figure 5-2 Natural gas production and reserve ratio in China

The price of electricity from natural gas–fired plants is highly affected by relative markets. Taking gas supply, price, and other factors into account, China's natural gas generation in the future should be moderate and located mainly in eastern load center regions to cover peaking power and develop cogeneration units. The installed capacity of gas-fired power is only 24 GW, and in-depth studies are still required to reach the comprehensive target of energy structure adjustment and power system peak shaving. Large-scale development of gas power is very difficult, as the natural gas supply is located far from the natural gas demand in China.

5.3.4 Promoting Distributed Energy Resources

Distributed energy resources should be allocated on the demand side and can bring about many benefits including improving energy utilization efficiency with energy gradient utilization, reducing energy transmission pressure and losses, reducing pollutant emission when using renewable energy and solving the problem of energy supply to remote or sparsely populated areas to achieve universal power service. At the same time, though, distributed energy resources also have problems such as large capacity per unit cost and high technical requirements. Currently development of distributed energy mainly focuses on distributed renewable energy, natural gas cogeneration, and combined heat and power (CHP) systems with energy-saving benefits. Today the installed capacity and total amount of distributed energy is small in China. Focusing on cogeneration or CHP systems, gas-fired distributed energy systems are mostly concentrated in Beijing, Shanghai, Guangzhou, and other big cities. Distributed renewable energy sources such as wind and solar power will be mainly concentrated in remote areas and are designed to meet local electricity demand.

In order to promote the development of distributed energy, the National Energy Board has stated that it has been put on schedule for the country's most large-scale cities to implement distributed energy systems by 2020. At a national energy conference in early 2010 the National Development and Reform Commission specified that the installed capacity of distributed energy should reach 50 GW by 2020.

However, there are still technical, economic and policy constraints for promoting distributed energy utilization. These constraints include lack of clear and unified technical standards, lack of a reasonable price system and mechanisms as current price systems cannot reflect energy scarcity and environmental value, and dependence on imports of key equipment. Therefore China should establish uniform technical standards and develop a rational energy price mechanism for distributed energy. In addition standardized management of distributed energy in China should be enhanced and the development of distributed energy should be promoted first on trial basis and later into wide application.

5.3.5 Strong and Smart Grid

China's 12th five-year plan has drawn significant attention to ultra-high voltage electricity transmission, which is entering the stage of heavy construction within the five-year period. Ultra-high voltage transmission has always been a focal point of the concept of China's strong and reliable smart grid when it was first put forward in May 2009 [124]. As the backbone of smart grid, the ultra-high voltage transmission network provides core physical support for smart grid construction to go from pilot stage to full-scale expansion including the promotion of all specific links and the integration of power grid related equipment. The State Grid Corporation of China will at the meantime speed up rural power network construction and renovation, develop managerial tools, service systems and core technologies to cater for the operation of smart grid. Under such circumstances it has been predicted that great technological breakthroughs will be achieved and broad application of "intelligent" electrical equipment will occur thus will create huge demand in relative markets.

A cross-regional, long-distance and high-capacity transmission channel connecting China's northwestern coal base and eastern load center regions will be built after the layout of optimizing coal-fired power is completed so as to achieve joint transport of coal power and wind power. Studies showed that the scale of wind power in Xin Jiang, Gan Su, Meng Xi, Meng Dong, and Ji Lin will be approximately add up to 80 GW, 75% of the total amount that needs to be sent inter-provincially. Abundant solar energy resources in northwestern areas will also be exploited greatly by 2020. This inter-provincial transmission infrastructure will allow China to expand the scale of utilization of wind and solar power for it can be transmitted along with coal power thus avoiding economic problems which would otherwise be caused by isolated development and delivery.

The diverse locations of fuel supplies, power plants, and population with electrical demand require China to make full use of the fundamental function of power grid infrastructure as long-distance, high-capacity, and high-efficiency energy passages. During the 12th Five-Year Plan period, it is important to accelerate the construction of inter-provincial transmission systems and promote the development of large bases for coal, hydropower, nuclear power, and other new energy resources. China should choose to optimize the allocation of these energy resources by the approach of “common transmission channel, joint development and network-to-network delivery.

Northwestern coal bases and southwestern hydropower bases have large potential to export power. According to the analysis of grid transmission ability, coal-fired power flow will increase 100% from 2015 to 2020. Southwestern hydropower will be the focus in the future, given the distribution and development of water resources. The outgoing capacity of hydropower from the Jin Sha River will be 13.9 GW and 30.9 GW in 2015 and 2020, respectively, while from Si Chuan it will be 17.2 GW and 22.2 GW. The massive pattern of “west to east” and “north to south” will be formed by then, and the ability of UHV and cross-transmission will be increased dramatically.

Power development should not only follow its own law but also seek for innovation and progress. On the supply side of power system adaption to technological advances and large-scale development with clean and efficient development of traditional fossil fuel generation is necessary. In addition, new development requirements brought about by the 12th five-year plan are also supposed to be met in fields of hydropower, wind power, solar power and other renewable energy. On the demand side, it is necessary to adapt technologies to meet the electricity needs of industrialization, urbanization, modernization, and intelligence while meeting green development, energy saving, and low-carbon requirements. So far as the grid itself is concerned, providing safe, economical, clean and efficient power delivery is always the ultimate goal. Based on an intelligent, modern, efficient information platform and service network, a smart grid can collect and respond to a diversified supply side and demand side, and satisfy the electricity needs of all.

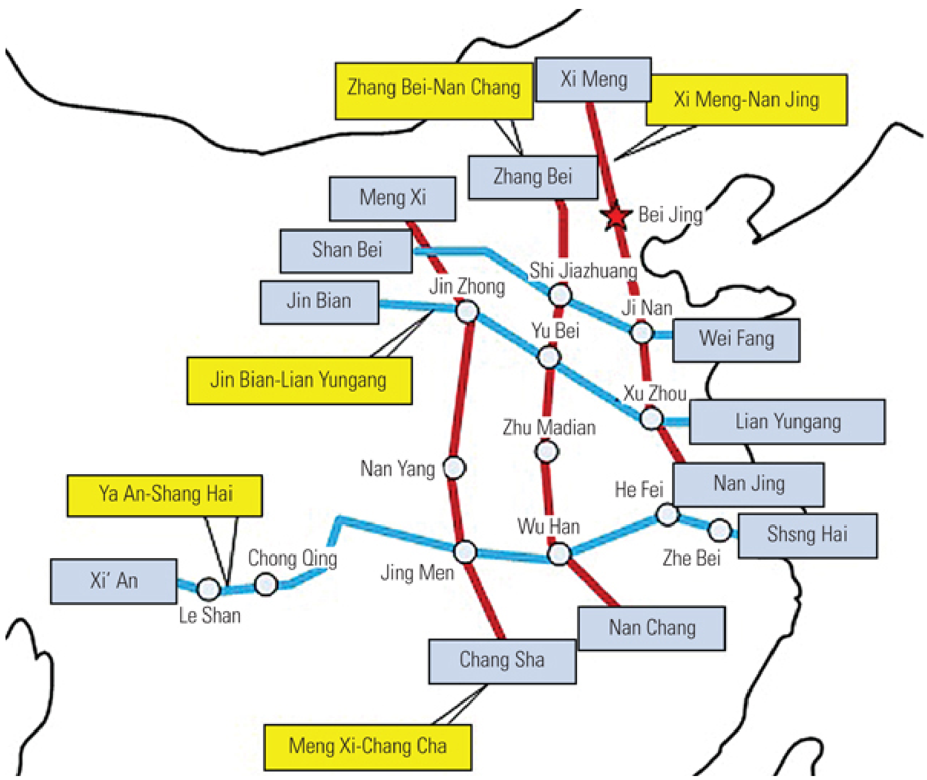


Figure 5-3 UHV power grid plan by 2015 (State Council, the 12th Five Year Plan for National Economic and Social Development)

In addition, a smart grid can provide an innovative application platform for electric vehicles and thereby help resolve issues such as power supply security and sustainable development.

Combining the characteristics of China's energy resources with the sustainability of its economy and society, the State Grid Corporation of China proposed strategic objectives for the national strong smart grid.

A strong smart grid requires an information and communication platform with the means of intelligent control. Incorporating generation, transmission, substations, and power distribution, a smart grid can allocate AC and DC rationally and cover all voltage levels to adapt to the development of inter-provincial transmission. The UHV power grid plan by 2015 for China is shown in Figure 5-3. In contrast with smart grid developments abroad which heavily stress on the demand side management, China's plan focuses primarily on the transmission of electricity.

As a new strategy for economic growth and emerging industries, the smart grid will bring great business opportunities for the power industry itself, for related upstream and downstream industries, and for the high-tech equipment manufacturing industries. At the meantime, we should always see the challenges that emerge along with opportunities. In future developments, China should emphasis innovation on critical power system equipment and master key technologies, key components, and raw materials production with intellectual property rights through independent innovation. Otherwise, the future implementation of smart grid will result in higher risks and poor economic effectiveness. In conclusion independent innovation of the power industry will play a very important role in the future development of the energy industry in China.

5.4 ISEMD-SRRM Policy Framework to Sustain China's EMD and 12th Five-Year Plan

The ISEMD-SRRM policy framework is a set of boundaries and principles basing on which policies and strategies can be formulated and assessed. This section aims at designing such a policy framework to serve the development of China's electricity market in a way which ensures that the new trends, policies and strategies concerning further electricity market developments are capable of reaching the economic and environmental targets addressed by China's 12th five year plan in the power sector. In this sense the framework should outline the specific goals of China's EMD and illustrate how these goals can be achieved through appropriate measures taken in further process of electricity market development.

The detailed goals of EMD with respect to China's 12th five-year plan are identified as follows:

Goal 1: Integration of new and renewable energy resources

A new power generation structure is required for new and renewable energy resources.

- Non-fossil fuel generation account for 11.4% of total primary energy consumption by 2015
- Renewable energy power generation accounts for 20% by 2020

In the meantime in order to reach emission reduction targets the proportion of new and renewable energy in China's overall energy mix will continually increase.

Goal 2: Construction of coal-based power plants

Electricity demand will grow rapidly in China for a long time in the future. The absolute consumption gap between supply-side regions and demand-side regions will continue to increase. In the meantime, though, coal will inevitably remain as the major energy resource for power generation within the five-year plan's time. Therefore optimization of coal-fired power generation capacity through rationally choosing location of coal-fired power plants is necessary. Decisions should be made such that the largest overall economic and social benefits can be acquired.

Goal 3: Allocation of peaking power

The necessity to rationally allocate peaking power is strengthened by:

- Large portion of coal-fired units and run-of water hydropower plants in Northern plants
- Rapid development of wind power of intermittent nature

Therefore gas-fired power plants and pumped storage power stations needs to be constructed to meet system peaking demand.

Goal 4: Exploitation of distributed energy resources

Goals and standards have been set by the central government through:

- The National Energy Board has stated that most large-scale cities in the country will implement distributed energy systems by 2020.
- The National Development and Reform Commission specified that the installed capacity of distributed energy should reach 50GW by 2020.

To achieve the national goal and meet the national standard, more detailed uniform technical standards need to be established. A rational energy price mechanism also needs to be developed to promote use and management of distributed energy.

Goal 5: Construction of a Strong and Smart Grid

A strong and smart power grid needs to be constructed to perform the following functions:

- An inter-provincial transmission grid for long distance, high capacity, and high energy efficiency power transmission to optimize the allocation of bulk volume production from various energy sources
- A smart grid which can collect and respond to a diversified supply side and demand side basing on intelligent, digital and efficient information platform and service network
-

A national strong and smart power grid can provide a dynamic platform for a variety of distributed energy resources to connect flexibly and provide an intelligent control and management platform to improve energy efficiency and achieve demand side management.

In accordance with the above description of the five goals, a concise graphical representation of the policy framework that we propose in this section is given as follows:

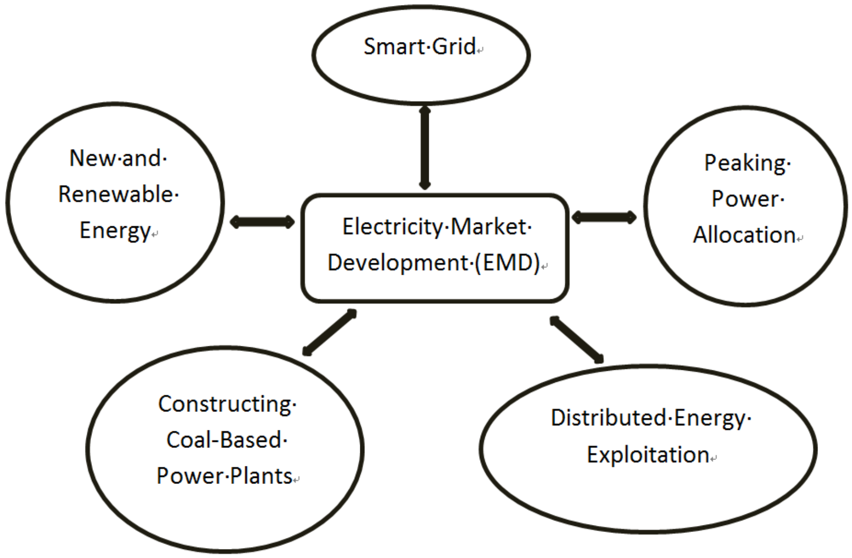


Figure 5-4 Integrated policy framework of EMD in respect of the 12th five-year plan

5.5 Summary and Prospective Implementation Strategies

The significance of the above graphical representation is that each one of the five goals can be somehow related to China's EMD. The essence of these relationships is how the EMD can help to achieve each goal without compromising the core intention of any one of them. Studies in this section show that there exists a value concept of balance between market force and regulation power in each of the five relationships. In other words, instead of going into extreme cases of overemphasizing free market or controlled regime people should always combine the contribution of market force and regulation power and continuously adjusting the portions.

The experiences of other countries can be useful in guiding Chinese restructuring efforts, but China's electric sector is marked by several important and unique characteristics that limit the direct applicability of those experiences.

- First, unlike those of the US and Europe, China's grid system is fairly unified, with most assets controlled by only two major state-owned grid companies.
- Second, generation is fairly concentrated and generally wholly or partly owned by government.
- Third, China explicitly emphasizes integration of environmental and power sector policy, and has a history of impressive measures, including environmental dispatch, differential pricing, strong support for renewables, and various energy efficiency programs. Power sector reform should retain and enhance these significant policies.
- Fourth, China has a track record of mobilizing huge amounts of investment, despite the absence of explicit market or contracting mechanisms. Most developing countries' power sector reform efforts have been driven by the need to attract capital. The challenge in China is directing investment in ways that better meet long-term efficiency and environmental goals.

The goals for China's 12th FYP have not yet been broken down for each sector in each province, but it is clear that the goals will be consistent with China's commitment to reduce carbon intensity by 40-45 % by 2020. The Plan also specifies aggressive goals for renewable energy, nuclear generation, and gas-fed generation.

China has succeeded in meeting in the total emission control targets of its 11th Five-Year Planning period, a 10% reduction in SO2 emissions at 2005 levels by 2010, primarily through the installation of flue gas desulfurization equipment on coal-fired power plants and a price premium to encourage operation of the equipment. Environmental goals for the 12th FYP call for an additional reduction in SO2 emissions of 8% and, for the first time, include a reduction target for NOx emissions (10% nationally), which will have operational and economic impacts on power generation. Additionally, pilot projects for mercury control have already been advanced around the country, setting the stage for broader multi-pollutant regulation of China's coal-fired power stations.

On 11 May 2010 the State Council issued rules relating to improving regional air quality, including a requirement for denitrification equipment on all new and existing coal-fired power plants by 2015. While not directly related to power sector reform the rule makes it clear that increased reliance on clean generation and energy efficiency are considered major options to achieve better air quality.

China's renewable energy law and related regulations are very aggressive. These rules will be major drivers of power sector investment and operation. Purchasing and interconnection obligations imposed on the grid companies, as well as the renewable energy quotas and mandatory market share requirements, make it clear that connecting and integrating wind and other renewable generation will be a major responsibility of the grid companies. These rules are aimed at solving one of China's longstanding problems. The environmental dispatch rules can deliver significant system efficiency and environmental benefits.

China has adopted world-class pricing and related policies aimed at encouraging large users to invest in energy efficiency and load control, including new load management requirements in the DSM Rule, which specify 70% of peak load to be outfitted with load monitoring equipment and 10% of peak load to be outfitted with load control equipment. However the benefits that these policy tools provide can be put at risk by poorly designed reforms.

Together China's achievements create a very powerful framework for making progress on energy efficiency and emissions reductions. But the basic polices and China's energy efficiency and emission reduction goals need to be reflected in the next steps of power sector reform. International experience shows that the types of generation markets China envisioned a decade ago will not deliver the amount or mix of generation China desires. Bid-based generation markets (which rely on variable fuel costs to determine the loading order) will not achieve all the benefits of China's dispatch policies. Likewise, reforms that call for direct retail access will undermine many of China's current and proposed innovative pricing policies, because those pricing policies are aimed at public objectives that competitive markets, by themselves, rarely value. Further reforms will need to better reflect the country's energy efficiency, renewables, and clean energy goals.

CHAPTER 6

PROSPECTIVE POLICY OPTIONS AND STRATEGIES

It has been argued that electricity transmission and distribution are in natural monopoly and should be operated as public utilities which require effective regulation. However, they are currently too powerful to be regulated in China. For a long time Chinese governments fail to take certain administrative responsibilities in the country's power sector and this has raised grid operators to a higher decisive level. For instance, the State Grid Corporation of China participates in national decisions on electric network planning, investments, electricity pricing and market access endorsement. On one hand, the company's professionalized tasks and technical advantages protect its core business from external interference. On the other hand, their involvement in policy making may create unfairness in contracts with generators or consumers. In this sense power grid operators may abuse their administrative power to expand market influence or stall further reforms in electricity supply industry.

6.1 A Roadmap to Facilitate Further Reforms

The "electricity dispatch authority" refers to a wide range of functions of China's power grid companies. As a status quo, it is the key to preserving certain administrative power within grid operators. This authority includes seven basic elements, namely power system command, industrial planning, network configuration, market access endorsement, electricity transaction, information integration and technical support. By classifying these functions into three aspects, the ways in which "electricity dispatch authority" is converted into administrative power are identified. Firstly, it empowers grid operators to organize the entire power system, guaranteeing the security of electricity supply. Secondly, it enables grid operators to coordinate between different stakeholders in electricity markets, affecting relative market shares and benefits. Lastly, it invites grid operators in formulating national goals and policies, making essential suggestions concerning the country's power industry. With these three methods, grid operators dominate China's power market.

By means of the pricing of electricity, China's power grid companies undertake certain responsibilities in national finance and macroeconomic regulation. When necessary, extra fees are inserted into the electricity price to subsidize central government's investments in national projects. For instance, by statistics in year 2009 electricity price of all categories contains a ￥0.02/kWh and a ￥0.013/kWh component which pays for the construction of the Three Gorges Dam and rural power grid renovation, respectively. Also in the case when price of thermal coal increases, corresponding feed-in and sales tariff cannot be adjusted accordingly in order to maintain the country's Consumer Price Index. As a result, electricity price is deprived of its marketing significance and paralyzed from guiding market behavior. At the meantime measures like the above subject electricity tariffs to government decisions and consequently enlarge grid operators' influence over government policies.

The State Electricity Regulatory Commission (SERC) is established in 2002 and empowered by the State Council to perform administrative and regulatory duties with regard to China's electric power sector in accordance with laws and regulations. As the most essential regulator in the country's electricity supply industry, SERC plays the leading role in fields like technical and security qualification, electric legislation, power market supervision and power company audit. However, the public usually questions its authority, independence and expertise as a third-party institution. As a matter of fact, there are three other institutions in China, which share similar supervisory authorities with SERC. The State-owned Assets Supervision and Administration Commission of the State Council, the Ministry of Finance of the People's Republic of China and the National Development and Reform Commission, each of which supervises China's power sector in one particular aspect, all have more bargaining power in national politics than SERC. For such reason SERC is functionally rather recommending than decision-making. At the meantime, while SERC is supposed to be independent, its branches may be beneficially connected to the electric power companies they regulate. When regional electricity regulatory bureaus and provincial electricity regulatory offices are established, the majority of their work force actually came from regional and provincial grid operators of the same level, thus inevitably affecting their impartiality. Last but not least, since SERC has no access to raw operational data of electric power companies, corresponding supervision or investigation is generally conducted basing on their internally revised reports. The credibility and efficiency of SERC's work is consequently harmed.

The fact that power grid operators currently control electricity transmission, distribution, and sales and that market regulation lacks authority and effectiveness has pushed the industry to a critical point. At this specific moment changes are ineluctable but compromises are to be made among different stakeholders. By aiming at solving contemporary problems, mitigating present conflicts and preserving the sustainability of electricity supply industry; we devise a “gradual approach” for China to facilitate further reforms. This approach is discussed as followed.

The real significance of dismantling electricity transmission and distribution segments lies in exploiting the potential market on sales side of electricity. Instead of dividing power grid assets, we can choose to separate the trading of electricity from power grids and establish third-party institutions, which are designated to the purchases and sales of electricity. The transmission and distribution of electricity are still bundled and run by original grid operators. The newly built institutions, or “electricity trading platforms” as we may call them, should have two functional levels and managed by corresponding electricity regulators. At the regional level, inter-provincial contracts are made and provincial operators act as suppliers/consumers who trade with each other through regional trading platforms. At the provincial level inner-provincial contracts are made, usually between power producers and industrial/commercial consumers, while provincial grid operators act as agents who buy electricity on behalf of residential consumers. In such case the “electricity trading institutions” perform necessary connections among generators, grid operators and consumers and are flexible in many aspects. Bilateral trades between power producers and high voltage/capacity consumers can be made more conveniently for the no longer suffer from grid operators’ interference. They can thus choose from more alternatives for a lower price or a better quality. This in return benefits the entire power sector for it brings a more liberalized environment at both generation and sales side of electricity. In China, industrial and commercial consumers account for over 80 percent of electricity consumption, which means their freedom in electricity markets can improve real competition to a good extent. Price will be determined mainly by market mechanism and pressure caused by rising thermal coal price over power producers can be greatly relieved. Moreover, without the function of electricity trading grid operators are nearly pure providers of power network infrastructure. Their responsibility as public utilities is more likely to be realized through reduction of operational costs and improvement of service quality. A more rationalized electricity tariff, namely "electricity transmission and distribution tariff", can also be launched as a guidance for direct trades.

An orderly and functional electricity market requires an independent, resourceful, powerful and open regulator to be in effect. To achieve this, the State Electricity Regulatory Commission (SERC) should be empowered with higher authorities than it currently has. Apart from organizing the "electricity trading platforms" as suggested in the Section 5.1, SERC should also take over certain administrative duties that now belong to power grid companies, such as network investment planning and market access endorsement. To fulfill these duties more efforts are needed in legislation process. Laws and regulations are to be formulated and passed to define the rights and responsibilities of different market players. Grid operation in particular, which is kept as monopolistic business, should be subjective to strict supervision. Transmission and distribution networks should be impartially accessible to all power producers and consumers and whenever possible, green generators like wind farms and hydraulic plants should be given a higher priority than regular generators. At the meantime, improvement in regulatory transparency is also necessary. Considering China's complex governing structures public supervision is relatively weak in the country. Therefore more systematic publication, more timely public consultation and notification procedures should be designed and carried out. Lastly, the country's evaluation tools for state-owned enterprises should be revised and rationalized. Grid operators should be assessed by their transmission/distribution capacity per asset value or by their general service quality. The strategies which aim at simple capital expansion, investments and acquisitions should doubtlessly be abandoned.

6.2 Prospective development of wind power in China

Since 2006, China has made great advances in wind power. Its proportion of the world's annual newly installed capacity increased from less than 10% in 2006 to 49% in 2010. Its total grid-connected wind power capacity reached 310 GW in 2010. In four short years, driven by the market, China's wind turbine manufacturing industry scaled up production; four Chinese wind turbine manufacturers now rank in the top ten in the world. The industry chain has been established and improved, covering technology research and development; component manufacturing; turbine assembly, testing and certification; wind farm development and other associated services. As market competitiveness continues to grow, China has solid foundations for large-scale wind power development and takes advantage of this most developed commercialized renewable energy technology.

Since China implemented its opening and reform policy 30 years ago, its energy development model followed the path of industrialisation seen in developed countries. An energy supply dominated by coal has supported rapid economic development, but this has put intense pressure on resources and the environment. Energy is the key driver of economic and social development, but fossil fuels can spell an end to clean, blue skies. So simple dependence on fossil fuels cannot be the fundamental solution, not only because it results in serious resource and environmental issues but also because it precludes the development of a global energy solution. In the next two or three decades, China will need more energy while reducing fossil fuel consumption and ensuring energy security. The only solution is a transition to a clean, reliable, low-carbon energy system, which uses the most cost-effective and environmentally friendly technologies to improve economic development while ensuring competitive energy prices and high living standards. The 21st century is an era for energy reform and innovation. China needs a strategic plan to address on these connected issues.

Sustainable energy development involves a concert of related policies setting regulations for increase of energy generation with reduced coal dependence and to diversify into a cleaner and more efficient option such as renewable. The results of analysis as presented in the section establishes that prospective wind power development is on the right track and ready for the scale-up to become a larger part of the energy mix. As a conclusive remark, the section suggests that the potential of wind power development is tremendous and will be reflected on her capability to resolve the following concerns.

Future power systems will need to feature more flexibility on the demand side as well as on the supply side if they are to optimise the full range of non-polluting, low-carbon energy sources, while maintaining security and reliability. This flexibility is essentially the ability to compensate for periods of low wind output, and to manage highs, using a portfolio of flexible generators, trade, and storage and demand- side response.

In anticipation of the continued scale-up of wind power, demand for inter-regional wind power integration will remain large for a long time, so advanced technologies and operation management will need to be applied widely in order to encourage energy structure and power system reforms to expand wind power integration within and between provinces and regions. The following key issues require attention in terms of grid integration.

- Smart grid technologies, smart power devices, energy storage facilities and electric vehicles should be deployed to enable flexible regulation of load to match power demand and greatly increase the capacity for integrating wind power and other fluctuating power sources.
- Transmission should be improved and optimised through widespread adoption of flexible transmission technology, especially ultra-high-voltage DC transmission and superconductive transmission. Transmission system cost recovery mechanisms need to be improved to maximise transmission line capacity and cost-effectiveness.
- Wider deployment of smart distribution network technologies and micro-networks should be encouraged, to improve decentralised wind power.

6.2.1 Issues on Grid Integration

In anticipation of the continued scale-up of wind power, demand for inter-regional wind power integration will remain large for a long time, so advanced technologies and operation management will need to be applied widely in order to encourage energy structure and power system reforms to expand wind power integration within and between provinces and regions. The following key issues require attention.

- Continued efforts should be made to expand integration of wind power within provinces in western China. Smart grid technologies, smart power devices, energy storage facilities and electric vehicles should be deployed to enable flexible regulation of load to match power demand and greatly increase the capacity for integrating wind power and other fluctuating power sources.
- Transmission from west to east should be improved and optimised through widespread adoption of flexible transmission technology, especially ultra-high-voltage DC transmission and superconductive transmission. Transmission system cost recovery mechanisms need to be improved to maximise transmission line capacity and cost-effectiveness.
- Wider deployment of smart distribution network technologies and micro-networks should be encouraged, to improve decentralised wind power integration and accommodation potential in eastern and central China.

6.2.2 Issues on Wind Power Technology

China has a continuous need for research and development on wind power technologies for large-scale deployment of wind energy beyond 2030. R&D depends on many factors, including wind power targets, wind resource characteristics, power load distribution and power grid distribution. Although China's wind power manufacturing industry grew quickly from 2006 to 2010, advanced large-capacity turbine system should be improved to meet the needs of the wind power supply chain and to ensure wind turbine quality and reliability.

- Enhancement of wind resource assessment technical standards and technical capability
- Development of wind resource database and application services
- Improvement of turbine performance
- Enhancement of the quality of the wind system components
- Improvement of the materials for the wind turbine blades and associated components
- Incorporation of the storage technologies for improvement of the grid integration

6.2.3 Issues on Off-shore Wind Farm Construction

Although land-based wind farm technology is relatively mature, but efforts should be made to develop micro-siting techniques to continuously improve planning, design and operation of wind farms, especially in complex terrain. The direction of development is poised to improve the wind power system design on choosing sites, particularly for hilly, mountainous and other complex terrain. Regarding the offshore wind power development, especially deepwater wind farm development and construction, China is still lacking behind. R&D activities need to be enhanced, based on China's specific planning and construction conditions. Project demonstrations should be accelerated to work out technical systems for far offshore and deepwater wind farms.

6.2.4 Issues on System Coordination

As the installed capacity of wind power increases, better coordination on wind power systems become vital. Accurate forecasts support reliable operation of the power system, effective management and maximum integration of wind power, while reducing system operating costs and the requirement for capacity margin. Sophisticated statistical techniques are required to provide forecasts ranging from 3 hours to 72 hours ahead of the time of delivery. It provides centralized and distributed wind power forecast service which will operate jointly with power grid dispatch, weather departments and wind farms to provide effective dispatching support. Alongside improvements in power grid infrastructure and operation techniques, and traditional AC transmission for large-scale wind farms and long distances, more flexible DC, high-voltage DC (HVDC), superconductive and low-frequency transmission technologies will need to be improved, especially for offshore wind farm electricity. Development of interconnection technologies on using super-high-voltage technologies including dynamic reactive power compensation, series compensation/TCSC, controllable high resistance, and automatic voltage control (AVC) are required to improve wind power output and energy quality, as well as to enhance safe operation of the power system.

6.3 China's 12th five-year plan

The driving force behind the restructuring of the Chinese electricity supply industry is the need to open the electricity generation market to all private participants. However, in a competitive market excluding the central planning, there is no guarantee on the investment return. Therefore, the real challenge in the restructuring process is how to ensure the market rules designed can send the right signals to attract sufficient investment to finance the development of the industry. Different aspects of market design should mutually complement each other to fulfill the ultimate objective of maximizing the long-term social welfare. Although it is believed that a properly designed electricity market can promote efficient investment, it is too risky to rely solely on this untested theoretical approach. Some forms of approaches guaranteeing a high investment return might still be worthy of maintaining as a way to attract capital in a certain period.

Consider the actual situation of burning coal for electricity in China – using coal does not reflect its external social costs. So, when building generating capacity, investors tend to build more coal-fired power plants than society desires. This tendency worsens the situation. The electricity market is a defined mechanism. If the externalities of burning coal can be internalized into the market price of coal, then electricity sector investors will voluntarily act according to the new market rules. Therefore, a proper ‘emission tax’ added to coal price might help lower coal use and make cleaner technologies more economical.

China could benefit from a combination of better planning and better markets. International experience demonstrates that generation markets that rely on spot market prices to guide new investment are unlikely to yield the optimal amount or mix of resources. This is especially true in China where the optimal mix of resources will be determined not only by cost, but also by factors such as climate and environment policy, resource diversity, and supply security. Relying on better planning to decide what resources should be added is a much simpler, less risky, and more direct approach than designing and redesigning generation markets in an attempt to force them to produce the outcomes that the planning process would have identified in the first place.

China already uses planning efforts to determine its future investment in energy efficiency, renewable energy, nuclear, coal, and natural gas generation. Our recommendation is that China should use improved power sector planning tools to identify the mix of supply- and demand-side resources that best meet its goals. The planning tools should also have the capability to evaluate grid expansion and operations, as they relate not only to conventional generating resources, but also to intermittent renewable generation and the integration of clean energy resources into the system generally. These methods aim to better integrate evaluation of demand- and supply-side options (including transmission and distribution), to identify the optimum mix of resources to meet economic, energy efficiency, climate, and environmental goals.

It is suggested to employ competitive acquisition for new generation for four reasons. Firstly, it is a well-tested, low-risk approach that can deliver new generation in a very cost-effective manner. Secondly, it provides an effective means to encourage new entrants. New entrants can improve competitive conditions and spur innovation and investment in new technologies. Thirdly, it can help address barriers to interprovincial trade. And, finally, it avoids most of the market power issues that would be present if markets were driven by spot prices.

There are very few structural requirements to support competitive acquisition of power under long-term contracts. Competitive generation using long-term contracts has worked well in both single-buyer markets and multiple-buyer markets.

It is recommended that buyers be the distribution companies rather than end-users. Retail competition, given the current state of China's system, provides few or no benefits but raises a number of complications. Therefore, if China chooses to adopt a multiple-buyer model, the multiple buyers should be the distribution companies. Each distribution company would be given the obligation to acquire the optimal mix of supply- and demand-side resources to meet its customers' demand. It would invest in end-use efficiency and buy power (and energy efficiency, too) in a regional or national market.

There are a few additional steps needed to resolve current generation pricing issues and barriers to entry. Government approval (or licensing) of new generation investment should be conditioned on certain findings:

- That the proposed power plant is consistent with national or regional energy and environmental plans;
- That the builders and operators of the proposed power plant meet reasonable technical and financial qualifications;
- That the proposed plant has been reviewed by the transmission company and the plant has been informed of any transmission costs it will be responsible for; and
- The proposed power plant has an approved long-term contract with a distribution company.

Contract terms and conditions, including prices, should be determined through competitive bidding. The contract should be approved if the bidding and bid evaluation process meets reasonable government standards. The contract satisfies appropriate least-cost (optimal resource mix) planning principles and any other reasonable resource obligations placed on the distribution company. The structure of any contract should be consistent with efficient dispatch rules. This means that contracts should:

- Reflect the underlying two-part, fixed (capital)/variable (energy) cost structure of the power plant. This will assure that economically efficient dispatch decisions can be made without harming the generators' ability to cover their capital costs. This will overcome the problems China has experienced in implementing the environmental dispatch rules and integrating renewable resources into system operations.
- Describe incentives for meeting availability requirements (and penalties for failing to do so). The current generation pricing practice provides internal incentives to

maintain high availability. The two-part (capacity/energy) pricing structure described in the first bullet retains that incentive if the capacity payments are conditioned on power plant availability.

- Explicitly address which party bears the risk of future costs relating to environmental risks, such as the need to install and operate pollution control equipment or pay environmental fees or taxes. The more of these risks that are borne by the generator, the greater the incentive will be to build the cleanest power plant possible.

In summary, a proper design for the electricity supply industry should consider the above factors and provide a consistent policy framework. In order to successfully complete the electricity market development, a wise strategy for Chinese policy makers would be to incorporate international 'best practice' of competitive electricity markets.

6.4 Prospective Policy Options of SRRM-ISEMD Policy Framework

For the purpose of analyzing the impacts of carbon policies with interactive markets on the decision making of a wind power considered GENCO, this section proposes a novel decision making model under multi-market environment. The model creatively deals with the decision making problem by two sequential processes. The first one is the production process which is solved by FDE and the second one is the trading process involving three interactive markets. The model accounts for emissions trading mechanisms by incorporating emissions constraints as well as the trading of emission allowances. A comprehensive case study is carried out to analyze a wind power considered GENCO's operation decision subject to constraints of different markets. From EM's point of view, a GENCO would produce the energy by wind power sources preferentially and reduce its total production so that prices in EM are expected to be increased in the short term. Furthermore, a GENCO would consider investing in more renewable units with merit priority in production planning. From CM's viewpoint, a harsh cap of emission would lead to a significant bring down of carbon in a short period whereas GENCOs are expected to pass the cost to their customers. On the other hand, CM might bring about a moderate level of emission and the market mechanisms are expected to reveal the true value of carbon allowances. From the standpoint of FM, transaction of fuel is a good supplement for GENCOs to operate in EM and CM. In summary, the proposed model lets GENCOs to make a good tradeoff between profit-making and emission reduction under three interactive markets environment. Furthermore, policies defining the three interactive markets may lead to a better environment for electricity supply industry to achieve the intended goals such as emission reduction, promoting renewables, and keeping electricity cost at a reasonable level.

In the long run, various essential legal components have to be built systematically into governing systems, institutions, and cultures as follows:

- Improve judiciary platform so as to:
    - reduce regulatory risk for attracting investment;
    - improve the regulatory environment which is overly-complex, multi- layered, often arbitrary and vulnerable to corruption;
    - provide sufficient regulatory safeguards reduce confidence in markets by - consumers and investors; and

    - improve checks and balances to ensure application of the rule of law for resolving dispute efficiently.

- Even where high-quality national laws available, creation of new institutions and implementation capacities has lagged behind, and hence the effects of many legal reforms have not yet been felt in the marketplace.
- The success of regulatory reform will depend on the consolidation of the rule of law throughout the governing structures.

CHAPTER 7

CONCLUSION AND FUTURE WORK

7.1 Conclusion

The thesis has successfully created the ISEMD-SRRM policy framework for sustainable electricity market development. The framework is not only justified to increase the overall benefits of the sustainable development, but also proved to contribute to achieve cost-effective operation, environmental use of energy and sustainable investment for the EMD process, which is capable to lead to the efficient expansion of the electricity supply industry. Another major contribution of this thesis lies in the detailed formulation of the ISEMD policy framework implementation in the three interrelated dimensions: economical, environmental, and regulatory. The derived results attribute to validate that the framework is capable to devise various comprehensive policy instruments.

The thesis has explored the status quo of China's power development from a macroscopic perspective and investigated the implementation of the ISEMD-SRRM framework for sustainable electricity market development. The exploration of the current status of China's power development has covered the electricity supply industry resources, policy and legal issues, economic benefits, and environmental concerns. The thesis has also established an evaluation process to investigate the optimized decision-making process of capital structuring in the ISEMD-SRRM framework. From the analysis of China's power development, the results of the evaluation show that, from both economical and political perspectives, the ISEMD-SRRM framework is capable to provide a healthier, sustainable and efficient way for developing clean use of energy for the power market in China. Furthermore, the findings also demonstrate that the developed investment model in wind power helps to achieve its social and economical goals. Socially, the findings contribute to identify sustainable and efficient energy portfolio. The results of the analysis also affirm that the prevailing policy for implementing the clean energy strategy supports the use of wind power as the main alternative energy source for achieving the low carbon target. Economically, the numerical case study on the wind power investment in China has confirmed the practicality of the developed economic benefits and feasible investment model. The results serve to quantify the contribution of the wind power in respect of the effects of energy saving and emission reduction. As revealed from the analysis on the wind power resources, China is taking lead among the world-class countries, in terms of the installed capacity and improving fast in the manufacturing capability of wind power generation units including their operational efficiency and the grid integration practices. The success of China's domination of the market shares in the domestic wind power manufacturing enterprises indicates her readiness to emerge into the international market soon. Regarding the associated legal and regulatory framework, the wind power generation in China is contributing positively for achieving the energy saving and emission reduction targets, which are proof of the successful implementation of the sustainable energy policy.

In order to examine and justify the framework, the thesis has successfully conducted a simulation case study to formulate and evaluate the effectiveness of the modified framework. The envisaged model is based on a multi-market simulation approach employed in the case study to justify and prove that the policies defining the three interactive markets with ISEMD-SRRM framework is capable to achieve the goals, such as emission reduction, renewable energy promotion, and keeping electricity cost at a reasonable level.

Based on the above analysis and justification, a serial of viable policy options has been developed and showed that innovative technologies continue to be the prime mover to propel generation and national grid expansion; open-economy policy supports the reform to achieve a balance among a multitude of dimension of interests; and legal reforms continue to strengthen the rule of law in general for establishing clearer market operation, pricing and effective governance systems.

Overall speaking, the new framework for electricity market policy making has been developed and shown to be working properly in the study. Operation of the framework is validated to be effective in the EMD process by cross-checking certain energy policy indicators which are devised to normalize their specified inter-relationship in the process. According to the China's 12th Five-year Plan, the most pivotal guidance government document for China's social and economical development will come out by 2015. By then, China is going to focus its EMD on emerging energy soucres and to optimize the industry performance. In effect, the thesis contribute to allow China to succeed its previous phases of EMD process: reform to raise capital for expansion, reform to achieve market-oriented restructuring, and reform to introduce competition in the electricity supply industry. In summary, the envisaged policy framework presented in the thesis affirms that China's

EMD is on the sustainable track that requires a firm and clear understanding of model and approach as advocated.

7.2 Future Work

Energy is the key driver of economic and social development and the use of fossil fuels can call an end to our clean and blue skies. Therefore, simple dependence on fossil fuels cannot be a sustainable solution, not only it results in depletion of the natural resources and cause of the environmental pollution concerns, it precludes the development of sustainable and reliable energy solution. The viable strategy appears to be one that would balance influence of regulation and market force; one relies on market to work out its solution and when the market might fail, regulation comes in. Hence, a new paradigm to re-defind the market rules and to guide the future development of the industry is required. In the next two or three decades, clean energy has to be carbon-free and achieved via proper policy formation and implementation of matching instruments to sustain the energy market development - an extension of the objectives envisaged in the thesis.

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