Overview of Relevant Researches on Electric Power Investment and Electricity Pricing Mechanism of Renewable Energy

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Abstract. Diversified energy structure, multi-player game relationship and the uncertainties contained in it form the basic background of the research on investment decision, risk management, social welfare evaluation and electricity pricing mechanism design which encircle the electric power of renewable energy. This paper is based on “microcosmic” and “macroscopical” layer, researches the delayed effect of electric power investment of renewable energy, analyzes the social welfare related to the electric power of renewable energy and expounds the design and application of the electricity pricing mechanism of renewable energy. It summarizes and reviews domestic and foreign researches on the electricity pricing mechanism of renewable energy. At last, it gives corresponding conclusion and enlightenment.

Introduction

Energy safety and human’s sustainable development have gradually become focus issues concerned by the whole world. Our country makes a promise that the consumption proportion of non-fossil energy will rise for about 15% by the year 2020; the discharge of CO2 in unit GDP will decline for 40%-45%. It is inevitable to push forward the development of the technology and industry of renewable energy.

Power generation technology is still the key point of commercially developing and utilizing renewable energy in existing technological conditions. Electric power market is a multi-player game market with diversified energy structure. Although our country has issued some supporting and subsidy policies, the electric power products of renewable energy are intermittent and unstable, which causes negative externality of the electric power of renewable energy. This is one of the important reasons why grid-connection of the electric power of renewable energy is difficult. The negative externality can aggravate the hesitation and delay of the electric power investment of renewable energy (real option features of investment in uncertain conditions always delay investment). This is adverse to the development of the industry of renewable energy. Therefore, new technology of electricity generation using renewable energy shall be developed. Through technological innovation, negative externality and unit cost of electricity generation can be decreased. In addition, the microcosmic process and decision-making law of the electric power investment of renewable energy must be intensively researched to find the “balance” of multi-player game and break the predicament “difficult grid connection”.

Since the beginning of this century, our country attaches more and more importance on development and utilization of renewable energy, enacts The Law of Renewable energy and successively issues a series of supporting policies which stimulate the development of renewable energy. Even if these economic incentive policies play important functions in stimulating the development of the industry of renewable energy, they need further improvement comparing with the development demand of the industry of renewable energy and foreign incentive policies of renewable energy. In existing technical conditions, power generation technology is the key point of commercially developing and utilizing renewable energy. From the international experience of developing the electric power of renewable energy and the efficiency of configuring energy and resources, we can see that pricing (subsidy) mechanism is the important mean of stimulating the power development of renewable energy. However, the technologies of renewable energy power
generation are diversified. The commercialized development degree of technologies is different. The conditions and quality of the renewable energy in different places of different countries are tremendously different (this determines different energy structure). Economic development level (determining electrical load) and loading capacity (determining the construction scale of power grid) are different. Therefore, manifestation pattern of pricing mechanism and price level are naturally different. Therefore, we urgently need to and must start from the cost and technology of the electric power of renewable energy, start from electric power investment environment of renewable energy, intensively research the microcosmic process and decision-making feature of electric power investment of renewable energy, combine the characteristics of electricity market of our country and development stage of renewable energy, explore a flexible and effective electricity pricing mechanism of renewable energy which stimulates the achievement of electric power target, strengthen social investment and financing confidence to electric power of renewable energy and stimulate the electric power development of renewable energy.

Scientific design and enactment of the electricity pricing mechanism of renewable energy depends on people mastering operational law and even formation mechanism of the electricity pricing mechanism of renewable energy. Therefore, we must start from “microcosmic view”, sufficiently consider the microscopic feature of power technology of renewable energy and research the microcosmic process and decision-making behavior of the electric power investment of renewable energy. The technical characteristics of the electric power of renewable energy determine its cost formation characteristics. In reality, uncertain cost and power technology development of different renewable energy can make investors of renewable energy power delay their investment. At the same time, power products of renewable energy are intermittent and unstable. Renewable energy are distributed in partial concentration and they are in contrary distribution with electrical load. The construction of the power investment project of renewable energy is faster than the construction of power grid engineering. Electric power market and relevant policies are uncertain. All above factors aggravate the hesitation and delay. In another aspect, the power of renewable energy has practical and potential positive external benefits (they mainly mean the positive influence on resources and environment, enormous technical progress potential and large application prospect). It can be weakened owing to the “rational” delayed investment of renewable energy power investors. The real option contained in power investment of renewable energy can cause delayed investment which exerts uncertain influence to social welfare. This is called delayed effect of electric power investment of renewable energy. At the same time, the active development of the power of renewable energy is not to ignore cost or to impose uniformity in all cases. Aiming at different power technology of renewable energy and according to different technical development stage and development scale, different price of power can be set. This “adaptive adjustment” process and idea of the price of renewable energy power is the core of electricity pricing mechanism of renewable energy. To seek the internal link between the “macroscopical” policy signal (namely power price of renewable energy) and the “microcosmic” behavior (investment in renewable energy power) is to reveal and research the law and mechanism of forming power price of renewable energy.

Domestic and Foreign Research Status and Relevant Analyses

From the scope of research on formation mechanism of the power price mechanism of renewable energy, the “microcosmic” electric power investment of renewable energy is involved; “macroscopical” social welfare and power price of renewable energy is also involved. Therefore, the following three aspects are used to summarize domestic and foreign relevant research status: the first is the delayed effect of the electric power investment of renewable energy; the second is the analysis on social welfare which is relevant to the electric power of renewable energy; the third is the design and application of Feed-in Tariff mechanism of renewable energy.

Research on Delayed Effect of the Electric Power Investment of Renewable Energy

At present, the researches on delayed effect of the electric power investment of renewable energy
mainly focus on investment decision-making. In other words, real option method is used in electric power investment project with deferring option to analyze optimal investment opportunity and investment value. As for externality of investment, especially the delayed replacement of traditional fossil energy caused by delayed investment, the research on it is not enough.

Wang Xiaotian and Xue Huifeng (2012) used behavioral decision-making theory to qualitatively describe the causal relationship among the influence factors of renewable energy investment behavior through building renewable energy investment decision-making behavior analysis model. Quantitatively, Cai Qiang (2016) built investment opportunity real option game model and analyzed the investment decision-making feature of renewable energy grid-connection power generation. Owing to the particularity of electric power industry, many actual limits must be considered while applying real option to analyze power investment decision problem. In electric power investment limited by operation, Tseng and Barz (2002) expanded common real option framework to the environment with the limit of starting time and the limit of work start and work stop. They researched the limit of maximum generating capacity and existing loss. The method of Tseng and Barz (2002) was complex and only suitable for making decision for short-term power project. For this, Deng and Oren (2003) put forward a relatively simple method to treat long-term projects. In electric power investment based on spread option, aiming at the two distinguishing features: non-storable power products and raw materials cost of certain electric energy, Deng (2001) put forward the idea that power futures were used for hedge. Hsu (1998) put forward the idea that ignition spread option was used for hedge. Deng (2001) offered ignition spread option formula based on futures market on the basis of the theory put forward by Margrabe (1978) and Shimko (1994). Keppo (2004) offered power swing options pricing formula. Ma Xin and Jiang Chuanwen (2004), Ma Xin and Hou Zhijian (2004a) put forward the concrete thought of power generating company applying swing options. Cai Qiang (2015) discussed the important applications of power financial derivatives in the four links of energy power (generation, transmission, distribution and sale) referring to the analysis on foreign power product market. In addition, he evaluated motion model of electric power price and the method of pricing power financial derivatives.

Following the gradual development of renewable energy, diversified energy structure is inevitable. Power investors may simultaneously face several power projects and make decisions. The mutual relation among projects cannot be ignored. Cai Qiang (2015) built option game model of renewable energy power investment in the respective three situations of complete monopoly, technological symmetry of double oligarchies and technological none-symmetry of double oligarchies based on environmental features of renewable energy power investment and the intrinsic characteristics of renewable energy power products. Through economically explaining and evaluating the model, the expansion scope and approach of option game model of renewable energy power investment can be further pointed out. Wang and Min (2000) considered the investment combination of two power projects in the angle of real option. The two projects influence each other. Wang and Min (2006) considered investment decision-making problem of several power projects. Keppo and Lu (2003) thought that connotative option value increase and possible value loss should be both considered while making decision if different projects were relevant. Ji Xingquan and Wen Fushuan (2005a) considered investment decision of several power projects and put forward the solution based on genetic algorithm according to B-S model.

In the aspect of uncertain load change and the power investment of market structure, Wang Yong (2005) expanded previous researches. His case simulation indicated that: comparing with simplex market mode, both capacity cost model and installed capacity model can lower the load critical value of optimal investment opportunity.

Considering the features of renewable energy power, Sekar (2005) compared the application of real option method and that of other methods in coal power investment. Venetsanos (2002) used traditional B-S model to analyze wind power investment decision. Moreira (2002) considered the complementation of thermal power and wind power of Brazil. Takizawa (2001) considered the optimal investment problem of single nuclear power project in classical real option principle. Kiriyama (2004) started from environment policy and considered the superiority of nuclear power
(without exhausting carbon dioxide) comparing with traditional power energy. In addition, real option method was utilized to price this superiority. Gollier (2005) compared different nuclear power investment strategies based on the ideas of Arrow and Fisher (1947), Dixit and Pindyck (1994), Henry (1974). Rothwell (2006) utilized the result of Dixit (1992) and regression fitting to estimate the optimal trigger price of high-level boiling water reactor built in Texas.


The existing researches mainly aim at positive externality evaluation on renewable energy. Roberto Dones (2005) aimed at the currently most comprehensive and profound energy utilization environment externality evaluation project of European Union (ExternE and subsequent projects) and summarized to get a set of calculation assessment framework which had been widely acknowledged and applied. IEA (2008) issued by international energy agency evaluated the social cost and profit of several renewable energies and regular energies. In its contents, externality included the social welfare influence of all costs or profits which were not reflected in market price and were not paid by relevant parties. The development research center of the State Council of our country (2006) stated that the externality of energy industry was mainly reflected by the influence on resources and environment. Yu Pingping (2011) showed solicitude for the general influence of uncertain future policy on the investment decision of power generation enterprises. Aiming at the grid-connection externality of renewable energy power, Cai and Huang (2015) analyzed and expounded the four indexes of environmental benefit, environmental influence, social benefit and market influence. Zhao Yongqiang (2010) put forward energy externality evaluation index system covering resource environment, economy and society. In addition, he analyzed formation mechanism, root causes, influenced objects, components and calculation approach of the externality and put forward the key direction of profoundly evaluating and coping with the externality of energy. Guo Haitao (2008) thought that the cost of most energy products was not complete and only included development cost in current energy price and tax revenue system of our country. External cost had not been completely internalized. Liu Yezhi (2008) thought that development of new energy was limited and the allocation efficiency of resources was low in the spontaneous function of market mechanism. In his opinion, fiscal policy could help to effectively achieve optimizing configuration of new energy and sufficiently reflect its external benefits. Moreover, Li Chunjie and Cheng Yancong (2011) researched the influence of increasing power efficacy and subsidizing power generation with renewable energy on social welfare. They explored the policy bases of implementing energy conservation and emission reduction to promote social welfare. Wang Jian and Lu Zhengnan (2012) analyzed the influence of the discount rate and regeneration rate of renewable energy on optimal price route through building renewable energy consumption model in the target of social welfare maximization. Botterud (2005) built real option model of power investment with the targets of social welfare maximization and profit maximization. He analyzed the optimal investment opportunity and social welfare in different decision-making target environment.

**Research on the Power Price Mechanism of Renewable Energy**

It is a widely-used policy means of the world to implement price subsidy for power generation with renewable resource. The existing researches mainly focus on grid-connection price level design, price adjustment method, cost apportionment methods and the evaluation on the effect of subsidizing power price of renewable energy.

At present, price level design has two methods. The first is to calculate the cost level of the power generation project of renewable energy. This is called “cost basis” method which is similar to average cost method. The other is to calculate the value of power generation of renewable energy. Based on the external cost of traditional power replaced by the power of renewable energy, it can be called “value basis” method which is similar to marginal cost method. According to the analysis of Klein (2010) and Cory (2009), most countries of Europe use “cost basis” method. Many states of America and few countries of Europe use “value basis” method. As for these two methods, “value
basis” method is much more difficult than “cost basis” method. According to the analysis made by Klein (2010) and Rowlands (2005), the reason is that the positive externality of renewable energy power lacks cogent calculation means and information is asymmetrical. Pan Qing (2012) analyzed the problems existing in fixed power price system and put forward several concrete suggestions for perfecting this system. Huang Junyi (2011) made comparative research on fixed price and tradable green certificate.

Price adjustment methods mainly include periodical revision of price level and price decreasing mechanism. The first method is simple and easy to be implemented and it has been used by most countries. Price decreasing mechanism can get better effect because it can stimulate technical progress and lower cost. Ragwitz (2007) stated that proper price decreasing rate was difficult to be determined because it was difficult to accurately describe technical learning curve. Mendonva and Jacobs (2009) thought that price decreasing rate depended on expected learning potential of each technology. At present, academic circle has no accordant method of formulating decreasing rate.

In the aspect of cost apportionment method, Beerepoot (2010) found that European and American developed countries preferred Feed-in Tariff because all consumers jointly undertook cost without increasing financial burden of the country. Zhao Zijian and Zhao Xu (2012) applied Ramsey pricing theory to electricity selling link and researched the apportionment mechanism of the Feed-in Tariff of renewable energy. Shi Jingli and Wang Zhongying (2008) described and reviewed the additional price levy and expense apportionment system of renewable energy, summarized the implementation and effect of existing expense apportionment mode and analyzed existing problems. Mendonva and Jacobs (2009) regarded “development speed” as evaluation index. Comparing with the countries which implement other policies, the countries which implement Feed-in Tariff support mechanism have prominent effect of renewable energy development. For example, Butler and Neuhoff (2008) made comparison between the effect of wind power development policy of UK and that of Germany. The comparison indicated that the wind power Feed-in Tariff of Germany got good effect. Lipp (2007) made comparison among the effectiveness of renewable energy policy of Denmark, Germany and UK. The comparison indicated that the renewable energy development of Denmark and Germany which implemented Feed-in Tariff policy was better than that of UK which implemented renewable energy quota standard (RPS). Meyer (2003) demonstrated the superiority of Feed-in Tariff mechanism in positive and negative aspects. He thought that the Feed-in Tariff policy used by Denmark, Germany and Spain was better than other policies used by other countries in the process of stimulating wind power development. The research of Cory (2009) indicated that proper Feed-in Tariff policy could get more cost benefit than renewable energy quota standard system. Aiming at the cost disadvantage of fixed Feed-in Tariff mechanism, Junginger (2005) thought that effective amendment method was to lower the price level of fixed Feed-in Tariff mechanism according to the decline speed of experienced curve price. Cai and Du (2016) used mathematical model and combined the features and development situation of wind power industry to analyze the functions of fiscal taxation policy for stimulating wind power investment and risk management. Huang and Wu (2011) thought that Feed-in Tariff policy was the most successful mechanism for pushing forward the development of renewable energy. The key for this mechanism to play important functions is to well design combining national conditions. Cai and Gao (2015) summarized the existing policies which stimulated the development of the industry of renewable energy power. They analyzed and evaluated the effectiveness of the current incentive policies in the angles of power generation technology, subsidy and tax levy. Wang, Yin and Li (2010) researched Chinese policy of renewable policy.

Conclusions and Enlightenments

From above summarization, we can get the following conclusions and enlightenments.

1) At present, the researches on power price formation mechanism of renewable energy are defective. They emphasize the subsidy and privilege offered to power generation with renewable energy on the basis of regular energy power price and lack corresponding basic theoretical framework for solving the actual problems of designing mechanism of renewable energy power price.
2) Delayed effect of renewable energy power investment is extremely complex and uncertain. It is comprehensively influenced by real option value deriving from uncertainty (such as technology, power grid-connection volume, policy etc.) and competition (among renewable energy power with diversified energy structure; between renewable energy power and traditional fossil energy power), strategy value and the positive and negative externality of renewable energy. At the same time, it is “controllable” in certain degree. Therefore, delayed effect can be “effectively controlled” through comprehensively considering all factors which influence the delayed effect of renewable energy power investment, finding and mastering the formation mechanism of renewable energy power price and designing scientific price mechanism on the basis.

3) The existing researches on designing price mechanism combining the development stage of renewable energy industry are insufficient. As for the methods of considering different cost influence factors and well controlling cost in mechanism design, further research is needed.

4) The present researches on the policies of renewable energy emphasize their convenience and actual effect. There is little research on the fairness and reasonability of policy formulation and implementation.

5) The quantitative research on the influence of renewable energy power price mechanism on social welfare lacks. The present researches are almost limited to qualitative argument. Or they tend to make applicability analysis on the basis of summarizing the effect and experience of implementing foreign price system. Cogent theoretical basis and quantized analysis tool lack. Therefore, it is reasonable and targeted to analyze the influence of renewable energy power price mechanism on renewable energy power investment decision and social welfare from the standpoint of social planners and power supervisors.

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