Application on the Improved Real Options Model in Investment Decisions of CCS Project for IGCC Power Plants

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Abstract
In this paper we build a ternary-tree real options investment decision model of Integrated Gasification Combined Cycle (IGCC) power plant's Carbon Capture and Storage(CCS) project based on the real options model and establish three key factors influencing the CCS project: CCS technical progresses, feed-in tariff and carbon permit trading. Effects of these factors on CCS are considered. Through a scenario analysis of CCS project investment decision with given parameters, the effects of fluctuation of these three key factors-variation coefficient of feed-in tariffs, coal fuel prices and CERs(Certified Emission Reduction) on CCS investment decision are further analyzed which indicates that this model can be applied to investment decisions of CCS.

Key words: CCS, CARBON EMISSION PERMIT, FEED-IN TARIFF, TERNARY TREE, REAL OPTIONS.

Introduction

The project applied Carbon Capture and Storage(CCS) is often featured with huge investment, large construction scale and task. Several constructed projects in China at present are mostly achieved by the government, financed and implemented by power enterprises, which appear as demonstration projects. Nowadays the operating costs of Integrated Gasification Combined Cycle(IGCC) power plant's CCS project are facing the restrictions of high technology, high operating and maintenance cost, which mean that investors have to tolerate longer payback period. The CCS technology has three modes of pre-combustion capture, in-combustion capture and post-combustion capture respectively, so that the investment of IGCC power plant's CCS project has the freedom of timing, and moreover, investor can invest at any time of the project running; and the implementation of CCS will produce mutual influences among local government, society, economy and environment. These factors affect collectively on different stages of project and cause increasing complexities of project risk, thereby leading to higher uncertainty of return on investment in CCS. Meanwhile, most researches on CCS are in theory stage both home and abroad, which makes CCS being in higher risk of technology and investment.

The CCS technology is one of the most potential emission reduction technology in the future that is capable of fundamentally resolving carbon emission problem of electric power industry and so on, and that is one of important strategic choices for global response to climate change[1-2]. Carbon emission reduction investment projects are becoming more and more favored by investors, with the maturity and globalization of carbon emission trading market. IGCC power plants can obtain huge economic interests by carbon emission trading, because of its huge amount of emissions. Economic interest and environmental benefit owing to carbon emission reduction have become the important driving force for IGCC power plants' investment in CCS project. Based on the driving force and related characteristics mentioned above, IGCC power plants' CCS project can be regarded as a combined option, and then putting the analysis of investment value as the options value instead. Because of a lot of future uncertainties caused by financing environment, social situations, and energy policies by the government, options to defer investment can be easily caused. In this paper, focusing on IGCC power plants as the investing body, we analyze major influences of investing on CCS project, and consider the fluctuations of feed-in tariff, technological progresses and carbon emission permit prices, in the case of taking into account carbon emission trade . Binary tree model has been widely applied to various kinds of investment project decisions as a common option numerical method, but it can't solve problems when the carbon emission permit prices have three or more possibilities. Therefore, in this paper we construct an investment risk decision-making model of CCS project based on ternary tree option method, and attempt to provide scientific decision-making basis for CCS investment projects.

Research status

In respect of evaluating decisions: At present, many experts and scholars at home and abroad have done a lot of studies of basic theories on CCS project decision evaluation, and have proposed some models, such as value chain analysis proposed by Olafr Røsnes et al., which offered rounded analysis and decision basis for value creation process of the project[3]. M.Gerstenberger et al. proposed logic tree method, which divides every CCS project into four major components(capture, transport, injection and reserve), and makes probability assignment considering risk factors of technology(engineering and geology), society, policies, security and economy[4]. This method contributes to avoiding the unacceptably high uncertainty and a distinct risk factor of adverse effect about successfully sealing although it can't reduce the possibility of uncertain risks. There are risk evaluations aiming at various subsystems of CCS(capture, transport, injection and reserve), which present a series of assessment methods. For geological storage of CO_2, Debbie Polson et al. proposed a risk assessment method based on the records of characteristic, incident and process, aiming at helping reduce uncertainties of the system and locate the highest risk storage area[5]. Joris Koornneef et al. , basing on literature review and pre-existing uncertain data(failure rate, pipeline pressure, temperature and etc.), proposed a systematic assessment method of distance and uncertainties[6]. It drew a conclusion that the QRA of CO_2 pipeline can be improved. Zhu Lei and Fan Ying at home, proposed a CCS investment evaluation model based on real option theory by considering uncertain factors about thermal generating cost, carbon price, thermal generating cost including CCS, technology deploy investment of CCS and so on[7].

In respect of real option: Laurikka did research on investment problems of remolding existing plants and installing combined heat and power which would stimulate random variables of carbon emission quotas, feed-in tariff, basic fuel price etc[8]. The result indicated that real option method could evaluate this investment problem better than discounted cash flow. Damen K et al. analyzed the factors such as various technologies of CCS, power plants' infrastructure and so on, and presented that compared with the power generation systems without this technology, the CCS technology was capable of realizing large-scale CO_2 emission reduction by 75%~100% , but the problem is that CCS resulted in higher generating cost[9]. Ming Yang et al. applied the method of real options to coal-fired and gas-fired power plants, which by estimating risks of carbon emission and energy prices, verified the effectiveness of the method at decision making of quantitative investment on power plants[10]. Jana Szolgayova et al. assessed with real options model the effects of various policies of climate change on investment, revenue, CER etc. in electric power industry[11]. As a result, large-scale introduction of CCS is facing substantial uncertainty. The feasibility of these power stations is significantly subject to the overcoming of technological risks. Wenji Zhou et al. proposed a real options model aiming at carbon prices with respect to introducing uncertain describe of policies, in the condition of probably potential technological innovation[12]. In addition, under the influence of China's uncertain environment and climate policies, this model is used to determine CCS's optimal investment strategy, aiming at the process of investment decision making of carbon storage. Zhang Xinhua et al. proposed a carbon capture investment model of power generation enterprises applying the theory of real options under the condition of uncertain carbon prices and CCS technology[13]. CCS's investment timing was searched by means of data simulation. As a result, the fluctuation of carbon prices would delay the investment timing. What's more, enterprises would give up investment if it fluctuated too much.

Throughout documents mentioned above, domestic and overseas researches on CCS's risk decisions are in their infancy so far. A few macro research methods are presented in most of foreign literatures, while domestic research is still in blank stage. In this paper, a ternary-tree method of real options is introduced aiming at uncertainties of IGCC power plants' CCS project and a corresponding real options model of CCS is established which is verified by means of scenario analysis and will guide enterprises' investment and development.

Analysis and modeling of uncertainties in the CCS project

Technological advancement

(1) Factors of technological advancement

The decline in the cost of technology depends not only on the product and cost, but also the corresponding learning rate, namely the learning curve. The shape of the cost reduction curve is subject to the learning rate of technological cost. The learning rate comes from the aircraft industry proposed by Wright(1936). In the production process, the unit labor hour drops with the increase of the cumulative production; however, it tends to be stable when the cumulative production reaches a certain level. Thus, the relationship between the average cumulative hour and the cumulative production is called the learning curve.

Given the current technical level, the capture cost of CO_2 is between $13-51 per ton [14]. The IEA research reveals that use of CCS can reduce the overall cost of lowering emissions. However, the cost will be 70% higher by 2050 to achieve the goal of emission reduction if CCS is not used [15]. In the long run, the cost will fall with technical advancement, and meanwhile, reduction of uncertainties in the process of investment and maturity of the market of greenhouse gases will make CSS more and more economical.

(2) The learning curve model of technical advancement

Reference [16] indicates that effectively lowering the energy consumption of CO_2 capture is the key to reducing the CCS's life-cycle cost of emission reduction. It also analyzes the possibility of reducing the cost according to the corresponding parse expression, in conjunction with the analysis method of learning curve, which indicates that there's a great potential for lowering the generating cost of IGCC system. The learning rate of the cost is 7.4% after increasing CO_2 recycling. Given the current technical level, we assume that the capital cost of CCS project in an IGCC power plant is I_0 in a reference year, and the overall capital cost is I_t after t years, it gives :

$$I_t = I_0 \times e^{-0.074t} \tag{1}$$

Feed-in tariff

(1) Factors of feed-in tariff

In order to reduce carbon emissions and further develop the CCS technology, clean coal generation is likely to be a major channel for China's energy conservation and emission reduction for the next two or three decades. Implementation of CCS project will be the major trend in emission reduction in power plants. However, it can not be controlled directly by enterprises due to our country's macro-control of the feed-in tariff. Therefore, the price of the feed-in tariff has a direct effect on investment decisions of the CCS project.

Given the high cost of carbon capture technology, if CCS is deployed, the power plant could hardly make profits in the short run according to the current price level, except that our country gives financial support or permits higher feed-in tariff. In order to remove the negative effect of high cost on the CCS implementation, the CCS project is taken as a sort of clean power generation technology by introducing the mechanism of feed-in tariff. So this paper puts the feed-in tariff as part of the CCS project uncertainty factors.

(2) Feed-in tariff

Given the mechanism of feed-in tariff based on the on-grid power tariffs in CCS, and given that there is no domestic discount standard concerning CO2 emissions so far, a related mathematical model is built as follows：

$$P_e = P + \rho \times S_c \qquad (2)$$

P_e represents the on-grid power tariff, P is the basic IGCC on-grid power tariff, S_c denotes the state subsidy for clean energy, ρ is the variation coefficient, by adjusting which the practical tariff after implementing CCS can be close to reality.

Carbon trade

(1) Factors of rights to carbon trade

Carbon trade is the market mechanism that promotes a global emission reduction of greenhouse gases and carbon dioxide, the basic principle of which is for one party to sign a contract to obtain credit for emission reduction of greenhouse gases by paying to the other party, and the buying party can achieve the goal of emission reduction by utilizing the purchased credit for mitigating the greenhouse effect. As the global climate crisis increases, the low-carbon economy has been accepted by a growing number of countries.

As a profit from investment to CCS, carbon trade becomes increasingly important. Moreover, it has been regarded by a growing number of power enterprises as an important means of offsetting high cost. The profit generated in CCS, subject to the simplified carbon trade that is assumed in this paper is embodied by the price of carbon emissions, thereby serving as a key parameter of the profit function.

(2) The ternary-tree pricing model of carbon trade

Yingyu He's [17] research indicates that the approximate value of the ternary-tree pricing model is prior to that of the binary-tree analogy. Moreover, error obtained in the ternary-tree model is far less than that in the binary-tree model, while calculations and corresponding time required by the former are significantly more than those by the latter. However, due to the lack of real-time demand on the prediction of options in this paper, the downside of the ternary-tree model that has heavier computation burden can be ignored. Therefore, we choose the ternary-tree model that is capable of handling the situation of multiple states, obtaining more accurate data and meeting the practical requirements as well.

Scholars throughout the world have done a lot of research on carbon trading price which is taken to be following the geometric Brownian motion [18,19] . Meanwhile, we assume that there's no riskless arbitrage in the carbon trade market.

We assume the carbon trading price as following the geometric Brownian motion in the time interval [0,T] based on its routine behavior, it gives: $\frac{dC}{C} = rdt + \sigma dz$, r represents riskless rate, σ is instantaneous Volatility, and dz denotes standard Weiner process, C is Carbon price。

Based on the study by Zhengzhong Ding et al. in reference [20],the price in interval [t, t+Δt] has following distributions after discretizing C that is originally continuous and equally dividing [0,T] into n slots:

$\frac{\Delta C}{C} = r\Delta t + \sigma dz$, and further derivation formula, we can get the price expectations (E),

$$E(C) = C \times e^{r\Delta t}$$
$$E(C^2) = C^2 \times e^{(2r+\sigma^2)\Delta t} \qquad (3)$$
$$E(C^3) = C^3 \times e^{(3r+3\sigma^2)\Delta t}$$

According to the trajectory of ternary-tree model, the pricing model is built as follows:

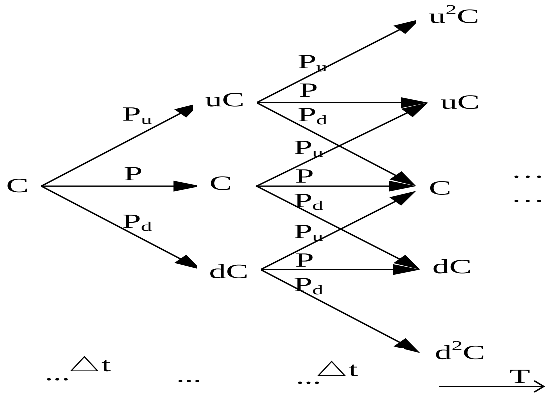

Figure 1. The ternary-tree diagram of carbon trading price

In $\triangle t$,the carbon trading price may first increase and then decrease or vise versa, namely $u \times d = 1$. Carbon trading prices will change according to the probability—the possibility of increasing, decreasing or remaining unchanged is : P_u、P_d、P respectively, and $P_u + P_d + P = 1$. At $t + \Delta t$, if we substitute these arguments into equations set(3),and consider the solving process in reference[21],results as given below can be obtained：

$$
\begin{aligned}
&u = M + \sqrt{M^2 - 1}\\
&d = M - \sqrt{M^2 - 1}\\
&P_u = \frac{e^{r\triangle t}(1+d) - e^{(2r+\sigma^2)\triangle t} - d}{(d-u)(u-1)}\\
&P = \frac{e^{r\triangle t}(u+d) - e^{(2r+\sigma^2)\triangle t} - 1}{(1-d)(u-1)} \qquad (4)\\
&P_d = \frac{e^{r\triangle t}(1+u) - e^{(2r+\sigma^2)\triangle t} - u}{(1-d)(d-u)}\\
&Here,\ M = \frac{e^{r\triangle t} + e^{(3r+3\sigma^2)\triangle t} - e^{(2r+\sigma^2)\triangle t} - 1}{2(e^{(2r+\sigma^2)\triangle t} - e^{r\triangle t})}
\end{aligned}
$$

The ternary-tree real options model in the CCS project

According to the Kyoto Protocol, China does not necessarily undertake emission reduction commitments before 2012, while we'll definitely accept this compulsory to some extent to face the increasing pressure of emission reduction, which means that enterprises can benefit from the carbon trade. Based on IGCC power plants' earnings concerning their actual cash inflow and outflow, a profit model of the CCS project can be established as follows:

$$NPV = P_e \times Q + C \times CER_{co_2} - V_c - V_{oc} - V_l - V_{fc} - I \qquad (5)$$

Here, P_e represents the on-grid power tariff.

Q: electricity output;

C: price of carbon trade (Euros/ton), following the ternary-tree process;

CER_{co_2}: CER (ton);

V_c is fuel cost for power, $V_c = \frac{C_{fuel} \times \alpha \times Q \times 0.33}{10000}$, in which C_{fuel} is standard cost of coal(RMB/kg), α is price variation factor, 0.33kg/kwh is electric-converted C_{fuel};

V_{oc}: maintenance and operation cost;

$V_l = P_e \times Q \times k$: project operating losses, k: energy consumption ratio;

V_{fc}: fixed cost;

I: investment cost.

A profit model of investment value can be obtained by substituting the CCS project's uncertainty model described in section III and the profit model obeys ternary-tree procedure as well, as illustrated in the figure below:

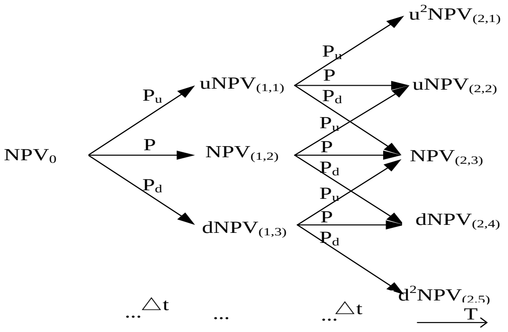

Figure 2. The ternary-tree diagram of CCS project's investment value

The reverse procedure in figure 2 is exactly the investment decision-making process of CCS project. Every node in the figure has three options: adding investment, withdrawing investment and remaining unchanged, and the investment value yields to:

$$\max(NPV_{(i,j)}, (P_u \times NPV_{(i+1,j)} + P \times NPV_{(i+1,j+1)} + P_d \times NPV_{(i+1,j+2)})e^{r\Delta t}) \qquad (6)$$

Suppose an IGCC power plant is brought with CCS project investment in the year $t = t_1$, and related equipment is put to use after one year of construction period, and further suppose r is the riskless rate.According to factors such as operating losses etc. in section III.1, we know that technology progress can reduce cost and operating loss, the net present value of CCS investment at t_1 gives:

$$NPV_{t_1} = \sum_{i=t_1+2}^{T} (P_e \times Q + C_i \times CER_{co_2} - V_c - V_{oc} - V_l - V_{fc})(1+r)^{t_1-i} - I_i(1+r)^{t_1} \qquad (7)$$

We expand NPV during CCS project period based on the ternary-tree model and calculate every NPV corresponding to every node. After that, we recurse backwards from the deadline to the starting point of investment, making decisions based on formula (6), and then the initial investment value of CCS project following the ternary-tree model can be obtained. NPV for every node is subject to:

$$NPV_i = (\sum_{i=t_1+2}^{T} (P_e \times Q + C_i \times CER_{co_2} - V_c - V_{oc} - V_l - V_{fc})(1+r)^{t_1-i} - I_i(1+r)^{t_1}) \qquad (8)$$

Substituting parameters into formula (8), expanding and simplifying this expression yields to a new formula as follows:

$$NPV_i = [\sum_{i=t_1+2}^{T}((P+\rho\times S_c)\times Q\times(1-k)+C_i\times CER_{co_2}-V_c-V_{oc}-V_{fc})(1+r)^{t_1-i}-I_0\times e^{-0.074t_1}(1+r)^{t_1}]$$

$$NPV_i = [(P+\rho\times S_c)\times Q\times(1-k)+C_{t_1}\times CER_{co_2}-V_c-V_{oc}-V_{fc})\frac{(1+r)^{T-t_1-1}-1}{r(1+r)^{T-t_1}}-I_0\times e^{-0.074t_1}(1+r)^{t_1}] \qquad (9)$$

Scenario Analysis

As in practice, many factors may affect the investment, operating, energy losses of CCS project such as specific CCS technology adopted by IGCC power plants, economic parameters, carbon trading market, macro-control policies by the government etc., parameter values of the model are simplified to ease computation.

Parameter settings

Table 1. Parameters in CCS project

Parameters	Notations	Value	Units	Remarks
CCS construction cost in the reference year	I_0	8.75	0.1bnRMB	100MW unit
On-grid power tariff	P	0.455	RMB/KWH	(1)
Government subsidies for clean energy	S_c	0.054	RMB/KWH	(2)
Price volatility of carbon emissions	σ	0.3954		(3)
Riskless rate	r	5.32%		(4)
Energy consumption ratio	k	12.4%		(5)
Annual energy output	Q	3176400000	KWH	(6)
Carbon trading price in the reference year	C_0	61.4	RMB/Ton	(7)
CER	CER_{co_2}	247.3	10,000Tons	(8)
Operating cost	V_{oc}	3.56	0.1bnRMB	(9)
Fuel’s unit price	C_{fuel}	700	RMB/Ton	(10)
Fixed cost	V_{fc}	3.14	0.1bnRMB	(11)
Lifetime	T	20	Years	
Coefficient of feed-in tariff	ρ	0%-200%		Varying

Additional specification:

(1) According to the NDRC document No.2622: Notice on Adjusting On-grid Power Tariffs in Eastern China, the fundamental price used in this paper is based on the average value of on-grid power tariffs of part of Generation enterprises in Jiangsu.

(2) Feed-in tariffs in China equal to on-grid power tariffs of renewable energy subtracted by the desulfurization price which are not equivalent due to the various desulfurization prices executed in different provinces. Therefore, we take the desulfurization price in Jiangsu province as the data source of the government subsidy for clean energy. Since Sept. 2010, public coal-fired thermoelectric units with installed capacity less than 10^5 KW have been allowed to implement the desulfurization price in Jiangsu, specifically, the price is 0.509RMB/KWH, based on which let $S_c = 0.509 - 0.455 = 0.054$ RMB/KWH.

(3) Use Europe’s carbon emissions price from Jan. 2011 to Nov. 2012 as the sample data source of its volatility[22], based on which $\sigma = 0.3954$ is obtained by means of GARCH (1, 1) model calculating the volatility of carbon trading price.

(4) Use the latest domestic 5-year treasury rates (Nov. 2012) as riskless rate.

(5) Year-on-year computation based on the consumption rate of the 100,000-ton carbon-capturing demonstration projects of 600MW unit in Huaneng Shanghai Shidongkou Power Plant II, in 2009.

(6) Annual energy output in this project is simplified based on the release by NDRC that the average generating time of China’s thermal power equipments is 5294 hours.

(7) Computation is based on average trading price: 7.47 euro/ton in Nov. 2012(euro exchange rate at that time was 8.2518).

(8) Due to the dispensability for China's power plants to undertake responsibility of emission reductions, we assume CO_2 emission reduction as certified emission reduction (CER) for simplicity. In addition, we estimate annual CO_2 emissions in this paper basing on what is mentioned in reference [23] that CO_2 emissions per KWH of a 600MW coal-fired unit is 778.545g, and it gives: $CER_{co_2} = Q \times 0.000778545 = 2.473$ million tons.

(9) According to reference [24], the cost of CO_2 emission reduction in an IGCC carbon capture power plant is $20.733/t, which is present as the operating cost of CO_2 capture in this paper.

(10) In order to simply the computation of fuel cost, we take the crude coal price: ￥700/t, as the calculation basis

$$V_c = \frac{C_{fuel} \times Q \times 0.33}{10000} = \frac{0.7 \times 0.7143 \times 3176400000 \times 0.33}{100000000} = 524$$

million RMBs(Reduced factor of crude coal: 0.7143).

(11) The fixed cost of a thermal power plant is usually constant, but it is uncertain among different units. In general, it's about 50~60% of unit total generating cost, here we choose 60%, by assumption.

Calculation of initial investment value

Given a delay in investments of real options in the CCS project, we calculate its value by using the ternary-tree model with feed-in tariffs and the stability of the coal market. The price of carbon emissions is expanded based on the model in the first place, and then we calculate the investing NPVs of every node based on its price in the delay.

Calculated NPVs at different time point based on formula (9) .Find the project's investment value by means of back-stepping concerning delayed investment real options based on formula (6).

Table 2. Back-stepping of the project's investment value (Unit: 0.1bnRMBs)

Delayed investment point	1	2	3	...	10
-26.27	-7.96	27.62	97.44	...	15127.49
	-26.01	-8.45	25.54	...	7260.62
	-34.69	-25.82	-9.05	...	3474.75
		...	...	...	...
			...	...	...
					-37.29
					-37.30

From table 2, it's easy to be aware that the investment value is negative, so the delayed investment is more rational rather than investment.

Sensitivity Analysis

In this paper, a ternary-tree model of real options has been established based on the revenue model in the CCS project, in which carbon trading prices, CERs, and feed-in tariffs from the government are seriously considered. According to previous analysis, the investment and operating cost is high, while subsequent limited CERs and the price of carbon emission trade continue to fall, thereby putting IGCC power plants that invest on CCS in the dilemma of deficit under the current conditions of technology and policies. As a result, subsidies from the government and market supply of coal fuelled are playing a crucial role in investment in CCS project. That's why we focus on the impact of the fluctuation of the three crucial factors such as variation coefficient of feed-in tariffs, price of coal fuelled and CERs on investments, in other word, we consider the effect of fluctuation of the three factors on current NPVs, thereby inspect how the value of real options change with them.

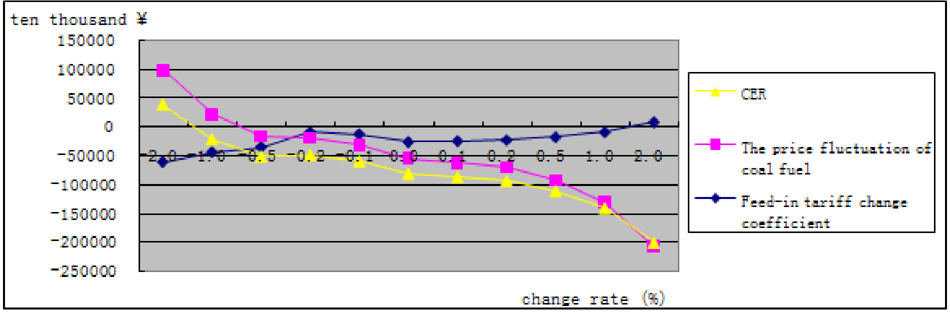

Figure 3. Impact analysis about CCS project's NPV

Table 3. Data of Sensitivity Analysis

Scaling	-2.0	-1.0	-0.5	-0.2	-0.1	0.0	0.1	0.2	0.5	1.0	2.0
Variation coefficient of feed-in tariff	-61.75	-44.64	-36.09	-10.42	-13.84	-27.53	-25.82	-24.11	-18.97	-10.42	6.69
Price fluctuation of coal fuelled	160.00	66.24	19.35	-8.78	-18.15	-27.53	-36.91	-46.28	-74.41	-121.30	-215.06
Limited CERs	-61.49	-44.51	-36.02	-30.93	-29.23	-27.53	-25.83	-24.14	-19.04	-10.55	6.43

From the figure above, we can see that the NPV of current options CCS goes up with an increasing of feed-in tariff and certified carbon emissions and falls with the increasing of coal price. In other words, tariff policy defined by the government and hard-earned certified carbon emissions are to be the crucial positive factors that determine the CCS investment, while price of coal fuelled is a negative one.

Advisement

High cost has been the biggest obstacle for application of CCS technology so far. Implementing CCS system will increase a series of costs. CCS technology can be used on a large scale only if the total cost goes down to \$25~30 per tCO_2 [25] .

Through the analysis above, crucial factors affecting CCS investment are clear, and therefore, reducing impacts of uncertainties and lowering costs are key to the massive application of CCS.

(1) The government should make related policies of emission reductions as soon as possible while at the same time establish a reasonably stable market of carbon emissions so as to raise its prices, thereby providing policy guarantee for the massive application of CCS.

Due to the high investment cost and low carbon prices, CCS can be implemented only if significant resources from the government have been obtained. In addition, financing channels should be expanded and all sorts of favorable conditions should be created.

(2) China leads the world in coal production, but the development or recycle of coal resource is far below the international level due to the serious waste of coal resources, low rate of comprehensive utilization, poor automation and low rate of raw coal washing etc, which result in the high coal prices and large market volatilities. Hence, strengthened national macro-regulation and guarantee of stable coal prices are key to promote CCS as well.

(3) An article published in United Morning Post on Dec.2012 revealed China’s coal market space is so huge that it’s capable of accommodating 0.6 billion CERs [26]. Obviously, the government should continually strive for more CERs and encouraging enterprises to make profits and reduce costs by means of lowering emissions.

(4) What’s more, there is great scope for growth in CCS per se. Statistics indicate CCS technology is expected to have a breakthrough in the next 5 years under the increasing pressure to cut emissions. It’s the most practical and feasible way that technological progresses lead to the cost reductions.

So far domestic and overseas researches on CCS’s risk decisions are in their infancy. A few macro research methods are presented in most of foreign literatures, while domestic research is still in blank stage. In this paper, the ternary-tree method of real options is applied to the decision-making of CCS, which in turn, a method of risk decision in the CCS project is presented, which provides scientific basis for CCS investment in the future.

Concluding Remark

In this paper, the CCS project is regarded as investment options by applying the theory of ternary-tree real options. Carbon trading price, feed-in tariffs and CERs etc. are mainly considered factors. Investment decision-making is verified through a scenario analysis. The calculated results indicate that there is a high risk in the implementation of CCS under the current conditions of technology, policies and carbon trading market. From the prospective of options, delayed investment is preferable.

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