

Real Options Embedded in a Solar Power Project: A Case Analysis of *AJU Energy**

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Companies in the renewable energy industry can rescue new projects, using real options model, which may be rejected otherwise in the process of capital budgeting. This paper analyzes an actual solar power project in order to evaluate whether real options can improve the project's value to the level of the acceptance point, and demonstrates how the strategic option such as the project's flexibility can be inverted to real options and added to NPV of the projects. In the course of the analysis, the estimation of the volatility implied in option value is the most technically critical step to obtain accurate option values. We estimate the volatility based on simulated future cash flows derived by the Monte Carlo simulation. The paper documents that the growth and abandonment options are marginally important to accept the project which may be rejected otherwise. Our estimation shows that the growth option value is equivalent to KRW 499.65 million (14.11% of the original PV estimate), thus turning around the value of the solar project from negative to positive value. Abandonment option and its sensitivity analysis, even if having the hypothetical assumption about volatility parameter, show practical implication on the risk controllability of long-term investment decision. It is the first case analysis conducted on solar power business, and offers interesting insight that real options can be extended to various types of projects including the Green business and the Green finance.

Key Words: Real Options, Monte Carlo Simulation, Project Financing, Green Finance, Photovoltaic, Solar Power Generation

1. Introduction

In Korea, the 2006 revision of the *Guidelines on the Standard Price of Electric Power Generation by Renewable Energy* stimulated a boom in solar power plant construction for

commercial and residential purposes. Furthermore, owing to the rapid growth of the global solar industry,¹⁾ many Korean companies in various industries have aggressively tried to enter into the industry with high expectations of new business opportunities. But they have also recognized the great difficulties in making

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1) According to the International Energy Agency (2010), the global capacity of solar power generation increased from 0.1GW in 1995 to 14GW in 2008

investment decisions due to the heavy initial investment cost and the significant uncertainties inherent in the solar business. The main objective of the study is to aid in the process of making investment decision and contribute to expanding opportunities within solar business by presenting a desirable solution, the real option value, which delineates the strategic value embedded in solar investment.

We analyze a discounted cash flow (DCF) model and a real options model using an actual business case, and present how they affect the decision to invest in the solar business. We show that an investment plan that might be turned down under the traditional DCF model can be a favorable business opportunity when the value of management flexibility is evaluated based on the real options model.

Our contribution can be summarized as follows. First, we develop the real business cases of real options model to be applicable to capital budgeting decisions with respect to the solar power business. This paper takes a first step towards analyzing such applicability, and the introduced methodology presented in this case could be extended to evaluate various investment opportunities in green businesses. Second, we demonstrate how to derive a project's volatility, which is a key factor in determining the option value. The process diagram deriving the project volatility provides a step-by-step guidance, from the collection of statistical data about solar irra-

diance to repeated runs of the Monte Carlo simulation. Third, we show by a separate case study that the abandonment option, as a put option, has great potential to develop as a new business model applicable to green finance: an option contract, between investment banks as the option writer and solar plant owners as the option holder, could realize efficient sharing of business risks inherent in the project. Finally, we carry out various sensitivity analyses, which demonstrate how the change in a macro variable, such as the market interest rate, will affect a project's value and at the same time the derived option value. The results show that adjusting the financial mix can offset changes in the option value, and eventually cause the owner of a power plant to choose only the most favorable case to increase project value.

The paper is organized as follows. In section II, we review previous articles on the real options model in renewable energy, especially the case studies of Korean papers. Section III presents two valuation models of a solar power project: the traditional DCF model and the real options model. In section IV, we introduce the actual business case of AJU Energy's and calculate the net present value (NPV) of its solar power plant as a project. Section V then shows how AJU Energy incorporates the real options model to estimate the investment opportunity, and which type of real options would be applicable. Section VI presents how to quantify the value of growth option with the emphasis on the im-

portance of the implied volatility derivation. We execute a specific program of the Monte Carlo simulation to calculate volatility. In section VII, we analyze the abandonment option, as the second case, by calculating option value, examining sensitivity analysis focused on interest rate change, and finally presenting some implication of the real option on green finance.

II. Literature Review

We begin by reviewing previous studies which applied the real options model to the renewable energy industry. Menegaki (2008) surveys the literature on valuation models of renewable energy resources and shows that not only is the real options model one of the most applicable, but that its applicability will only increase as the energy industry becomes more flexible and deregulated. Furthermore, he suggests this model as a useful tool to hedge against various risks such as fossil fuel price volatility, environmental regulation changes, demand supply, technology and market structure uncertainty. Kumbaroglu (2008) uses a dynamic programming formulation to apply the real options model to the power generation of renewable energy. He focuses

on learning curves and the rapid development of technologies, and proves that the flexibility to delay an irreversible investment has a profound effect on the diffusion prospects of renewable power generation technologies. Yang (2008) analyzes the effects of uncertainty about government climate policy on the decision making of private investors in the power sector, especially those involving fossil fuel and CO₂ price variations, and uses the real options model with a dynamic programming approach to quantify the impacts of uncertainty about climate change policy on power investment. Ansar (2008), considering the energy paradox,²⁾ analyzes why many households and firms delay investment decisions on renewable energy or energy savings. He proves the energy paradox by using a geometric Brownian movement and presents the simulation results from the case of the option to defer.

Next, we review previous papers published in Korea, which applied the real options model to capital budgeting decisions. Many of these studies focus mainly on case analyses in relation to IT and R&D projects. However, analysis of the real options model in relation to energy-related projects is scarce. Specifically, this dearth of studies in the power generation industry can be explained by the current status of the Korean power industry,³⁾ which

2) Households and firms are inclined to require very high rates of expected returns with regard to energy investment.

3) In the power grid network, the market is monopolized by the Korea Electric Power Corporation (KEPCO) and its child companies in the area of power distribution and generation: the selling price of electricity is determined using the cost plus approach with government guidelines.

lacks sufficient incentive to stimulate investment by the private sector. Yoon (2003) proves that the real options model fits the feasibility analysis of investments in the Korean energy industry better than the traditional NPV. He summarizes the reasons as follows: 1) high levels of uncertainty inherent in the energy industry because of the high price volatility of imported fossil fuels; 2) the existence of various uncontrollable variables such as the economy, climate change, and so on; and 3) characteristics of the energy industry that require intensive capital, high initial irreversible investment, and high operating and maintenance costs caused by high fossil fuel costs. Using a case analysis of a co-generation power plant, he compares the project value, including the value of the derived option, with the traditional NPV, and determines whether the implied option value exists or not. This paper is the first research in Korea to apply the real options model to power generation projects. But in the case analysis, volatility is based on a simple assumption without sufficient explanation of the calculation procedures and methods. Sung (2004) criticizes that prior studies and case studies in Korea lack sufficient explanation on how volatilities are generated under which assumptions and by which methods. In his paper, he demonstrates that

volatility is generated from the cash flow of a project using the Monte Carlo simulation, and analyzes the real options model with simple business cases of technology investment in R&D. Yoon (2006) applies the real options model to a case analysis of investment in two nuclear power plants in Korea. Adopting the Black-Scholes model, the paper uses the standard deviation of electricity price changes as the volatility of the project value.⁴⁾

III. Valuation Models of a Solar Power Project⁵⁾

3.1 The DCF Model for Solar Power Generation

Equation (1) shows how to calculate the NPV of a solar power project.

NPV = Present value of (revenue from power generation + salvage value of solar plant) - Present value of (capital expenditure including net working capital + total cost including corporate tax)

$$= \sum_{t=0}^n \frac{\{P_t + \frac{Q_t}{(1+DEG)^t} + SALV_n\}}{(1+r)^t} - \sum_{t=0}^n \frac{\{I_t + \Delta NWC_t + OM_t + [P_t + \frac{Q_t}{(1+DEG)^t} - OM_t - DEP_t]R_{tax}\}}{(1+r)^t} \quad (1)$$

4) Project volatility should be obtained by estimating future cash flows of the power plant, because the electricity price is an input variable (input value) and does not sufficiently explain all value changes in the underlying asset.

5) Solar power means electric power generation using photovoltaics (we use this to mean the same as solar power in this paper), which is a method of converting solar radiation into direct current electricity using semi-conductors that exhibit the photovoltaic effect.

where

- P_t = Selling price of generated electricity in period t
 Q_t = Quantity of power generation in period t
 DEG = Degradation ratio of plant equipment
 $SALV_n$ = Salvage value of solar plant at end of period n , which includes NWC_n
 I_t = Investment in period t
 ΔNWC_t = Change in net working capital (NWC) in period t
 OM_t = Operation and maintenance costs in period t
 DEP_t = Depreciation of plant equipment in period t
 R_{tax} = Corporate tax rate
 r = Discount rate (WACC to the project)

The major characteristics of solar power are 1) low operation and maintenance costs⁶⁾ because it consumes no fuel to generate electricity, using only solar energy; and 2) degradation of solar equipment such that the efficiency of converting sunlight to electricity gradually declines for the economically durable periods of the solar module.

3.2 Real Options Model Applicable to the Solar Power Plant Projects

The difference between the DCF model and real options model lies on whether to introduce the respective probabilities of occurrence obtained through the discrete simulation process. The expanded NPV is the sum of 1) the NPV of the deterministic part, and 2) the strategic option value, which takes into account the value of flexibility. The real option has a certain value of hedging the downside risk and capitalizing on the upside uncertainty. Even though real options are not an explicit right as financial options are in determining beforehand the conditions of when and how much to buy or sell the underlying assets, both options do share similarities: no loss occurs, even if the right is not executed.⁷⁾ Table 1 compares the key variables in the two models.

Black and Scholes (1973) show that the rate of returns, or of value changes, in the

(Table 1) Comparison of Financial and Real Options

Financial options	Variable	Real options
Exercise price	K	Investment in photovoltaic project
Stock price (current)	S	Present value of future cash flows in project
Time to expiration	T	Time to expiration of options
Standard deviation of stock returns	σ	Standard deviation of natural logarithm of cash flow returns change (volatility of project)
Risk-free rate	r_f	Risk-free rate

6) The economic value of a conventional power plant using coal and gas depends heavily on fluctuations in the fuel price. Not consuming such fuels is a major reason to prefer renewable energy.

7) Sonu (2004), p. 222.

underlying asset can be expressed by the geometric Brownian motion, as in equation (2):

$$\frac{\delta S}{S} = \mu(\delta t) + \sigma \epsilon \sqrt{\delta t} \quad (2)$$

In (2), μ is the average growth rate of the underlying asset and ϵ is the probabilistic errors in the simulated value from the normal distribution $N(0,1)$. That is, $\mu(\delta t)$ is the deterministic part, in the estimated future cash flow, to explain the slope or the average growth rate of the Brownian process for the time between steps, and $\sigma \epsilon \sqrt{\delta t}$ is the stochastic part of the model, which has a volatility component (σ), a time component (δt), and a simulated component (ϵ), to explain the fluctuation around the slope.

Copeland and Antikarov (2001) note that the seven assumptions embedded in the Black-Scholes model turn into practical limitations on the real option analysis, which requires relaxing one or more of the assumptions.⁸⁾ This is a reason we choose a binomial model for case analysis in this paper. In a binomial model, the change in the underlying asset has the exponential Brownian motion as in equation (3).

$$\begin{aligned} \frac{\delta S}{S} &= e^{[\mu(\delta t) + \sigma \epsilon \sqrt{\delta t}]} \\ &= e^{\mu(\delta t)} \times e^{\sigma \epsilon \sqrt{\delta t}} = e^{\mu(\delta t)} \times e^{\sigma \sqrt{\delta t}} \quad (3) \end{aligned}$$

A binomial approach is a discrete simulation model and no longer requires re-simulation for every time period. The simulated variable (ϵ) can be discarded, because the ϵ is already accounted for when using a binomial approach. In the remaining stochastic part ($e^{\sigma \sqrt{\delta t}}$), the up-step size (u) and down-step size (d) are calculated as in equations (4) and (5).

$$u = e^{\sigma \sqrt{\delta t}} \quad (4)$$

$$d = \frac{1}{u} = e^{-\sigma \sqrt{\delta t}} \quad (5)$$

These are the up-down equations that form the step size of a discrete simulation in a binomial lattice and explain how much the size goes up or down. Another important equation is that for risk neutral probability, which evaluates a lattice through backward induction. Equation (6) shows upward probability p and downward probability q .⁹⁾

$$p = \frac{e^{r_f(\delta t)} - d}{u - d} \quad (6)$$

Under the assumption of j times up and $n-j$ times down in the n times lattice steps with time to expiration T , the value of call option C in a binomial model can be calculated as in equation (7).

$$C = \left\{ \sum_{j=0}^n \binom{n}{j} p^j (1-p)^{n-j} \text{MAX}[S(u^j d^{n-j}) - K, 0] \right\} e^{-r_f(\delta t)n} \quad (7)$$

8) Copeland and Antikarov (2001), p. 106.
 9) Downward probability q is defined as $(1 - p)$.

S is the present value of the solar plant as the underlying asset, and K is the capital expenditure that can be executed during the option period. r_f is the risk-free rate, which uses the interest rate of the government bond during the same period. The standard deviation in the rate of return of the underlying asset is defined as volatility σ . Equations (8) and (9) show how to calculate the value changes in the project in period t (w_t) and the standard deviation (σ) as volatility.

$$w_t = \ln \left[\frac{\sum PV(CF_{t+1})}{\sum PV(CF_t)} \right] \tag{8}$$

$$\sigma = \sqrt{\frac{1}{(n-1)} \sum (w_t - \bar{w})^2} \tag{9}$$

The changes in project value over time decrease, because projects are not replicable and they have finite lives. That is, because the solar modules, which are major materials composing the solar power plant, have a finite durable period, the plant's value must decrease as the remaining useful life also decreases. In the real options model, such a decreasing effect can be regarded the same as the payout of a dividend. Therefore, the

assumption of the annual diminishing rate of capacity (div) being a fixed rate¹¹⁾ can modify equation (6) into equation (10).

$$p = \frac{e^{(r_f - \text{div})\delta t} - d}{u - d} \tag{10}$$

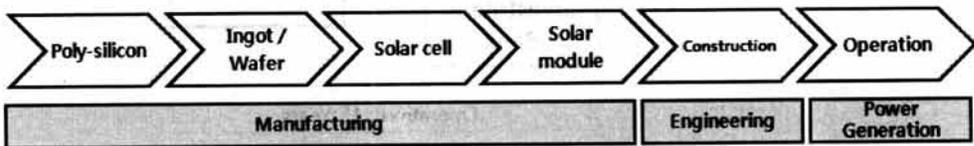
where
 $\text{div} = 1 / F$

IV. Estimating Net Present Value of the *AJU Energy's* Project

4.1 Background of the *AJU Energy's* Project

AJU LNF Group (called "*AJU*" hereafter), whose main businesses are rental, retail, and finance, discovers a new business opportunity from the solar business in the photovoltaic industry, and is examining whether investing in the photovoltaic business would be economically feasible.

The original plan is to enter into the solar manufacturing area (solar cells and solar modules), as described in Figure 1, but the company finds that an initially irreversible



<Figure 1> Value Chain in the Photovoltaic

11) Fixed rate means the same rate for every period during the economically durable periods of the project (F). Solar module manufacturers usually have a 20-year warranty policy.

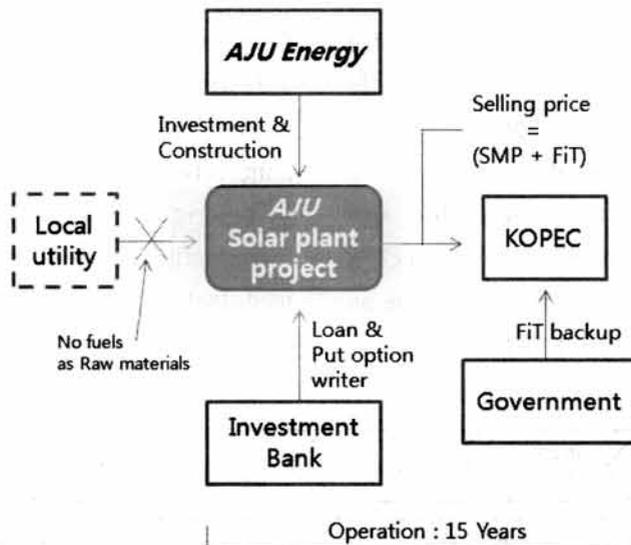
heavy investment is required with high level of uncertainty. Alternatively, AJU has an option to join in the solar business from the downstream of the value chain, namely engineering, construction, and power generation, which requires less initial investment, and in addition government support under the Feed-in Tariffs (FIT) system can also be expected.¹¹⁾ AJU decides to defer the timing of the investment in solar manufacturing for a couple of years in order to make a better decision with more knowledge and experience, which can be collected from operating a solar power business.

AJU has decided to construct its own solar plant with project financing from an investment bank and start the operation to sell

the electricity to the Korea Power Engineering Company (KOPEC) for the entire period applied for under the FIT system, as shown in Figure 2.

4.2 Basic Information about the AJU Solar Plant

AJU bought the building site for the solar plant at Naju in 2007, obtained the operating license to engage in the solar power business from the regional government of JeollaNamdo, and in 2008 started operating the solar power plant with 500kWp capacity and KRW 677.38/kWh, which is the fixed selling price applied to the total operating period of 15 years under the FIT system, as shown in Table 2.



<Figure 2> Operation Scheme of AJU Solar Plant Project

11) FIT is the incentive system guaranteeing that the selling price of generated electric power will be a fixed price, which is the most critical factor in stimulating the solar power business. See appendix 1 for more detailed information.

(Table 2) Basic Information: the *AJU* Solar Plant

	Basic information	Description
Location of plant	Naju-Si, JeollaNamdo in Korea	
Preparation and construction periods	-Nov 2007: Purchase of plant site (land) -Feb 2008: Acquisition of business permission -Feb-May 2008: Construction	Total expenditure: KRW 40 million (7 million for land & permission and 33 million for solar plant equipment)
Operation periods	Started operation in June 2008 for 15-year operation (will decide whether to continue operation at end of the 16-year period - T_{16})	Depreciation for 15 years even if economically useful life is expected to be 20 years.
Capacity of power generation per hour	500 kWp	Hourly generation under standard test conditions (STC) ¹²⁾
Selling price of generated electric power	KRW 677.38/kWh	Fixed during the whole operating period (T_2 - T_{16})
Solar panels	162W per panel (total 3,086 panels)	Sharp (Japan)
Inverter (PCS)	250kWp capacity * 2ea	Xantrax (Canada)

4.3 NPV Estimation of the *AJU* Solar Plant Project

In applying the FIT system, annual revenue from selling the harvested power turns out to be affected only by the quantity of power generation, which depends on the weather conditions. That is, solar revenue is determined by solar irradiation, such as daily generation hours, as follows:

Annual sales = Selling price (fixed) *
Quantity of total generation (variable)

Quantity of total generation = Capacity (fixed, kWp) * Averaged daily generation hour (kWh/m²/day) * 365 days

We assume a construction period of 1 year

(T_1), and total operating period of 15 years (T_2 - T_{16}), which are the same periods as under the FIT system. Table 3 shows the basic assumptions concerning cash flow and time value.

NPV at period T_1 is estimated by equation (1), as shown in Table 4.

The estimated present value of the *AJU* solar plant project in period 1 is KRW 3,541 million. After deducting investment amount of KRW 4,000 million, the net present value (NPV) of the project is KRW -459 million. A negative NPV calculated by the traditional DCF model rejects the acceptance of the investment opportunity.

12) STC: the standard conditions for measuring the output of solar equipment -solar radiation 1kW/m², spectrum air-mass 1.5, and normal temperature (25°C).

〈Table 3〉 Basic Assumptions Concerning Discounted Cash Flow

Variable	Description
Total period (T)	Total 16 years: T ₁ (construction), T ₂ ~T ₁₆ (operation)
Selling price (P _t)	Fixed to KRW 677.38/kWh for entire operation period
Quantity of power generation (Q _t)	500kWp * 3.7 kWh/m ² /day ¹³⁾ * 365 days: forecasting daily generation hour based on historical data of solar irradiation at Kwangju.
Degradation ratio (DEG)	Annual 0.5% decrease in performance of power generation
Salvage value (SALV _n)	1) Equipment: 10% of the initial value (KRW 33 million) 2) Land: nominal value at the end of T ₁₆ with inflation rate
Investment (I _t)	Assume only the initial capital expenditure (KRW 33 million)
Change in net working capital (ΔNWC _t)	The harvested electricity cannot be stored as inventory, and there is no account receivable, because monthly revenue is paid automatically by KOPEC. Thus, we assume no ΔNWC.
Operation and maintenance costs (OM _t)	Monitoring cost (remote), insurance, and periodic maintenance cost: assume OM ₂ to be 1% of the initial investment, which appreciates annually with the inflation rate.
Corporate tax rate (R _{tax})	27.5% with inclusion of surcharge tax
Discount rate (r)	Annual 7.8% (WACC to the project): debt financing (32 million * 6%) and equity financing (8 million * 15%)
Depreciation (DEP _t)	Straight-line method for 15 years (useful life) without residual value
Inflation rate	Annual 3%

〈Table 4〉 NPV Estimation of AJU Solar Plant Project (Unit: KRW 1 million)

	T ₁	T ₂	T ₃	T ₄	T ₅	...	T ₁₄	T ₁₅	T ₁₆	
Annual sales		457	455	453	451	...	430	428	425	
(kWh) Generation		675,250	671,874	668,498	665,121	...	634,735	631,359	627,983	
(Won) Selling price		677	677	677	677	...	677	677	677	
Total cost		253	254	255	256	...	267	268	270	
Depreciation		220	220	220	220	...	220	220	220	
O&M costs		33	34	35	36	...	47	48	50	
Operating income (OI)		204	201	198	194	...	163	159	155	
OI * (1-tax rate)		148	146	143	141	...	118	115	113	
(+) Depreciation		220	220	220	220	...	220	220	220	
Operating cash flow		368	366	363	361	...	338	335	333	
Salvage value						...			1,453	
Discount rate (7.8%)		WACC(7.8%) = 3,200 * 6%(R _D) + 800 * 15%(R _E)								
Present value (annual)		342	315	290	267	...	127	117	579	
Investment	-4,000	Land (700) + Plant (3,300)								
Net present value	-459	Internal rate of returns				6.1%				

13) Daily averaged generation is estimated using the historical data of the annual average (3.7 kWh/ m²/day).

V. Real Options Applicable to *AJU* Solar Plant Project

However, *AJU* would like to consider an alternative valuation model which takes into account the hidden value inherent in the project, namely, the value of management flexibility. The most suitable tool for evaluating the embedded value, which reduces future uncertainty and changes uncertainty into an opportunity, is the real options model. *AJU* selects two options among the various types of real options, according to the measurability and the size of the impact, as noted in Table 5. The other options such as the defer option, switching option are first considered but eliminated from the consideration at last due to their weak enhancement effects on the value of the project. (see <Table 5>)

Figure 3 shows the procedure on how the two options are applied in the course of pro-

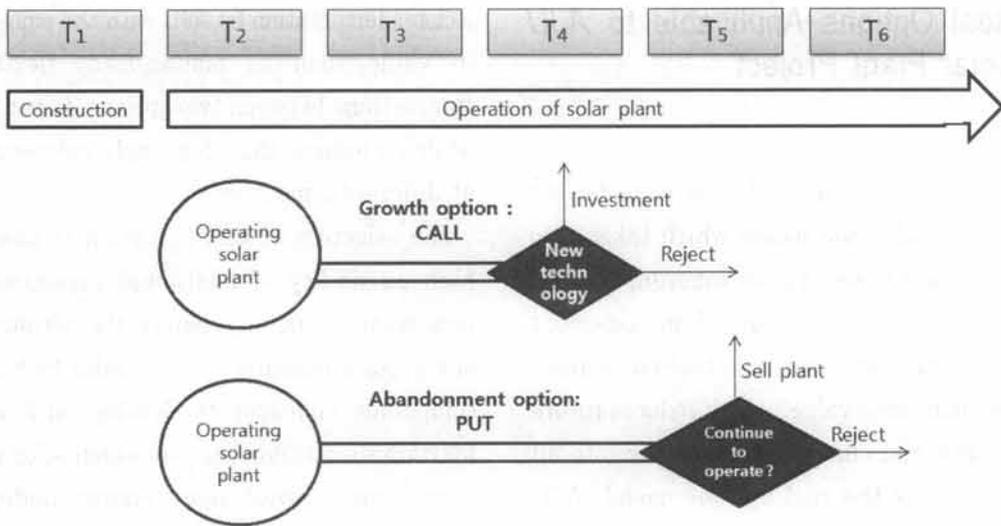
ject implementation by *AJU* with the embedded-in value such as management flexibility. Interactions between two options do not exist, while we assume that they apply independently at different time frames.

The selection of growth option is based on high possibility of additional investment in new solar technology before the termination of the plant operation. Many solar technology companies endeavor to develop such power maximization technology, by which solar power plants can harvest more energy under the same natural conditions as solar radiation. *AJU* concludes that it would be worthwhile to incorporate the possibility of new technology into the value of the solar plant as an option. This could serve as the example of the growth option, which is a right to make an additional investment in the future in order to achieve higher enhancement or productivity. Execution of the future investment is not an obligation but an option for the company. The company

<Table 5> List of Real Options Considered in Respect of the Value Enhancement¹⁴⁾

Real options	Accept	Impact	Remarks
Growth	O	Strong (on project value)	Early investment as a prerequisite to step into new business (solar), and open up future growth opportunities
Abandonment	O	Moderate (on green finance)	Existence of a contract to realize the resale value of the plant project, optionally at the time of poor operation.
Defer	X	Weak	Less time to defer the investment to be a government backup solar plant (applicable to FIT system)
Switching	X	Minimal	No flexibility to change input, throughput, or output mix (manufacturing business is more proper to apply.)

14) See pp.204 (Trigeorgis L., Real options and interactions with financial flexibility, 1993) for detail of each option. Although the quantitative calculation of each option is not thoroughly carried out, the qualitative measurements are used for this decision.



〈Figure 3〉 AJU’s Options in the Solar Power Business

estimates the future possible payoffs, comparing the additional benefits with the additional costs, and calculates the option value by backward induction with risk-neutral probabilities and the discount of future payoffs with a risk-free rate. The value of the growth option to invest in new technology at the beginning of T4, 2 years later on T2, is calculated by equation (11), which is modified from equation (7).

$$\text{Growth option value} = \left\{ \sum_{j=0}^n \binom{n}{j} p^j (1-p)^{n-j} \text{MAX}[S(u^j d^{n-j}) \text{ENHANCE} - K, 0] \right\} e^{-r_f(\delta t)n} \quad (11)$$

On the other hand, the abandonment option is chosen by AJU, because it provides perfect protection against the loss caused by poor performance, a right to sell at the predeter-

mined limit value. AJU finances the total investment amount of KRW 4 billion, which is composed of KRW 800 million from equity capital and KRW 3.2 billion from debt capital of investment banks by project financing contract. AJU’s agreement with the investment banks is incorporated as a put option into the terms and conditions within the loan contract. The option that the power plant owner holds is a right to sell the solar plant at a certain time in the future at a predetermined price, which enables the owner to reduce the absolute level of business uncertainty.¹⁵⁾ This is the example of the abandonment option, and we include it to this case analysis. Risk reduction by utilizing the option and effective management of the under-performed power plants after the exercise of the option can help to promote the green business and green

15) Of course, it is possible, even probable, that the moral hazard problem would exist during the contract.

finance. The option which AJU can sell its solar plant to the investment bank is assumed to be executable at the beginning of T_5 , 3 years later from the start of the operation. We calculate the value of the abandonment option from equation (12), which is modified from equation (7). AJU can thus sell its power plant if the estimated future value of the plant decreases less than the predetermined selling price on the option contract.

Abandonment option value =

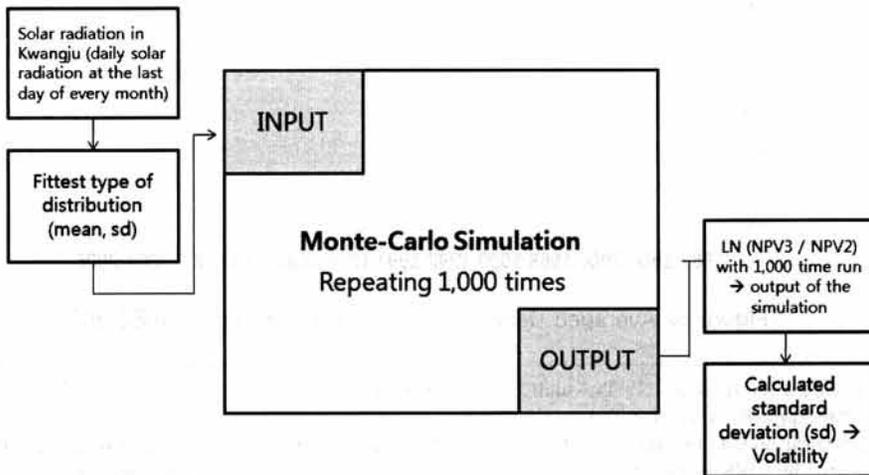
$$\left\{ \sum_{j=0}^n \binom{n}{j} p^j (1-p)^{n-j} \right. \\ \left. \text{MAX}[K - S(u^j d^{n-j}), 0] \right\} e^{-r_f(\delta t)n} \quad (12)$$

We use Real Options SLS and the Risk Simulator¹⁶⁾ to calculate the option value and run the Monte Carlo simulation in this paper.

VI. Growth Option and the Monte Carlo Simulation

6.1 Calculating the Volatility of the Solar Plant

In the case analysis of real options model, the most technically challenging and critical area is the estimation of the volatility implied in option value. We obtain it from the simulated future cash flows derived by the Monte Carlo simulation. As Figure 4 shows, we repeatedly calculate the natural logarithms of the expected rate of returns on the business plan using a Monte Carlo simulation, and finally calculate the standard deviation of the probability distribution of the natural logarithms as the project volatility. Daily generation is defined as the INPUT value of the Monte Carlo simulation, and the generated



<Figure 4> Process Diagram in Monte Carlo Simulation and Volatility Calculation

16) This software is supplied by Real Option Valuation (www.realoptionsvaluation.com).

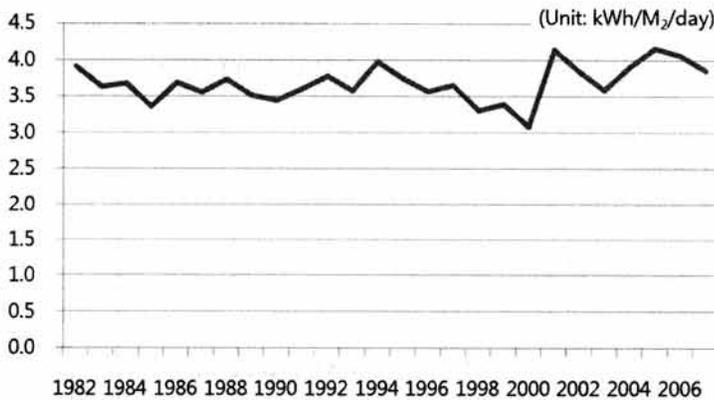
OUTPUT value is defined as $\left(\frac{NPV_3}{NPV_2}\right)$, where $NPV_2^{17)}$ in period 2 is a fixed value unchanged regardless of the simulation, and NPV_3 in the adjacent period 3 is changed by every simulation result during the 1,000 runs.

First, we collect the regional historical data on solar radiation to define the probability distribution of daily generation, which is the input value in the simulation procedure in Figure 4. The statistical data on the daily solar radiation at the last day of every month¹⁸⁾ are for Kwangju-Si¹⁹⁾ from 1982 to 2007. To smooth out the high deviations in monthly solar radiation, we use the averaged daily radiation data per year²⁰⁾ in Figure 5 as the input factor of the simulation.

We run a statistical program in the Risk Simulator to find the statistical distribution that best fits these daily solar radiation data from 1982 to 2007, and select a lognormal distribution (mean: 3.7, sigma: 0.26), as shown in Figure 6, as the best fitting probability distribution.

To execute the Monte Carlo simulation, we define the selected lognormal distribution of daily solar radiation as the INPUT assumption of solar generation, and $LN\left(\frac{NPV_3}{NPV_2}\right)^{21}$ as the OUTPUT forecast. Table 6 shows the profile of the simulation run.

Figure 7 shows the results of 1,000 repeated simulations by the Monte Carlo simulation program.

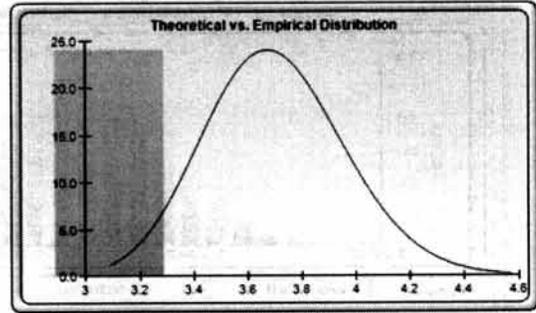


<Figure 5> Averaged Daily Solar Radiation in Kwangju 1982-2007

17) NPV_2 is calculated for 15 years (T_2-T_{16}) under the FIT system, while NPV_3 is calculated for 14 years, from the year after T_2 to the expiration year (T_3-T_{16}).
 18) This is horizontal global insolation (unit: kWh/m²/day) sourced from the Renewable Energy Resource Map Data Center operated by KIER (http://kredc.kier.re.kr/kier/03_dataEnquiry/solar_measure_tab01.aspx).
 19) We use the data from Kwangju because it located nearest to Naju (statistical data for Naju-Si is not available).
 20) Because of high seasonal differences, we use "the averaged daily data per year" to give greater meaning for the analysis. (The equation is $\sum_{t=1}^{12} \frac{\text{Daily solar radiation data of the last day at month } t}{12}$).
 21) Mun (2002), p. 200.

Statistical Summary

Fitted Assumption	3.69	
Fitted Distribution Lognormal		
Mean	3.70	
Sigma	0.26	
Kolmogorov-Smirnov Statsbc	0.08	
P-Value for Test Statsbc	0.9964	
	Actual	Theoretical
Mean	3.69	3.70
Standard Deviation	0.26	0.26
Skewness	-0.08	0.21
Excess Kurtosis	0.03	0.08



(Figure 6) Selection of the Best Fitting Probability Distribution

(Table 6) Profile in the Monte Carlo Simulation

(Unit: KRW 1 million)	Construction		Operation periods (15 years under FIT system)						
	T ₁	T ₂	T ₃	T ₄	T ₅	...	T ₁₄	T ₁₅	T ₁₆
Cash inflow (Power Sales)						...			
T ₂ ~ T ₁₆		368	366	363	361	...	338	335	1,786
T ₃ ~ T ₁₆			366	363	361	...	338	335	1,786
NPV2: NPV (T ₂ ~ T ₁₆) at T ₁ (Fixed)									3,541
NPV3: NPV (T ₃ ~ T ₁₆) at T ₁ (Simulated)									Simulated value
						LN (NPV3/NPV2)			-0.1014253

The estimated volatility (σ) is 5.3%, which results in a relatively small value. This shows that revenue can be reliably forecast over the operation period without critical bias from the business plan, since the selling price is guaranteed for the entire 15-year period by the FIT system.

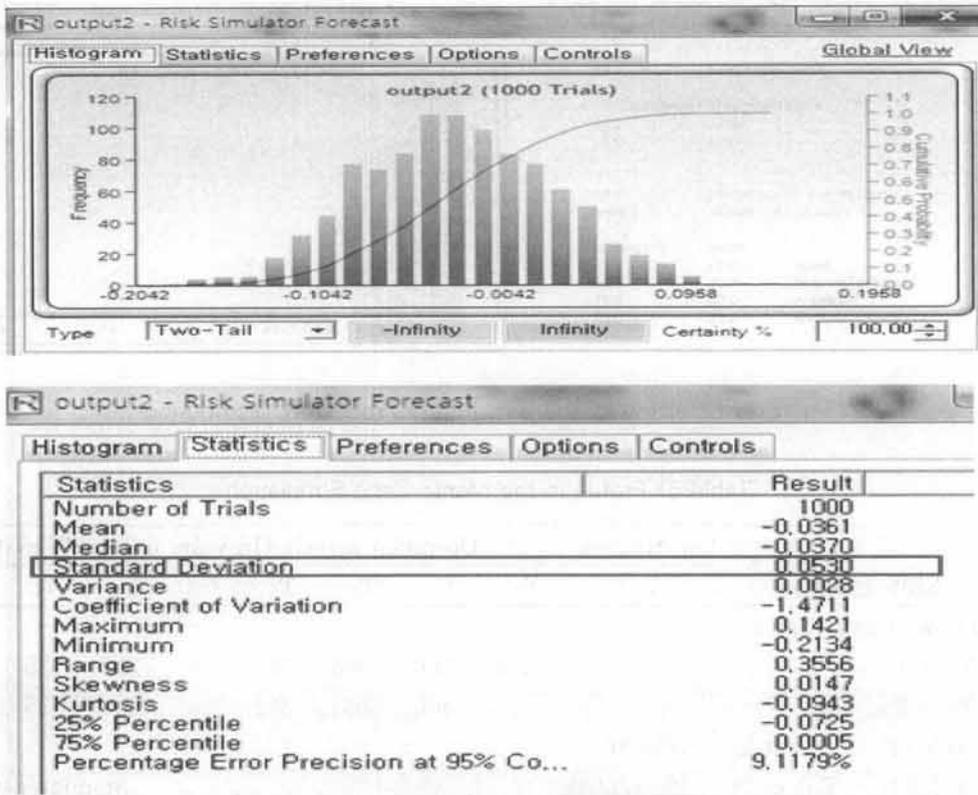
6.2 Calculating the Value of Growth Option

AJU quantifies the growth option as a real option to invest in the new technology (KRW

500 million) at T₄, 2 years later, rather than from the start of the operation (T₂), as in Table 7. Executing the growth option (T₄) is assumed to add 30% (ENHANCE)²²⁾ to the value of the power plant as an underlying asset.

The value of the growth option to invest in new technology at the beginning of T₄, 2 years later on T₂, is calculated by equation (11). We assume the basic input data as follows: S as the present value of the underlying asset at T₁ is 3,541; σ is 0.053; T as

22) The solar technology of power maximization is being developed by many solar technology companies; we assume 30% more energy based on realizing expectations in the near future.



<Figure 7> Volatility (Standard Deviation) after Simulations

<Table 7> Investment Plan for the New Technology (Power Maximization)

(Unit: 1 million KRW)

	T ₁	T ₂	T ₃	T ₄
Present value of future operating cash inflow (PV at T ₁)	3,541			
Initial investment in power plant	4,000			
NPV of solar business	-459			
Additional investment (K) at T ₄ , expecting a 30% increase in plant value				-500

time to expire is 2, meaning that the execution of the option at T₄, r_f is 4%²³⁾; and K as the additional investment is 500. We build a binomial lattice model at each step of 0.2

years, which n is 10, that are a total of 10 lattices, and δt is 0.2. Because the power plant has a finite life to operate, we incorporate the fixed rate of the diminishing

23) According to data disclosed in August 2010 by KOFIA, the 3~5-year KTB yield rate is 3.98%, and over 10 years it is 4.6%. In this thesis, 4% is assumed to be the risk-free rate.

value (div) into the calculation, as in equation (10). The div²⁴ is 5% equally divided into 20 years, which is the economically durable period of a solar plant. We then calculate upsize (u) and downsize (d) by equations (4) and (5) as follows:

$$u = e^{0.053 * \sqrt{0.2}} = 1.0240$$

$$d = 1/1.0240 = 0.9766$$

We further calculate upward probability (p) and downward probability (q) with div, using equation (10):

$$p = \frac{e^{(0.04 - 0.05) * 0.2} - 0.9766}{1.024 - 0.9766} = 0.4519$$

$$q = 1 - 0.4519 = 0.5481$$

We then can determine future possible outcomes based on the calculated value of the variables. By rolling back to the prior lattices through multiplying risk-neutral probabilities using the backward induction calculation, we calculate the option value at T₁, the beginning of period 1, to be 499.65, as shown in Table 8.²⁵

When we take the calculated option value into account, the present value of the underlying asset is converted from a negative KRW 459 million to a positive KRW 41 million. Therefore, given that the real option has such a strategic value, investment in the solar power business should be accepted. This proves that strategic and flexible business

<Table 8> Valuation of Growth Option (Unit: 1 million KRW)

Assumption	Intermediate computations		
PV of solar plant (S)	3,541	Stepping time (δt)	0.2000
Additional investment cost (K)	500	Up size (u)	1.0240
Enhancement factor (ENHANCE)	30%	Down size (d)	0.9766
Maturity (T) (years)	2	Risk-neutral probability (p)	0.4519
Risk-free rate (r _f) (%)	4.00%		
Fixed rate of diminishing value (div)	5.00%	RESULT	
Volatility (σ) (%)	5.30%	Option value	499.65
Lattice steps (n)	10	(14.11% of the original present value)	
Option type	European		
Equation of objective function	Max [FV(S)*ENHANCE - K, 0]		

Original NPV at T ₁	=	-459
(+) Growth option	(+)	499.65
e-NPV at T ₁ , including the value of growth option	=	41

24) When the div is included in the estimation, the upward probability p must be decreased, because the div affects how much the risk-neutral growth rate is decreased.

25) See appendix 2 for the numerical value of each lattice in detail.

options enable managers to make more rational decisions. Therefore, real options can be used as a more accurate evaluation tool as it incorporates the value of various options which are not considered in traditional valuation models.

VII. Abandonment Option and the Sensitivity Analysis

7.1 Calculating the Value of Abandonment

When the calculated volatility of solar power generation is 5.3%, the probability of executing the abandonment option occurs too seldom in the case of AJU. Abandonment option exemplifies the real options model in AJU case as Table 5, even though the actual coefficient of volatility is not sufficient for

the execution of the option. Therefore, instead we hypothetically assume 40% to be the volatility for case analysis of the abandonment option.

The assumption of the put option is that AJU can sell its solar plant to the investment bank at the beginning of T_5 at the pre-determined price of KRW 2.112 billion, which is 80% of the depreciated book value of plant equipment at T_5 .²⁶⁾ It is assumed the option will be executed 3 years later, which is the beginning of T_5 , because the solar plant starts operating at T_2 . We assume the basic input data as follows: S is 3,541, σ is 0.4, T is 3, r_f is 4%, and K as the predetermined selling price of solar plant is 2,112. A binomial lattices model with nine steps is built up for this abandonment option. Each step is assumed to last every 4 months, and δt is 0.33, which divides the time to expiration of 3 years into 9 lattices. The fixed

〈Table 9〉 Valuation of the Abandonment Option(Unit: 1 million KRW)

Assumption	Intermediate computations		
PV of solar plant (S)	3,541	Stepping time (δt)	0.3333
Predetermined selling price (K)	2,112	Up size (u)	1.2598
Maturity (T) (years)	3	Down size (d)	0.7938
Risk-free rate (r_f) (%)	4.00%	Risk-neutral probability (p)	0.4354
Fixed rate of diminishing value (div)	5.00%		
Volatility (σ) (%)	40.00%	RESULT	
Lattice steps (n)	9	Option value	237.4
Option type	European	(6.7% of the original present value)	
Equation of objective function	Max [K - FV(S), 0]		

26) $2,112 = 3,300 * (12/15) * 0.8$: We assume that a 20% discount of the plant value would be sufficient to exercise from the option writer's (investment bank's) point of view.

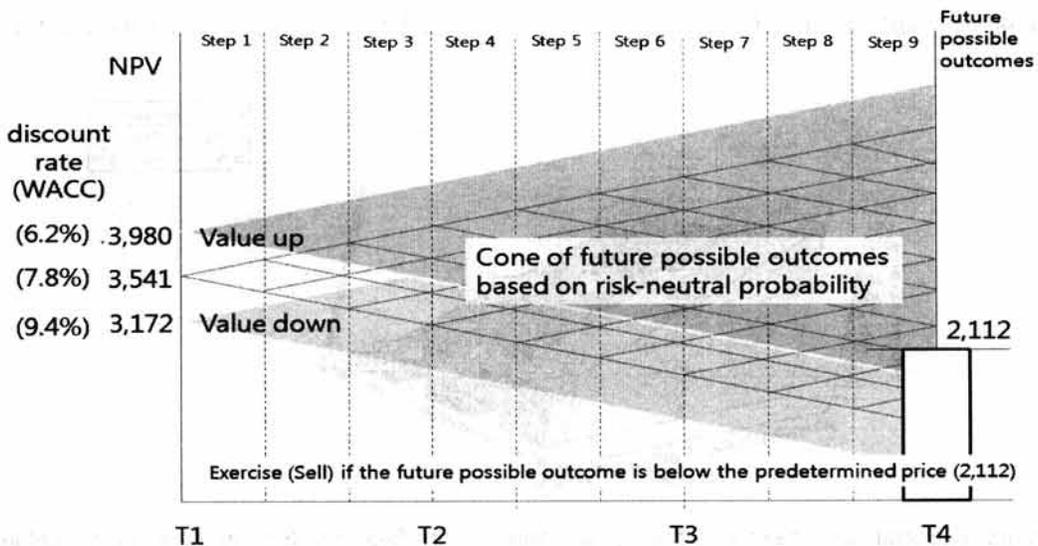
rate of diminishing value (div) is 5%. We calculate the value of the abandonment option from equation (12).

As shown in Table 9, the calculated option value is KRW 237.4 million.²⁷⁾ AJU as the option holder can add the value of management flexibility to the traditional NPV of the power plant.

7.2 Sensitivity Analysis and Optimal Financial Mix

The put option protects the project owner against exposure to market risk, such as fluctuations in interest rates as well as its own business risks incurred from operating the solar plant. Expected future cash flows incurred from the latter are similar to the cash flows generated from long-term bonds

as security. Changes in market variables such as interest rates may significantly influence project value; an increase (decrease) in market interest rates will cause the solar plant value to decrease (increase). Figure 8 shows that the put option can protect against such a critical risk so that the value of the solar plant will decrease less than the minimum level, namely, the predetermined selling price of the solar plant. We set an assumption that if the market rate goes up or down 2%, the cost of debt as the borrowing rate will change from 6% to 8% or 4%, respectively. Because of the original financial mix, the discount rate by WACC will then change from 7.8% to 9.4% or 6.2%, respectively, and the project value will then change from 3,541 to 3,172 or 3,980, respectively, using the DCF model. The risk-



(Figure 8) Market Risk and Abandonment Option

27) See appendix 3 for the numerical value of each lattice in detail.

neutral probability (p) builds up the lattices with the structure of future possible outcomes in the shape of a cone, which can be shifted upward (decrease in discount rate) or downward (increase in discount rate). Even though the possible lattice shifts downward in the event the value of the solar plant decreases by the increase in the discount rate, the exercise price (the predetermined selling price of the solar plant) of 2,112 could protect the plant value against such an undesirable situation that the probable outcomes would decrease less than the minimum level.

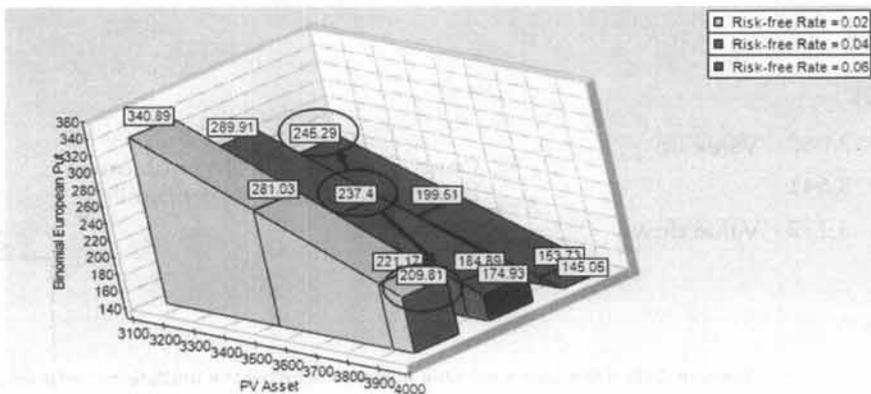
Next, to proceed further with the sensitivity analysis, we extend the fluctuation in the interest rate to the different case of changes in the risk-free rate. In the same European model of the abandonment option, we present how much the change in the risk-free rate from 4% to 2% or 6% affect the option value, based on the change in NPV (S), namely,

3,172/3,980. The option value 237.4 at the 6% borrowing rate and 4% risk-free rate shifts to 245.29 at the 8% borrowing rate and 6% risk-free rate, or to 209.81 at the 4% borrowing rate and 2% risk-free rate, as shown in Figure 9.

The change in market rate affects both the borrowing rate of the project finance and the risk-free rate. Figure 10 presents the cause-and-effect relationship to explain how the change in a market variable such as the interest rate affects the option value. An interesting finding is that the abandonment option can create a hedging effect to offset the changes by which the project value (S) and the risk-free rate (r_f) both affect the option value.

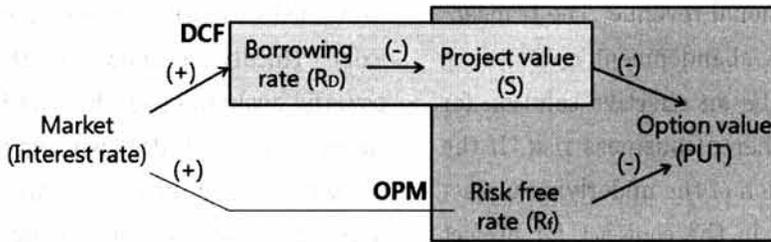
Table 10 shows a sensitivity analysis to present the offset effects in this case.

Furthermore, the power plant owner could take a hedging position²⁸⁾ by adjusting the financial mix of equity and debt capital, as



<Figure 9> Sensitivity Analysis of the Option Value by the Risk-free Rate and the Project value

28) This means that the option value is not affected by the change in market rate if the project owner can freely change the financial mix.



〈Figure 10〉 Effects of Market Interest Rate on the Value of the Abandonment Option

〈Table 10〉 Offset Value of the Option

Market rate (Δ)	Δ Option value by Δ risk-free rate	Δ Option value by Δ borrowing rate	Offset value of the abandonment option
-2%	+43.63	-62.47	-18.84
+2%	-37.89	+52.51	+14.62

〈Table 11〉 Adjusted Financial Mix for Hedging Strategy

Option value		Risk-free rate (r_f)		
		2%	4%	6%
Debt ratio (Financial mix)	90%	164.97	203.67	226.18
	80%	209.81	237.40	245.29
	70%	260.10	267.99	262.90
	60%	304.71	295.75	279.40
	74.70%	237.40		
	84.15%			237.40

shown in Table 11.

Even if the market rate decreases to 2%, the same option value of 237.40 can be maintained if the project owner intentionally adjusts the financial mix from an 80% debt ratio to 74.7%. This, therefore, proves that the project owner could take the full hedging position of the option value if he could adjust his financial mix freely.

7.3 Implication of the Abandonment Option to the Green Finance

This abandonment option as a put option has important implications on the possibilities for managing various business risks. Managers who want to initiate a new business opportunity in green business and green finance could adopt this put option model. Financial derivatives products, originated by investment banks as a supplementary service to their clients, have become the main sources for

creating the additional revenue. The transaction model of the abandonment option as a put option could be an effective solution for controlling the inherent business risk. If the abandonment option of the underlying project can be embedded in the contract for project finance, it will create a strong motivation for business owners, who are actively investing in the promising but highly risky business to efficiently allocate the project risk between business owners and investment banks. Furthermore, this can serve as an alternative way to promote green business at the government level.²⁹⁾ Thus, studies on incorporating the abandonment option into a formal contract between the business owner and the project financier will be an attractive area to the future government policy as well as the academic research.

VIII. Conclusion

The real options model assumes that the expected rate of return on the underlying asset is the risk-free rate of interest in a risk-neutral environment. Use of the risk-neutral framework to evaluate investment projects offers three major advantages. First, it allows for the proper inclusion of the flexibilities and the "real-life" options that the project has. Second, it uses all information

contained in market prices when such prices exist. Thirdly, it allows for the use of the powerful analytical tools developed in contingent claims analysis. It does not require estimating a risk-adjusted discount rate, but simply uses the risk-free rate of interest as the discount rate. In this paper, we use a real options model to examine an actual business case of solar power business. Although many previous papers have applied option pricing theory to evaluate real assets, practical application of these ideas to various real business cases has not been sufficiently studied. We show that when *AJU Energy* incorporated the growth option in the capital budgeting process, the underlying asset of the solar power project is valued at KRW 41 million while the value generated by the DCF model is negative KRW 459 million. The findings serve as evidence that real options can dramatically change the decisions made by management especially in cases where managers need to rely on their intuition in making investment decision. Therefore, neglecting the management flexibility embedded in the project might cause the investment opportunity to be undervalued and ultimately lead to misallocation of resources. The shortened business life cycle and the simultaneous increased uncertainty in the current business environment make the real options model an indispensable management tool. This model has become a widely used tool of expanded topics from strategy or

29) These positive effects on green business are in line with the *low carbon and green growth policy* envisioned by Korean government.

organization such as performance evaluation and rewards, to application industries such as energy, pharmaceuticals, defense, and venture investment. Furthermore, the real options model could be used to evaluate corporate assets and liabilities based on the concept of fair value in the International Financial Reporting Standards (IFRS).

This paper also has significant implications for both project financing contract and green finance. Major financing methods in green business could originate from various practical types of project finance. Incorporating the abandonment option into the contract schemes of project finance could create additional value for project owners by hedging the risk of their own businesses. In the case analysis of *AJU Energy*, we show with the assumption of 40% volatility that the abandonment option generates a positive value of KRW 237.40 million. If a more sophisticated business model with regard to trading business risk, such as a financial product, could be quantified, it might significantly influence the development of practical models in project finance and green businesses.

Our study is subject to several limitations. First, our analysis is based on a single case study, *AJU Energy's* investment in solar business. Our results may not be generalized to other business cases. Secondly, the option decision-making framework employed in this study uses binomial models. It is possible that such required modeling assumptions in the option model are violated in some cases.

Thirdly, in capturing the exercise price of the abandonment option, we use the amount of loans around the time of resale to the investment bank, an estimate which may be different in the real world.

In spite of these caveats, this paper makes an interesting contribution. It provides a strong case for the use of real option valuation to properly assess the value of the projects in consideration. The inclusion of option values will substantially benefit managers who undertake projects with a great deal of flexibility, contingency, or volatility, by providing a much more accurate estimate of the project value. Also, the study can serve as valuable reference or guidance for managers to understand the characteristics of the underlying assets more clearly and help properly estimate volatilities of the project.

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Appendix 1) Feed-in Tariff (FIT) System

A feed-in tariff (FIT) is a policy mechanism designed to encourage the adoption of renewable energy sources and help accelerate the time to reach grid parity. The system typically includes three key provisions: 1) guaranteed grid access, 2) long-term contracts for the electricity produced, and 3) purchase prices that are methodologically based on the cost of renewable energy generation and that tend towards grid parity. Under a FIT, eligible renewable electricity generators (the owners of power plants) are paid a premium price for any renewable electricity they produce. Europe's FIT incentive system boosted the global solar industry with extraordinary growth, Germany being the first to adopt, followed by Spain and Italy.

In the case of Korea, the electric power harvested from renewable energy (including photovoltaics) can be traded on the Korea Power Exchange (KPX) and distributed through the power grids owned by the Korea Electric Power Corporation (KEPCO). The FIT system guarantees a fixed price for fixed periods (with the option to choose 15 or 20 years at the beginning), so that the power plant owner of renewable energy can sell the electric power at any time at the same price. Every year the government discloses the new price to be applied to newly operating solar plants. The price is based on the levelized cost of energy (LCOE)³⁰⁾ and is composed of the following two parts:

$$\begin{array}{lcl} \text{Selling price} & = & \text{Monthly SMP}^{31)} + \text{FIT} \\ \text{(Photovoltaic)} & & \text{(Weighted average)} \quad \text{(Government budget)} \end{array}$$

Even if the system marginal price (SMP) fluctuates on an hourly basis, any difference between the selling price and monthly SMP can be automatically covered by the government budget. Such a fixed price allows the solar plant owner to forecast future cash inflow as planned, because the harvested electric power can be sold at the predetermined fixed price for the guaranteed period. Therefore, the FIT system contributes to the stability of the solar power business. Under the system, the solar power business has similar characteristics to long-term debt security, because in both cases it is possible to generate stable cash flows.

30) LCOE is the price at which electricity must be generated from a specific source to break even: this means an economic assessment of the cost of an energy generating system, including all costs over its lifetime. Levelized cost P^* is calculated by the following formula:

$$P^* = \frac{\sum_{t=0}^n \frac{C_t}{(1+r)^t}}{\sum_{t=0}^n \frac{Q_t}{(1+r)^t}}$$

where

n = Life of the system (year)

Q_t = Electricity generation in year t (kWh)

C_t = All costs in year t (initial investment, operation and maintenance costs, cost of fuel, cost of capital, etc.)

r = Discount rate (%)

31) The SMP is the hourly electricity price determined by KPX. The highest variable cost among all operating power sources is selected as the SMP.

〈Appendix 2〉 The Procedure of Option Valuation: Growth Option

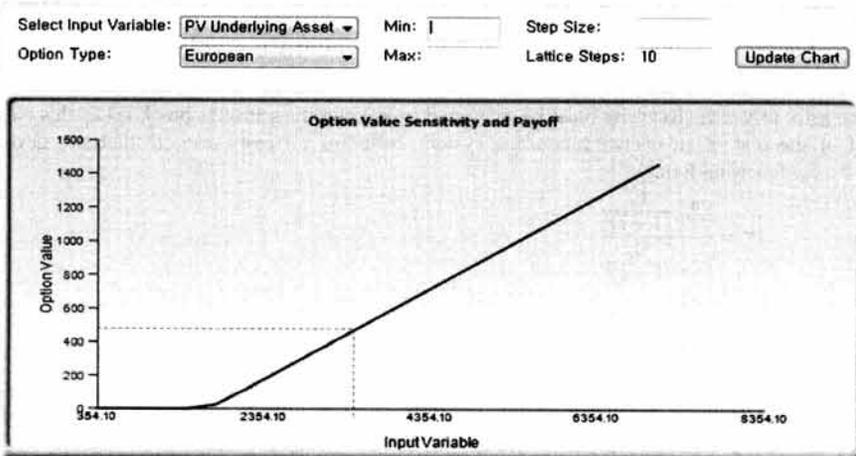
In this appendix we present procedures to calculate and derive the value of the growth option in detail. The procedures are as follows:

- ① Calculate volatility of the underlying asset (volatility is directly derived from AJU's business plan using a Monte Carlo simulation)
- ② Calculate the up-step and down-step size using equations (4) and (5) and estimate future value of the underlying asset (FV (S))
- ③ Decide on whether to exercise or continue to hold the option, based on objective function (MAX)
- ④ Discount the value of ③ with the risk-neutral probabilities equation: derive up possibility (p) using formula (6) and risk-free rate (r_f). Finally, obtain option value.

From the starting point of an underlying asset value of ($S = 3,541$) at T_1 , we calculate the probable future value of the next lattice (0.2 years later) to be $u \cdot S$ (3,625.93) and $d \cdot S$ (3,458.06), and finally the future value at T_4 to be $u^{10} \cdot S$ (4,488.11), $u^9 \cdot d^1 \cdot S$ (4,280.32), and $u^8 \cdot d^2 \cdot S$ (4,082.15), continuing to the last $d^{10} \cdot S$ (2,793.75) in the final lattice.

Once the calculation of the project's future value is completed, the next step is to calculate the possible payoffs by choosing the larger value between the net value of investing in new technology ($0.3 \cdot S - K$) and 0. In the cases of ($0.3 \cdot u^{10} \cdot S - K$), ($0.3 \cdot u^9 \cdot d^1 \cdot S - K$), ($0.3 \cdot u^8 \cdot d^2 \cdot S - K$), and the last row ($0.3 \cdot d^{10} \cdot S - K$), all have some positive value. Therefore, this growth option must be executed for all possible payoffs.

By rolling back to the prior lattices through multiplying risk-neutral probabilities in terms of the backward induction calculation, we calculate the value of the growth option at T_1 to be KRW 499.65 million.



태양광사업에 내재된 실물옵션 가치에 관한 연구: 아주에너지(주) 사례를 중심으로

김경남* · 선우석호**

요 약

2010년 10월 정부가 발표한 “신·재생에너지산업 발전전략”에 따르면 태양광산업을 제2의 반도체 산업으로 육성하여 2015년까지 한국을 세계 5대 신·재생에너지 강국으로 도약한다는 계획을 수립했다. 2006년 정부의 발전차액보전제도 개정 이후 태양광 발전소 건설이 활발히 이루어져서 2008년 한해 동안 한국의 태양광발전 규모 증대는 세계 5위를 기록했다. 그러나 장기 투자사업이면서 사업의 불확실성이 높고 비가역적인 초기 투자비용이 크다는 점은 기업들이 태양광사업에의 투자를 용이하게 결정하지 못하게 하는 요인이다. 따라서 태양광산업은 전형적인 프로젝트 파이낸싱 방식의 사업특성을 가지고 있으며 녹색산업 및 녹색금융에의 적용 가능성이 높다고 할 수 있다.

기업이 투자하고자 하는 실물자산이나 프로젝트에는 미래 현금흐름의 불확실성이 존재한다. 이러한 불확실성이 꼭 투자대상의 가치를 하락시키는 것은 아니다. 불확실성이 미래 사업성과의 발생 가능한 범위를 넓혀주고, 기업이 동 범위에서 자신에게 유리한 경우만을 선택할 권리를 보유한다면 동 투자대상 안의 가치는 커진다. 실물옵션은 사업에 내재된 부가가치로서 사업의 불확실성으로부터 기회를 창출하게 해준다. 따라서 기존 연구 결과에 따르면 실물옵션을 기업이 보유한 경영 유연성으로 정의하고 있다.

본 논문은 첫째, 국내 태양광 분야 투자분석에 실물옵션모델을 적용한 실제 사례를 처음으로 개발하였다. 본 논문 사례에 적용한 방법론을 통해 다양한 신재생에너지 분야의 자본예산기법으로 확장 적용될 수 있다는 점은 동 사업분야에 전통적인 순현재가치의 대안으로 새로운 투자분석기법을 제시했다는 경영학적 가치가 있다. 둘째, 실물옵션의 핵심변수인 변동성 값의 도출을 프로세스 방식으로 분석하였다. 순현재가치의 할인율과 같은 주관적인 변수를 배제하고 객관적인 시장변수를 사용한다는 점이 옵션모델의 큰 장점이다. 실물옵션의 경우 시장의 공정가치가 존재하는 금융옵션과는 달리 투자대상사업의 가치 변동성을 어떻게 산출할 것이냐가 모델적용의 성패를 좌우한다. 본 논문에서는 지역 일사량 통계정보로부터 시작해서 태양광 발전사업의 변동성을 도출하기까지의 프로세스를 정의하였고, 몬테카를로 시뮬레이션을 활용해서 동 사업의 변동성을 산출했다. 셋째, 실물옵션의 일종인 포기옵션을 통해 태양광 발전사업자가 사업실패 위험을 프로젝트파이낸싱의 주체인 투자은행과 공유할 수 있는 사업모델의 가능성을 분석했다. 효율적인

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위험관리를 통해 금융파생상품의 수익원을 창출한 투자은행의 선례와 같이, 녹색사업자가 파생시킨 포기 옵션을 전문투자은행이 거래화시킬 경우 새로운 녹색금융모델로 발전시킬 수 있다는 가능성을 본 논문은 제시한다. 넷째, 포기옵션가치에 대한 다양한 민감도분석을 하였고, 대표적인 거시변수인 시장금리의 변화가 투자사업의 가치 및 포기옵션 가치에 미치는 영향을 분석했다. 금리 변동에 따라 사업자의 타인자금 조달비율을 조정할 경우 옵션가치의 변동위험을 제거하고 투자사업의 가치 증식만을 도모하는 것이 가능함을 알 수 있었다.

주제어: 실물옵션, 변동성, 몬테카를로 시뮬레이션, 프로젝트 파이낸싱, 녹색금융, 태양광 사업, 태양광 발전

〈Teaching Note〉

태양광사업에 내재된 실물옵션 가치에 관한 연구: 아주에너지(주) 사례를 중심으로

Synopsis

지구 온난화 현상 및 석유, 석탄, 천연가스 등 화석연료의 부존자원 감소에 대응해서 선진국 중심으로 신·재생에너지의 적극적인 개발과 보급 확산이 추진되어 왔다. 특히 태양광은 가장 성장가능성이 큰 신·재생에너지로 각광받고 있다. 한국도 2006년 개정된 "신·재생에너지이용 발전전력의 기준가격 지침"이라는 보급 육성정책에 의해 국내 상업용 태양광발전소 건설이 활발히 이루어져 왔다.³²⁾ 또한 폴리실리콘, 태양광전지, 태양광모듈 등의 발전설비 및 관련 소재 제조사업 분야에서도 한국 대기업들은 적극적으로 참여하고 있다. 한국 태양광 업체들은 세계적인 태양광 업체로 성장할 잠재력이 크다. 그 이유를 열거하면, 1) 반도체, LCD, 전력기기, 플랜트 등 기술적 연관성이 높은 산업에서의 사업경험이 풍부하고, 2) 정부의 녹색성장에 대한 적극적인 지원이 있으며, 3) 가치사슬 전반에서 연구개발 및 투자가 활발히 진행되고 있다는 점이다.

본 사례는 아주에너지(주)의 태양광산업에의 진출 사례를 다루고 있다. 아주에너지(주)는 2007년 아주 L&F그룹이 태양광산업의 고성장 가능성을 기대하고 설립 투자한 회사이다. 본 사례는 아주에너지(주)가 어떤 전략으로 태양광사업에 진출하고자 하였으

며 의사결정과정에서 투자 타당성에 대한 적절한 검증이 이루어졌는지를 분석하고 있다. 성장 가능성이 큰 산업에 진출한다고 해서 성공이 보장되는 것은 아니다. 성공을 위해서는 투자 대상인 사업을 이해하고 자신의 역량에 맞추어 적절한 진입 전략이 수립되고 실행되어야 한다.

태양광 가치사슬 중 발전설비 및 관련 소재 제조사업의 경우 소재 사업으로 갈수록 (업스트림) 초기 투자 금액뿐 아니라 시장 수요예측상의 어려움으로 인해 사업 변동성도 커진다. 따라서 투자규모 및 사업 위험이 적은 태양광 발전사업 (다운스트림)에 우선 진출하는 것은 상대적으로 용이하다. 아울러 태양광발전사업에의 투자는 미래의 더 큰 투자를 유리하게 선택할 수 있는 옵션을 매입하는 효과를 가진다. 태양광 발전사업의 추진은 업스트림 분야에 대한 보다 많은 정보와 사업기회를 얻도록 하여 미래 시점에서의 후속적인 투자를 유연하게 결정할 수 있게 해준다. 이 같은 실물투자과 관련된 옵션, 즉 실물옵션은 경영 의사결정과정에서 누릴 수 있는 유연성으로 태양광 발전사업 관련 투자에도 다수 존재한다. 즉 상기한 확장투자과 관련한 옵션 외에도 태양광 발전사업 자체에 내재된 실물옵션을 고려해 볼 수 있으며, 본 사례는 사업에 내재된 성장옵션 및 포기옵션에 대해서 집중 분석한다. 사례기업인 아주에너지(주)는 태양광 발전사업

32) 2008년 한해 동안 건설된 태양광발전소 규모가 전세계 5위 차지.

에 우선 진출기로 결정하고 발전소 부지 매입, 발전사업 허가 및 설비 투자로 이어지는 일련의 투자(40억원)를 2008년 집행하였다. 순현재가법을 적용하면 해당 투자안의 순현재가가 -459백만원 음의 가치로 산출되어 프로젝트 기각으로 결정되어야만 했다. 그럼에도 불구하고 투자를 집행한 것은 회사가 단지 태양광 산업에 대한 막연한 기대감만 가지고 결정을 한 것은 아님을 본 사례에서는 실물옵션모형을 통해서 증명하고 있다.

사례 연구에서 활용된 첫번째 실물옵션은 기술진보와 관련된 성장옵션이다. 태양광 발전 기술이 활발하게 개발되고 있으므로 미래시점에 운영중인 발전소에 신기술도입을 위한 소규모 투자를 실행할 경우 발전소의 전력생산량 증가로 사업 가치 상승을 추가로 기대할 수 있다. 미래 시점에서의 이러한 기술투자는 성장옵션의 행사를 의미한다. 본 사례분석에서는 499.65백만원³³⁾의 성장옵션이 산출되었고, 동 옵션가치를 가산했을 때의 발전사업 순현재가는 41백만원 양의 가치로 반전되었다. 이는 아주에너지(주)의 투자결정이 합리적이었음을 증명한다. 두번째 사례로 분석한 실물옵션 유형은 포기옵션이다. 시뮬레이션에 의해 계산된 프로젝트의 변동성계수가 5.3%에 불과해서 의미있는 옵션가치가 산출되지 않았다. 본 논문을 통해 적용 가능한 사례들을 보다 많이 개발하기 위해 포기옵션 사례에서는 변동성계수로서 40%라는 임의값을 가정했다. 아주에너지(주)가 태양광발전소 투자자금의 80%인 32억의 장기차입금을 투자은행으로부터 프로젝트 파이낸스 방식으로 조달하였다. 차입금 계약 내용 속에 회사가 일정기간 경과 후 사업을 포기하고 사전 약정금액으로 투자은행에 양도할 수 있는 옵션을 회사의 권리로 포함시킨다. 사례 분석을 하였더니 237.4백만원³⁴⁾의 포기옵션 가치가 산출되었

으며, 동 금액만큼 프로젝트의 가치가 상승하였다.

아직 국내 기업의 재무담당자들은 실물옵션모형을 실무에 적극적으로 활용하지 못하고 있다. 현재와 같이 프로젝트가 가지고 있는 위험에 대한 가치, 더 나아가 전략적 가치를 과학적으로 분석하지 못하고 프로젝트 "수락" 또는 "기각"이라는 이분법적 평가를 할 경우 태양광사업과 같은 큰 미래 성장동력에 참여할 기회를 놓치게 될 수도 있다. 본 사례분석은 실무자들이 실물옵션을 좀 더 깊이 이해하고 다양하게 적용할 수 있도록 하는데 목표를 두고 있다. 또한 포기옵션의 사례의 경우 투자은행과의 옵션계약을 통해 회사가 가지는 사업 위험을 경감시킬 수 있음을 보여준다. 이를 프로젝트 파이낸스 방식의 녹색산업 투자에 확장 적용한다면 하나의 녹색금융 모델로 발전시킬 수도 있음을 본 연구는 제시하고 있다.

Teaching Point

본 사례는 먼저 아주에너지(주)의 태양광사업 신규 진출과 관련한 투자 타당성을 순현재가법과 실물옵션 모델로 분석하고 있다. 본 사례의 이해를 위해서는 태양광산업 가치사슬 및 태양광 발전 사업에 대한 기본적인 이해가 필요하다. 또한 태양광 기술과 관련한 기초 지식의 효과적인 습득도 요구된다. 강사는 사례 수업 진행 첫 부분에 실물옵션모델에서 사용되는 변수들이 옵션가치와 양/음의 관계인지 설명하여 학생들이 옵션모델을 이해하도록 해야 한다.

본 사례분석의 핵심은 크게 다음 3가지로 분류할 수 있다. 첫째는 순현재가법에 의해 투자 기각될 수 있는 사업기회가 실물옵션을 통한 추가적인 가

33) 당초 산출된 사업가치의 14.11%에 해당

34) 당초 산출된 사업가치의 6.7%에 해당

치 인식으로 양의 순현가를 지닌 투자가능 프로젝트로 전환될 수 있음을 증명한다. 학생들이 이러한 옵션가치를 직접 산출해 볼 수 있도록 아래의 Assignment에서 간단한 예제 및 답을 기술했다. 둘째는 옵션변수들 중 가장 추정이 어려운 부분인 "사업가치의 변동성"을 어떻게 도출하느냐의 문제이다. 본 사례에서는 정부 보조금 지원 정책인 발전차액보전제도 (FIT)의 적용을 받는 태양광 발전사업을 분석한다. 이럴 경우 사업 가치의 변동성은 가격 요소 (판매하는 생산 전력이 가격이 15년간 고정)가 아닌 수량 요소 (태양광 일사량)에 의해서만 영향을 받는다. 따라서 과거 일사량 데이터를 토대로 일일 발전시간을 가장 잘 설명해 주는 확률분포도를 선정하고, 동 분포도를 입력정보로 정의한 몬테카를로 시뮬레이션을 정해진 횟수만큼 반복 실행한다. 시뮬레이션의 출력정보인 사업 현재가치 변동률 값의 분포도에서 평균 및 표준편차가 산출되고, 동 표준편차를 옵션모델의 변동성 변수 값으로 결정하였다. 셋째 시장이자율 변동이 포기옵션의 가치에 미치는 영향에 대한 민감도 분석이다. 지분대 차입 투자 비중을 적절히 조정할 경우 이러한 변동성 위험을 회피할 수 있음을 사례에서 증명하고 있다. 또한 사업자가 포기옵션 계약에 의해 자신의 사업위험을 경감시킬 수 있게 된다면 이는 사업자로 하여금 보다 적극적으로 신규사업 투자를 실행케 하는 동기부여로 작용할 수 있음을 본 사례는 보여준다. 이는 장기 미래 현금흐름을 기초로 하는 프로젝트 파이낸싱 방식의 대출계약 내에 포기옵션을 내재화시킬 경우 정책적 육성과제인 녹색산업 활성화에 기여할 수 있음을 의미한다.

선정된 학생들은 우선 사례 개요 및 실물옵션의 적용여부를 발표한다. 이후 학생들 각자 실제 옵션가치의 산출 과정 연습을 위해 실습사례에 사용한 가정 및 변수 값을 엑셀 표 또는 실물옵션모형 계산프로그램에 대입해 보고 변수 범위 구간에서의

옵션가치와 이의 민감도 분석을 실시한다. 학생간의 발표 및 토론시간을 가진 후 강사의 부연 설명 및 총평을 듣는다.

Assignment Question & Analysis (Answer)

1. 태양광발전 기술에 대해 간략하게 조사하고, 태양광 보급 육성을 위한 정책 수단에 대해 어떤 것이 있는지 설명하시오.

태양광발전 (PV, Photovoltaic)은 무한정, 무공해의 태양에너지를 직접 전기에너지로 변환시키는 발전방식이다. 반도체 혹은 염료, 고분자 등의 물질로 이루어진 태양전지를 이용하여 태양빛을 받아 바로 전기를 생산한다. 시스템의 구조가 간단하고 수명이 20~30년 정도로 길며, 유지 보수가 거의 요구되지 않는 안전하고 친환경적인 시스템이다. 태양광발전의 산업시장은 지난 6년간 연평균 30% 이상 성장하였으며, 특히 최근 2~3년간은 약 40%이상으로 급성장하고 있다. 태양광발전 시스템의 주요 자재는 태양광모듈이며, 다수의 태양전지를 전기적으로 직/병렬로 구성하여 만들어진다. 태양전지의 소재는 주로 폴리실리콘 등의 실리콘 소재이다.

태양광에 관련한 정책수단은 크게 보조금 (FIT: Feed-In Tariff)과 할당제 (RPS: Renewable Portfolio Standard)로 구분되며, 한국은 2006년 개정된 "신·재생에너지이용 발전전력의 기준가격 지침"에 의해 보조금 방식의 지원 정책을 실행해 왔고, 2012년부터 지정된 대형 발전사업자가 의무적으로 일정 비율의 신·재생에너지를 발전 및 매입을 통해 확보해야 하는 할당제를 시행할 예정이다.

2. 본 사례에서 적용된 유형별 실물옵션들을 설명하고, 사례에서 직접적으로 적용되지 않은 유형들의 경우 태양광 가치사슬 하에서 어떠한 사례들에 적용 가능할 것인지에 대해 토의해 보자

- 1) 성장옵션(Growth option): 기초 연구개발, 미개발 부지 및 유전에 대한 임대계약, 전략적 인수, 인프라 구축투자자와 같은 초기투자가 반드시 요구되는 분야에 성장옵션이 존재한다. 신규제품이나 공정 개발, 신시장 진입, 핵심사업 강화 등과 같은 기업의 미래성장 기회를 제공하는 투자에서 볼 수 있는 옵션으로 본 사례연구에서는 운영중인 태양광 발전 프로젝트를 대상으로 미래시점에 태양광 발전 수확량을 증대시키는 발전 최적화 기술에 추가 투자할 수 있는 옵션으로 정의하였다.
- 2) 포기옵션 (Abandonment option): 항공, 철도 등과 같은 자본집약적인 투자사업, 잔존가치가 시장성이 있는 연구개발 사업 등 계획투자에서 철수할 경우 투자비의 일부를 보상받을 수 있는 보험적 성격을 갖는 옵션이다. 본 사례연구에서는 사업자가 태양광발전 프로젝트를 투자 은행에 매각할 수 있는 풋옵션으로 정의하였다.
- 3) 연기옵션 (Option to defer): 투자기간 중에 제반 여건 변화로 인해 예상수익을 이룰 수 없을 때 사업환경이 호전되거나 불확실성이 해소될 때까지 연기할 수 있는 옵션이다. 본 사례에서는 발전차액보전제도의 적용 혜택을 받기 위해 프로젝트 투자를 연기할 수 없는 상황이어서 적용치 않았지만, 태양광 제조사업과 같이 대규모 초기투자가 요구되고, 사업의 불확실성이 클 경우 투자시점을 뒤로 연기하고 보다 사업전망이 확실해 지는 이후 시점에서 투자하는 옵션 사례가 있을 수 있다.
- 4) 전환 옵션 (Switching option): 수요의 변화

에 따라 생산제품의 종류를 바꿔서 수익을 증가시키는 생산의 유연성과 동일한 제품을 생산하기 위한 투입물 조합을 바꿔가는 공정의 유연성 등을 의미하는 옵션이다. 발전 사업의 경우 전력 수요의 변화에 따라 디젤, 석탄 및 가스 중에 수익을 극대화시키는 연료로 전환 사용할 경우에 해당된다. 태양광 발전의 경우 투입연료가 요구되지 않는 신/재생에너지이므로 적용되기 힘들며, 오히려 화력발전 사례에 적용 가능한 옵션이다.

3. 실물옵션모델에 사용되는 변수들을 태양광 사업 사례와 연관해서 설명하고 실물옵션 가치와 어떤 관계성을 갖고 있는지에 대해서 설명하시오.

- 1) 기초자산가치: 투자나 합병과 같은 실물옵션의 경우 기초자산가격이 상승하면 옵션의 가치는 비례적으로 상승하게 된다. 본 사례에서는 태양광발전 프로젝트의 가치 (미래 현금흐름의 현재가)를 기초자산가치로 정의하였다.
- 2) 실행가격: 콜옵션의 경우 태양광 발전소 설비를 구입, 건설할 때 지출하는 투자액, 반대로 풋옵션의 경우 보유 태양광설비를 약정 조건으로 매각할 때 받을 금액을 의미한다. 콜옵션 (본 사례에서는 성장옵션의 경우)은 실행가격이 낮을수록 옵션가치가 커지며, 풋옵션 (본 사례에서는 포기옵션의 경우)은 실행가격이 높을수록 옵션가치가 커지게 된다.
- 3) 옵션만기: 옵션만기가 길어질수록 옵션가치가 커지게 된다. 본 사례에서 성장옵션은 2년, 포기 옵션은 3년의 만기로 분석하였다.
- 4) 기초자산가격의 표준편차 (변동성): 옵션의 가치는 기초자산가격의 변동성이 클수록 증가하게 된다. 옵션 보유자에게 유리한 경우에만 행사하는 옵션의 성격상 변동성이 큰 위험자산일

옵션변수	형태	관계	의미
기초자산가치	투자로 유입되는 미래현금흐름의 현재가	+	현금흐름이 클수록 순현재가가 커지고 옵션가치가 증가
행사가격	실물자산에 대한 투자금액	-	콜(풋)옵션의 경우 투자금액이 커질수록 옵션가치 감소 (증가)
만기	실물자산의 옵션 행사기간	+	만기가 길수록 옵션의 시간가치가 커지므로 옵션가치 증가
변동성	미래현금흐름의 변동성	+	옵션의 특성에 따라 변동성이 클수록 옵션가치 상승
무위험이자율	옵션만기와 같은 무위험이자율	+	무위험이자율이 클수록 기초자산가치는 상승하나, 행사가격은 하락하여 옵션가치가 상승

수록 미래가치가 큰 폭으로 상승/하락하므로 옵션의 가치가 커진다. 본 사례에서는 발전차액보전제도가 적용되는 발전사업 프로젝트가 기초자산이므로 변동성 수치가 5.3%라는 낮은 값이 적용되었다.

5) 옵션만기까지의 무위험이자율: 무위험이자율이 커질수록 기초자산 가치는 상승하는 반면 행사가격가치는 하락하게 되므로 결국 옵션가치는 상승하게 된다. 본 사례에서는 옵션기간에 상응하는 국고채 금리를 적용하였다.

4. 사례에서 이용한 실물옵션계산 프로그램인 Risk Options SLS³⁵⁾을 활용해서 아래의 성장옵션 및 포기옵션의 가치를 계산하고 범위 구간의 민감도 분석을 실행하세요.

1) 성장옵션

발전 용량 10MW 규모의 태양광발전소 건설을 계획하고 있다. 전체 투자금액은 400억원, 발전사업을 통한 미래현금흐름의 현재가는 380억원으로서 순현재가법에 의하면 20억원의 적자사업으로서 기각

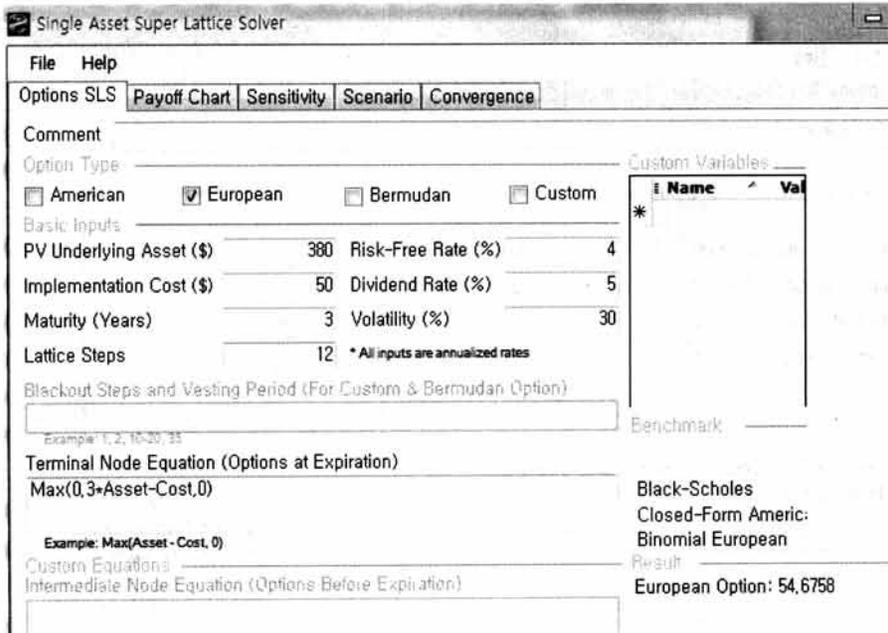
될 수 있는 투자안이다. 그러나 3년내 발전 효율을 40% 증가시킬 수 있는 기술이 상용화될 가능성이 크다. 따라서 일단 발전소 사업을 개시한 후 3년 뒤, 동 기술에 추가 투자를 할 수 있는 옵션을 가치 분석한다. 3년 뒤 추가투자 금액은 100억원으로 예상된다. 옵션가치 산출을 위한 제반 변수 값은 다음과 같다.

- 발전소 프로젝트 현재 (S): 380
- 발전소 추가투자 금액 (K): 100
- 옵션만기 (T): 3년, 옵션의 이항시간은 매분기로 설정하므로 총 이항수는 12
- 프로젝트의 변동성(σ , 표준편차): 30%
- 무위험이자율 (r_f , 3년만기 국고채금리): 4%
- 발전소 가치 하락율 (div, 내용연수 20년 기준): 5%

아래 그림과 같이 SLS 입력화면에 변수 값들을 입력하고 실행한 결과 옵션 가치는 54.67억원이 계산됨.

따라서 동 성장옵션 가치를 포함시킬 경우 발전소 프로젝트 가치는 434.67억원이 되며, 순현재가도 34.67억원의 양의 값을 가지므로 프로젝트 투자안

35) 프로그램 제작사인 Real Options Valuation사의 홈페이지(www.realoptionsvaluation.com)에서 10일 동안 무료 사용이 가능한 프로그램의 다운로드가 가능함.

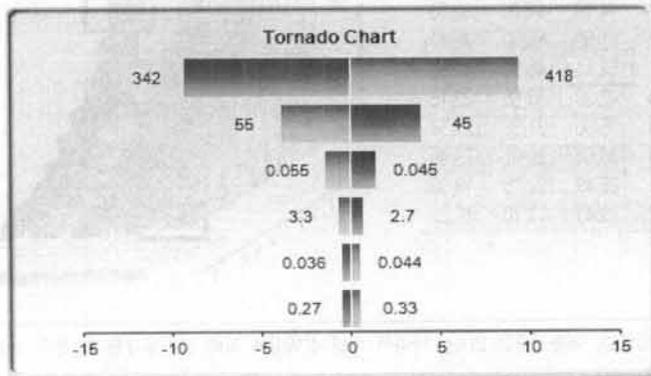


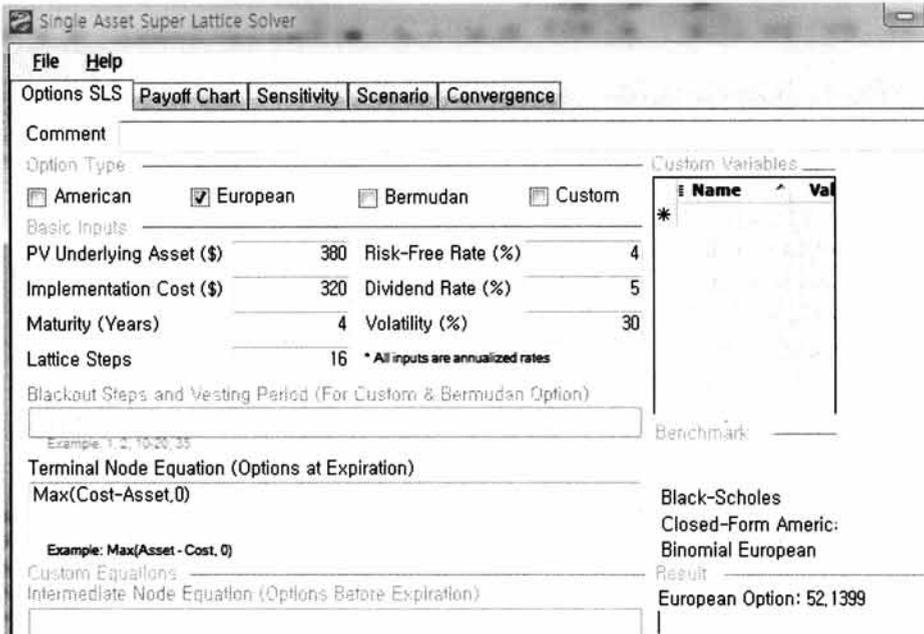
은 수락될 수 있다. 각 옵션 변수가 옵션가치에 미치는 영향 ($\pm 10\%$ 범주)을 분석한 민감도 분석의 결과는 다음과 같다.

2) 포기옵션

상기 동일한 발전소 투자자금에 대한 장기 차입

Inputs	Output Downside	Output Upside	Effective Range	Input Downside	Input Upside	Base Case Value
PV Underlying Asset	45.34	64.09	18.75	342.00	418.00	380.00
Implementation Cost	58.65	50.81	7.84	45.00	55.00	50.00
Dividend Rate	56.11	53.27	2.84	0.05	0.06	0.05
Maturity	55.36	53.99	1.38	2.70	3.30	3.00
Risk-Free Rate	54.19	55.15	0.96	0.04	0.04	0.04
Volatility	54.22	55.17	0.96	0.27	0.33	0.30





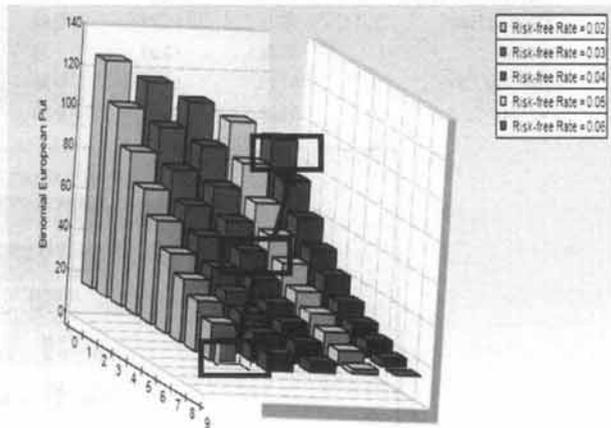
과 동시에 4년 뒤 발전소 장부금액으로 투자은행에 매각할 수 있는 포기옵션을 투자은행과 계약하였다. 동 옵션 변수 값은 아래 두 변수 값을 제외하고는 상기 1)의 성장옵션 조건과 동일하다.

- 발전소 매각금액 (K): 320³⁶⁾
- 옵션만기 (T): 4년, 옵션의 이항시간은 매 분

기로 설정하므로 총 이항수는 16

아래 그림과 같이 SLS 입력화면에 변수 값들을 입력하고 실행한 결과 포기옵션의 가치는 52.14억 원이 계산됨. 따라서 동 성장옵션 가치를 포함시킬 경우 발전소 프로젝트 가치는 당초 380억원에서

Column:	Risk-free Rate					Row:
	0.02	0.03	0.04	0.05	0.06	
228.00	126.10	116.26	106.99	98.25	90.05	
266.00	107.36	98.33	89.87	81.95	74.56	
304.00	89.98	81.78	74.16	67.09	60.53	
342.00	76.12	68.73	61.90	55.60	49.81	
380.00	64.81	58.21	52.14	46.58	41.50	
418.00	53.51	47.69	42.38	37.56	33.18	
456.00	45.46	40.29	35.60	31.36	27.54	
494.00	39.30	34.70	30.54	26.81	23.45	
532.00	33.14	29.11	25.49	22.25	19.36	
570.00	26.98	23.52	20.43	17.70	15.27	



36) 발전소 투자금액은 총 400억원, 내용연수는 20년. 따라서 매년 정액법에 의해 감가상각을 할 경우 4년 뒤 상각후 장부금액은 320억원임.

432.14억원으로 상승하게 된다.

금리 변화에 따른 민감도 분석을 아래 그림과 같이 실행했다. 무위험이자율이 당초 4%에서 2% ~ 6%로 변화한다고 할 경우 현가의 할인율 변화에 따른 “발전소 프로젝트 현가 변동분”과 “무위험이자율 변동분”이 옵션가치에 미치는 영향은 서로 상쇄된다. 즉, 차입비율을 적절히 조절할 경우 시장이자율 변동에 따른 옵션가치변동 관련 위험을 회피할 수 있음을 증명한다.