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Diversified Energy Investment Strategies based on Real Options: Hydropower vs. Solar Power

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Abstract: Based on real options approach (ROA), this paper presents a diversified investment strategy, that is, a company invests in two distinct renewable energy technologies (solar photovoltaic (PV) and hydro). Assumed that the learning curve of PV technology is a function of cumulative capital investment, the cost of hydropower investment is constant. Under the uncertain conditions of future electricity price, learning rate and initial cost, we use ROA to evaluate the minimum threshold of stochastic electricity price when the company's investment in these two technologies is optimal. The more capital invested, the more learning rate can stimulate the early exercise of investment options. However, if all the capital is invested in PV technology, the company will predict the investment option and exercise it at a lower threshold. If capital investment is diversified, options will be exercised at a higher threshold. When all capital is invested in hydropower, the critical threshold is the highest. This is because hydropower technology tends to be mature or even outdated, and it is difficult to reduce the cost according to the existing technology level. More uncertainty about electricity prices delays investment choices. Although investment in solar energy and hydropower may be profitable under certain price uncertainties, the best strategy in theory is usually to invest in only one technology, namely solar energy. This suggests that in most countries, the diversification of renewable energy may reflect a wrong strategy.

Keywords: Real options; Diversified investment strategy; Solar PV; Hydropower; Learning curve

1 Introduction

Energy shortages, global warming, and extreme weather have prompted the world to turn its attention to renewable energy (RE). Among them, solar energy and wind energy are favored by many power generation companies because of their inexhaustible use, environmental friendliness and zero emissions. Therefore, solar energy and wind power plants came into being, and RE power generation is in full swing throughout the country. However, these energy generations are susceptible to weather and geographical location, are unstable and uncontrollable, and need to be combined with other forms of energy generation. Therefore, in order to make the energy supply sustainable and stable, this paper considers a power generation company to invest in two RE technologies, such as solar energy and hydraulic. The problem that this paper needs to solve is what proportion of investment in the two technologies can make the company most profitable, and what factors affect the company's investment willingness?

The traditional evaluation method is cash flow discount method [1, 2], i.e. by calculating net present value (NPV): when $NPV \geq 0$, invest project; when $NPV < 0$, give up project. Using NPV, the result will always be in two states: either invest immediately or never invest. However, energy investment decision-making has the following three basic characteristics: (1) investment is partially or completely irreversible. (2) Future returns from investments are uncertain. (3) There is room for manoeuvre in the timing of investments [3]. Traditional NPV does not recognize the irreversibility, uncertainty and flexibility of investment decision-making, so it is not suitable for investment evaluation. A more accurate evaluation method is the real option approach (ROA). This method considers that the enterprise with investment opportunity has a kind of "option" similar to financial call option. And ROA is able to quantify the value of uncertainty,

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to recognize the investment flexibility and irreversible of RE projects, to perfect investment decision of RE investment projects. So, in here ROA is more fit.

The concept of real options comes from financial options developed by Black and Scholes [4], Merton [5]. It was first proposed by Stewart Myers [6] of MIT, and Tourinho [7] was the first one to use real options in energy industry evaluation. Later, Brennan and Schwartz [8] used real option pricing theory to evaluate the irreversible natural resources of Chile's copper mine.

In the period 1990-2000 real options theory was developed. Important contributions are Dixit and Pindyck [3], Trigeorgis [9] and Amram and Kulatilaka [10]. Later on, the theory was applied to investment in different fields, including the energy sector. Table 1 introduces the most important studies applying this method and summarizes their main features, such as the types of uncertainties addressed or the form of solution employed.

Table 1. Real option studies of renewable energy

Energy types	Essential information	Uncertainty	Solution
Solar PV	Sarkis and Tamarkin [11], 2008, Not regional	Technology and policy	Numerical
	Martinez and Mutale [12], 2011, UK	Demand response	Numerical
	Gazheli and di Corato [13], 2013, Italy	Price	Numerical
	Jeon , Lee and Shin [14], 2015, Korea	Price	Numerical
	Li et al. [15], 2018, China	Price and cost	Numerical
wind	Venetsanos et al. [16], 2002, Greece	Price	Analytic
	Fleten et al. [17], 2007, Norway	Price	Analytic
	Boomsma et al. [18], 2012, Norway	Price and cost	Analytical/numerical
	Monjas and Balibrea [19], 2014, Germany	Price, cost, technology	Numerical
	Loncar et al. [20], 2017, Serbia	Price	Numerical
	Mansaku and David [21], 2019, USA	Price and cost	Numerical
hydro	B?ckman et al. [22], 2008, Norway	Price	Analytic
	Nadarajah et al. [23], 2017, Not regional	Price	Numerical
	Kim et al. [24], 2017, Indonesia	Technology	Numerical

As shown in the table, these studies are mostly applied and focused on particular regions. The main objective of such studies is to test specific climate or energy policies for particular countries or regions. Other studies address general issues associated with investments in RE.

Therefor, this study consider a diversified investment strategy, the cost of solar PV technology decreases with the learning rate, and the cost of hydropower is constant (because hydropower has a certain history, so the cost has reached the lowest), power price fluctuates randomly and carbon price is fixed.

The remainder of this study is organized as follows. Section 2 presents a real options model and obtains analytical solution. Section 3 offers numerical simulation and sensitivity analysis of uncertainty. Section 4 concludes.

2 Real options model

In order to make the power supply continuous and stable, assume a power generation company considers investing in two types of energy generation, namely solar energy and water power. The company's revenue is profit minus cost (investment and operating costs). There are two sources of income: one is the sale electricity generated by two kinds of energy; the second is the additional revenue that enterprises earn by trading in their greenhouse gas emissions reductions.

Next, we consider that the cost of PV technology decreases with the learning rate, while the cost of hydropower is constant. The initial cost of solar energy is higher than that of hydropower, but because of the learning rate, the former decreases rapidly and is eventually lower than that of hydropower.

Assume that time is continuous, and the investment period of project and the life cycle of PV technology are both T. In the initial stage of investment, the company has to decide the proportion of investment to the two technologies. A unit of capital cost i, so investment in K units of capital requires an investment expense of $I(K) = iK$. This capital will be divided between the two technologies, k_s and k_h.

Assume that the PV generation cost decreases with the learning rate α , and the cost of hydropower is constant. So, the cost satisfies the following relationship [25]:

$$s_t = s_0 e^{-\alpha Q_t}, h_t = h_0 \tag{1}$$

s_t is the yearly cost of production and maintenance of the solar panels, and h_t is the annual cost of investment and maintenance of hydraulic engines (Fig.1). As shown, the initial cost of PV power generation is higher than that of hydropower. Due to the learning rate, s_t drops rapidly and intersects the h_t curve at point τ. After this point, the cost of PV power generation is lower than that of hydraulic power.

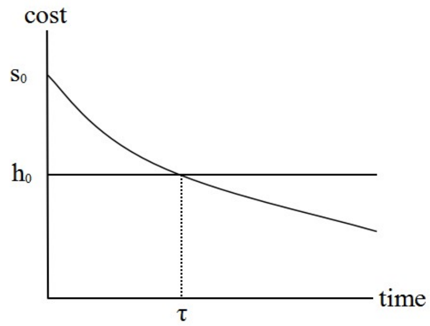

Figure 1: Cost curves of hydro is constant and solar decreasing due to learning

We know that the cost decreases with the cumulative installed capacity Q, and Q satisfies the following expression:

$$Q_t = \int_0^T q_{s,t} dt \tag{2}$$

After investment, the NPV of the project is:

$$NPV = \int_0^T \pi_t e^{-rt} dt$$

where r is risk-free interest rate.

Total profit π_t equal to the sum of profits from each technologies:

$$\pi_t = \pi_{s,t} + \pi_{h,t} \tag{3}$$

Profit from investing in PV technology equals income minus expenditure. Revenue refers to electricity sales revenue and carbon price income, and expenditure is cost expenditure. So $\pi_{s,t}$ satisfies:

$$\pi_{s,t} = (P_t + c_t - s_t) k_{st} \tag{4}$$

Similarly, hydropower profits is:

$$\pi_{h,t} = (P_t + c_t - h_0) k_{h,t} \tag{5}$$

where P_t is power price, c_t is carbon price. The products produced by the two technologies is no difference and is sold on the market at a uniform price.

In here, we assume that the electricity price satisfies the following inverse linear demand function [25]

$$P_t = a - b (q_{s,t} + q_{h,t}) \tag{6}$$

This simply reflests that more supply leads to a lower price. In Eq. (6), we consider b as a strictly positive constant and a , the demand shift parameter, fluctuates according to a geometric Brownian motion with drift μ and standard deviation σ.

$$da = \mu a dt + \sigma a dW_t \tag{7}$$

and $\mu < r$, dW_t denotes an increment of the independent standard Brownian motion.

Substituting (1) and (6) into (4) and (5), we get:

$$\pi_{s,t} = \left(P_t + c_t - s_0 e^{-\alpha Q_t}\right) k_{s,t} = \left[a - b (q_{s,t} + q_{h,t}) + c_t - s_0 e^{-\alpha Q_t}\right] \times k_{s,t} \tag{8}$$

$$\pi_{h,t} = (P_t + c_t - h_0)\, k_{h,t} = [a - b\,(q_{s,t} + q_{h,t}) + c_t - h_0] \times k_{h,t} \tag{9}$$

For simplicity, we assume that the input and demand are equal, i.e.$q_{s,t} = k_{s,t}$, $q_{h,t} = k_{h,t}$, then:

$$\pi_t = [a - b\,(k_s + k_h) + c_t]\,(k_s + k_h) - \left(s_0 k_s e^{-\alpha k_s t} + h_0 k_h\right) \tag{10}$$

Setting $c_t = c$, we have:

$$NPV = \int_0^T \left(aK + cK - bK^2 - s_0 k_s e^{-\alpha k_s t} - h_0 k_h\right) e^{-rt} dt \tag{11}$$

Using Ito integral:

$$NPV = \frac{a_0 K \left(1 - e^{-(r-\mu)T}\right)}{r - \mu} - \frac{\left(bK^2 - h_0 k_h - cK\right)\left(1 - e^{-rT}\right)}{r} - \frac{s_0 k_s \left(1 - e^{-(r+\alpha k_s)T}\right)}{r + \alpha k_s} \tag{12}$$

Taking the real option perspective, the firm can be seen as holding an American call like option. The firm with exercise the option at the critical time threshold, a^*, at which, accounting for the uncertainty in the price of electricity, the initial cost of the two technologies and the learning curves, investing gives the maximum benefit to the firm.

Note $V(a)$ is the option value of investing in two technologies, then $V(a)$ satisfies:

$$V(a) = e^{-rt} E[V(a + da)] \tag{13}$$

Using Ito Lemma, we have:

$$\frac{1}{2}\sigma^2 a^2 \frac{\partial^2 V}{\partial a^2} + \mu a \frac{\partial V}{\partial a} - rV = 0 \tag{14}$$

The general solution of the above equation is$V(a) = C_1 a^{\beta_1} + C_2 a^{\beta_2}$, where β_1 and β_2 are the roots of the following quadratic equations:

$$f(\beta) = \frac{1}{2}\sigma^2 \beta(\beta - 1) + \mu\beta - r = 0 \tag{15}$$

In addition, the triggering investments threshold threshold a^* satisfies the following three boundary conditions:
(1) First value matching condition: $V(0) = 0$. Therefore , $V(a) = C_1 a^{\beta}$.
(2) Second value matching condition: $NPV\,(a^*) = V\,(a^*)$.
(3) Smooth pasting condition: $NPV'\,(a^*) = V'\,(a^*)$.
From boundary conditions(1)-(3), we obtain that critical threshold a^* is

$$a^* = (\frac{\beta_1}{\beta_1 - 1}) \left[\frac{\frac{(bK^2 - cK)(1 - e^{-rT})}{r} + \frac{c_{s,0} k_s (1 - e^{-(\gamma k_s + r)T})}{r + \gamma k_s} + \frac{c_{h,0} k_h (1 - e^{-rT})}{r}}{\frac{K(1 - e^{-(r-\mu)T})}{r - \mu}} \right] \tag{16}$$

The value of the option takes the form:

$$V(a) = \begin{cases} A_1 a^{\beta_1}, a < a* \\ NPV(a), a > a* \end{cases} \tag{17}$$

The critical threshold a^* represents the optimal threshold in the stochastic energy prices where the firm decides to invest in the two technologies. For energy prices lower than a^* , the firm should keep the option to invest, while for energy prices higher than a^* , the firm should exercise the option and invest in the two technologies. The amount of investment to address to each of the two technologies depends on the initial cost, the learning curves, the drift and volatility of energy prices, and the discount rate. In order to provide a numerical solution on the different combinations on capital in the two technologies the technology invested in the solar PV technology is considered as δK while the capital invested in the hydro technology as $(1 - \delta)K$.

Table 2. Default values of model parameters for numerical simulations

Description	Symbol	Value
Initial cost of electricity production by the solar technology	s_0	35
Initial cost of electricity production by hydro technology	h_0	25
Learning rate of the solar technology	α	0.06
Discount rate	r	0.05
Demand parameter	b	0.2
Drift	μ	0.04
Volatility	σ	0.1
Root of fundamental quadratic Eq. (15)	β_1	1.216991
Carbon price	c	0.15
Capital invested in the two technologies	K	100
Investment duration	T	25
Price intercept parameter	a	Solvedbythemodel

3 Numerical analysis

Since insightful analytical solutions are impossible because of nonlinearities in the model, here we perform numerical analysis with the models to understand the characteristics of optimal investment in hydro and solar technologies.

Table 2 shows the values of the parameters. They reflect average values obtained from reviewing the earlier literature as captured in Table 1. Total investment is set at 100, allowing for easy interpretation of investments in each alternative as a percentage.

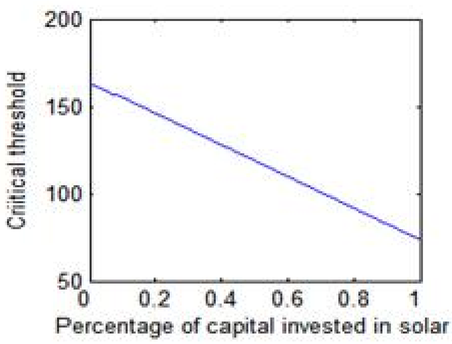

Figure 2: Critical threshold a^*

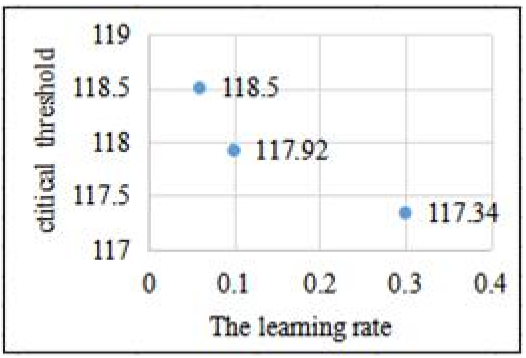

Figure 3: Sensitivity analysis of the learning rate

Here, we consider PV technology cost declines with the learning rate, while hydropower cost is fixed. Figure 2 shows the critical threshold a^* for which the project is profitable by executing an option to invest.

The figure shows that if all capital is invested in the technology with hydropower, then we postpone the option to invest and require a high value of $a^*(a^* = 162.27)$. As we diversify our investment and invest an increasing part of capital in the solar technology, its costs decreasing with the learning rate, causing exercising of the option to invest to be optimal at lower, decreasing values of a^* . If capital investment is diversified as 50% in the solar and the remaining 50% in the hydro technology, then the option is exercised for critical threshold equal to 118.5. If all the capital is invested in the solar technology, then we are willing to exercise the investment earlier at a minimum value of $a^* = 73.287$, i.e. also for any value larger than this.

Fig.3 shows the relationship between the critical threshold and the learning rate. The learning rates is set as 0.06, 0.10, and 0.30, respectively. We compare the critical thresholds of the above three cases under the determined investment share, such as $\delta = 50\%$, which is 50% investment in PV power and 50% investment in hydropower. From Fig.3, we can seen that the higher the learning rate, the faster the cost decline, which leads to an earlier option to invest at a lower threshold.

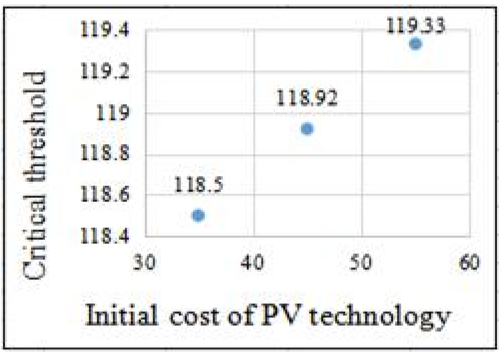

Figure 4: Sensitivity analysis of initial cost of PV technology

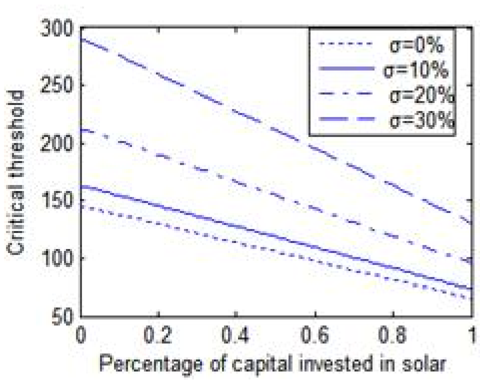

Figure 5: Sensitivity analysis of volatility rate

On the contrary, the higher the initial cost of the solar technology, the later one invests on average and a higher value of is required (the initial cost is set as 35, 45, and 55, respectively, Fig.4). The uncertain time delay results from the fact that prices steadily increase but stochastically. In addition, the costs of production of the solar technology will start at a high value, and even if it falls due to learning, it will be relatively high for a long period. For this reason one will be forced wait and require a higher critical threshold price to exercise the option.

Fig.5. shows the sensitivity analysis of volatility. According to real option theory, the higher the volatility in the market, the more willing people are to defer investment and need a higher trigger threshold to execute the option.

As can be seen from Fig.5., the higher the volatility, the higher the threshold of triggering investment. This is because the greater the volatility, the more uncertain the expected return of investment, people are more willing to wait for more market information in the future, thus postponing investment until the threshold reaches a higher level. For fixed volatility, the trigger threshold of investing all capital in PV technology is the lowest. For example, energy price volatility $\sigma = 0\%$

(i.e. no volatility), all capital is invested in technology with learning rate, the critical threshold $a^* = 65.335$. With the diversification of investment, the threshold of triggering investment increases. When all capital is invested in hydropower, a^* reaches to 144.67.

With the increase of volatility, when $\sigma = 30\%$, the investment will be delayed until the critical threshold reaches $a^* = 130.67$. It's just to fully invest the money in PV technology. If a portfolio of two technologies is considered, the threshold threshold of triggering investment will be higher. The cause is that diversified investment, the cost will slow down with the decline of learning rate. So the company will wait for a sufficiently high price to cover the cost of both technologies.

4 Conclusion

The results of our model show that the higher the uncertainty of electricity prices, the more one is willing to wait before exercising the option. This fact is also explained by the necessity to wait and have more market information in periods of high uncertainty. With high uncertainty the critical threshold in energy prices will grow, and the firm will require a higher price to exercise the option to invest, thereby postponing the option to exercise.

The effect of learning is quite important in anticipating the option to invest and exercising earlier the option. Learning is straight forward connected to cost reduction. As a result, the higher the learning rate, the higher will be the amount of cost we reduce during the whole investment duration. In addition, the learning parameter is also positively connected with the share of capital in order to reduce costs. The more capital we invest in PV technology, the more we learn from that technology, and the more we reduce costs. The cost of production on the other hand postpones the option to invest. The higher the initial cost of production of the technology, the higher will be the price of electricity required to exercise the option to invest in order to make enough revenues to cover such cost. For this the investment will be postponed until prices will be at a higher level.

Although investment in PV power and hydropower may be profitable under certain price uncertainties, the best strategy in theory is usually to invest in only one technology, namely solar energy. This suggests that in most countries, the diversification of RE may reflect a wrong strategy.

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