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REAL OPTIONS ANALYSIS OF RENEWABLE ENERGY INVESTMENT SCENARIOS IN THE PHILIPPINES

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Abstract

With the continuously rising energy demand and much dependence on imported fossil fuels, the Philippines is developing more sustainable sources of energy. Renewable energy seems to be a better alternative solution to meet the country's energy supply and security concerns. Despite its huge potential, investment in renewable energy sources is challenged with competitive prices of fossil fuels, high start-up cost and lower feed-in tariff rates for renewables. To address these problems, this study aims to analyze energy investment scenarios in the Philippines using real options approach. This compares the attractiveness of investing in renewable energy over continuing to use coal for electricity generation under uncertainties in coal prices, investments cost, electricity prices, growth of investment in renewables, and imposing carbon tax for using fossil fuels.

Keywords: real options approach, investment under uncertainty, dynamic optimization, renewable energy

JEL Classification: C61, G17, Q42, Q47

NOMENCLATURE

ADF	Augmented Dickey-Fuller
BAU	business as usual
DCF	discounted cash flow
FiT	feed-in tariff
GBM	geometric Brownian motion
IRENA	International Renewable Energy Agency
NPV	net present value
O&M	operations and maintenance
PV	photovoltaic
RES	renewable energy resources
ROA	real options approach

I. INTRODUCTION

Increasing environmental concerns and depleting fossil fuels have caused many countries to find cleaner and more sustainable sources of energy. Currently, renewable energy sources (RES) supply 12.65% of the total world energy demand in 2016 which includes wind, solar, hydropower, biomass, geothermal, and ocean energies [1]. In the recent years, new investments in renewable energy have grown from US\$1043.8B (2007-2011) to US\$1321.9 (2012-2016) with a geographic shift from the Asia-Pacific region [2], [3]. In the Philippines, renewable energy accounts to 25% of the energy generation mix, mostly from geothermal (13%) and hydropower (10%) [4]. The country is aiming to increase this percent share to 60% in 2030 by investing and developing localized renewable sources at 4% annual growth rate [5]. According to International Renewable Energy Agency (IRENA), the country's topography and geographic location makes a good potential for renewable energy with 170GW from ocean, 76.6GW from wind, 4GW from geothermal, 500MW from biomass, and 5kWh/m²/day from solar energy [6]. Despite its potential, the country's 60% renewable energy goal seems unachievable as the growth in electricity demand increases faster than investment and generation from RES. Meanwhile, the country is burdened by heavy dependence on imported fossil fuels, particularly coal and oil. As more power plants are needed due to closing old coal plants and rising electricity demand, renewable energy seems to be the long-term solution to address the country's problem on energy security and sustainability. However, investment in renewable energy sources is challenged by competitive prices of fossil fuels, high investment cost and lower feed-in tariff (FiT) rates for renewables. These serve as an impetus to evaluate the comparative attractiveness of renewable energy over coal for electricity generation in the Philippines.

This study presents a general framework of investment decision-making for shifting technologies from coal to renewable sources that can be applied to developing countries. By taking the case of the Philippines, this study applies the real options approach (ROA) to analyze various investment scenarios. Traditionally, the discounted cash flow (DCF) or net present value (NPV) techniques are mostly used in evaluating investment projects. These methods, however, do not cover highly volatile and uncertain investments because they assume a definite cash flow. This assumption makes DCF and NPV underestimate the investment opportunities leading to poor policy and decision-making process, particularly to energy generation projects. Further, these approaches do not allow an investor to define the optimal time to invest or to estimate the true value of project uncertainties [7]. ROA overcomes this limitation as it combines risk and uncertainty with flexibility of investment as a potential positive factor, which gives additional value to the project [8]. This approach evaluates investment projects by considering the investor's flexibility to delay or postpone his/her decision to a more favorable situation [9]. These ROA characteristics are highlighted in this paper as the decision-making process to invest in RES is evaluated in every investment period (annually) using dynamic optimization under various uncertainties.

Recent studies employ ROA to analyze investment decisions, specifically renewable energy, including: Zhang et al. [10] on investment in solar photovoltaic (PV) power generation in China by considering uncertainties in unit generating capacity, market price of electricity, CO₂ price, and subsidy; Kim et al. [11] on analyzing renewable energy investment in Indonesia with uncertainties in tariff, energy production, Certified Emission Reduction price, and operations and maintenance (O&M) cost; Kitzing et al. [12] on analyzing offshore wind energy investments in the Baltic under different support schemes as FiT, feed-in premiums, and

tradable green certificates; Tian et al. [13] on evaluating PV power generation under carbon market linkage in carbon price, electricity price, and subsidy uncertainty; and Ritzenhofen and Spinler [14] on assessing the impact of FiT on renewable energy investments under regulatory uncertainty. This research contributes to existing literatures by presenting a multi-period investment coupled with uncertainties in coal prices, cost of renewable technologies, growth of renewable energy investment, FiT price of renewables, and externality for using coal.

The main goal of this paper is to analyze investment scenarios that make renewable energy a better option than continuing to use coal for electricity generation. Specifically, this study employs ROA to evaluate the (1) maximized option value of either continuing to use coal or investing in renewables, (2) value of waiting or delaying to invest in renewables, and (3) optimal timing of investment characterized by the trigger price of coal for shifting technologies from coal to renewables. Sensitivity analyses are done to investigate how the above-mentioned uncertainties affect the optimal investment strategies.

II. METHODOLOGY

The proposed real options methodology is divided into two subsections. The first subsection describes dynamic optimization to calculate the maximized value of investment and identify the optimal timing of investment. The second stage includes the sensitivity analyses with respect to growth rate of renewable energy investment, prices of renewable energy, investment costs, and CO₂ prices.

- **Real options model**

Consider a renewable energy project with lifetime T_R , which can be irreversibly initiated in three installment periods τ , $\tau + 5$, and $\tau + 10$ with investment costs $I_{R,0}$, $I_{R,5}$, and $I_{R,10}$. Assume that the project construction can be finished instantaneously and operated in full load after project completion. If renewable energy project starts in period t , the total net present value of the project NPV_R can be represented by Equation 1.

$$NPV_R = NPV_{R,0} + NPV_{R,5} + NPV_{R,10} = \sum_{r=0,5,10} \left[\sum_{t=\tau+r}^{T_R+r} \rho^t PV_{R,t} - (1 + \varphi_r) I_{R,r} \right] \quad (1)$$

where r is the installment periods of renewable energy investment, φ_r is the growth of renewable energy investment cost, and τ is the period where investor decides to invest in renewable.

The yearly cash flow $PV_{R,t}$ of renewable energy project comprises of returns from selling electricity from RE, O&M cost C_R .

$$PV_R = \pi_R = P_{ER} Q_R - C_{R,r} \quad (2)$$

On the other hand, there exists a power plant generated with coal. The net present value of yearly cash flow from coal depends on the returns from selling electricity from coal, O&M cost C_C , stochastic cost of fuel $P_{C,t}$, and CO₂ price C_{C,CO_2} as given in Equation 3

$$\begin{aligned}
NPV_{C,t} &= \sum_{t=0}^{\tau} PV_{C,t} = \sum_{t=0}^{\tau} \rho^t \pi_{C,t} \\
&= \sum_{t=0}^{\tau} \rho^t \{P_{EC} Q_R - P_{C,t} Q_C - C_C - C_{C_{CO_2}}\}
\end{aligned} \tag{3}$$

where ρ is the social discount factor, P_{EC} and P_{ER} are the prices of electricity from coal and renewable, Q_R is the quantity of electricity generated from coal/renewable, and Q_C is the quantity of coal needed to generate Q_R .

Following previous literatures [15]- [19], this research assumes that the price of coal is stochastic and follows Geometric Brownian motion (GBM). The current price of P_C depends on its previous price, and the drift and variance rates of time series of coal prices as shown in Equation 4

$$P_{C,t} = P_{C,t-1} + \alpha P_{C,t-1} + \sigma P_{C,t-1} \varepsilon_{t-1} \tag{4}$$

with α and σ are the GBM rate of drift and variance of coal prices, and ε a random number.

The parameters α and σ are approximated using augmented Dickey-Fuller (ADF) test from time series of coal prices [20]. The estimates obtained in ADF test are used to generate a matrix of random numbers that represent possible prices of coal from initial values of zero to US\$200 at every investment period from zero to T . These values are then used to calculate the present values of electricity generation from coal for each period.

Using Monte Carlo simulation, the expected NPV for generating electricity from coal is estimated by calculating the $NPV_{C,t}$ in Equation 3 and repeating the process for a sufficiently large number $J = 10000$ times. Expected net present value is calculated by taking the average of NPV_C for every initial price of coal $P_{C,0}$ as shown in Equation 5.

$$\mathbb{E}\{NPV_{C,J}|P_{C,0}\} \approx \frac{1}{J} \sum_{j=1}^J NPV_{C,j} \approx \mathbb{E}\{NPV_C|P_{C,0}\} \tag{5}$$

The next exercise in identifying the optimal timing and associated trigger price of coal for shifting technologies is done with dynamic optimization as shown in Equation 6

$$\max_{0 \leq \tau < T+1} \mathbb{E} \left\{ \sum_{t=0}^{\tau} \rho^t \pi_{C,t} + \sum_{t=\tau}^T \rho^t \pi_{C,t} (1 - \mathbb{I}_{\{\tau \leq T\}}) + [NPV_R + NPV_C](\mathbb{I}_{\{\tau \leq T\}}) \right\} \tag{6}$$

where $\mathbb{I}_{\tau \leq T}$ is an indicator equal to 1 if switching to renewable energy, otherwise, equal to 0. This model describes an investor who is given a specific period T to decide whether to continue generating electricity from coal or invest in renewable energy. In this model, $\sum_{t=0}^{\tau} \rho^t \pi_{C,t}$ accounts to the net present value of using coal from initial period $T=0$ until τ when the investor makes the decision. If the investor chooses not to invest ($\mathbb{I}_{\tau \leq T}=0$), he incurs a net present value of $\sum_{t=\tau}^T \rho^t \pi_{C,t}$ from period τ until the end of the coal plant's lifetime. If the investor chooses to invest ($\mathbb{I}_{\tau \leq T}=1$), he incurs a net present value of NPV_R from successive

(three-period) investment in renewables plus NPV_C , as generation from coal will continue at a lower quantity because other electricity will be generated from renewables.

From Equation 6, the investor's problem is to choose the optimal timing of investment τ , to maximize the expected net present value of investment. The problem is solved backwards using dynamic programming from the terminal period for each price of coal $P_{c,t}$ as shown in Equation 7

$$V_t(P_{c,t}) = \max\{\pi_{c,t-1} + V_t(P_{c,t-1}), NPV_R + NPV_C\} \quad (7)$$

with V_t as the option value of investment at coal price $P_{c,t}$.

The optimal timing of investment \widetilde{P}_C is characterized by the minimum price of coal so that switching to renewable energy is optimal as shown in Equation 8 [19] – [21].

$$\widetilde{P}_C = \min\{P_{c,t} | V_0(P_{c,t}) = V_T(P_{c,t})\} \quad (8)$$

Finally, investment strategy is described by a decision to invest when $\widetilde{P}_C \leq P_c$, otherwise, investment can be delayed in later periods until $\widetilde{P}_C = P_c$.

- **Parameter Estimation and Investment Scenarios**

The following scenarios describe various environments that affect investment decisions in renewable energy in the Philippines. Sensitivity of investment values and optimal timing are analyzed with respect to growth rate of renewable energy investment, price of electricity from renewable energy, investment cost, and carbon prices.

The first scenario is the BAU case which describes the current renewable energy investment scenario in the country. To estimate a suitable set of parameters in this scenario, secondary data from the Philippine's Department of Energy and Energy Information Administration are used [12], [22]. A 30-year period of average annual coal prices from 1987-2016 is used to run the ADF test described in Equation 4. The ADF test result (see Supplementary Information - Table 2) implies that the null hypothesis that pt has a unit root cannot be rejected at all significant levels, hence, coal prices conform with GBM. From this test, the estimated GBM parameters are $\alpha=0.032027$ and $\sigma=0.249409$, and are used to approximate stochastic prices of coal for each investment period. The social discount rate is set to 7.5%. From Equation 3, $C_{c_{CO_2}}$ is set to zero as there are no existing carbon prices in the Philippines at present. The growth rate of renewable energy investment is set to 2% per annum. This is equivalent to 470GWh of electricity generation from renewables. From this value, the investment cost and operations and maintenance cost for renewables are estimated, as well as the costs and quantity of coal needed to generate this amount. The prices of electricity, $P_{ER} = P_{EC} = \text{US\$}182.2/\text{MWh}$ are set equal to the current domestic electricity price, constant during the entire investment period, and independent of the domestic demand. Assumptions indicate that renewable energy sources can generate electricity at an annual average of Q_R all throughout its lifetime; there are no technological innovations that affect energy efficiency and overnight costs of renewables; and stochastic prices of coal are independent of the demand for renewable energy.

The second scenario describes a situation of an accelerated growth rate of renewable energy investment from the current 2% to 4%, 6%, and 8%. Meanwhile, the third scenario analyzes the effect of prices of electricity from renewable energy by increasing the current FiT rates to proposed rates. Three prices are set: US\$182.2/MWh at the BAU case, US\$160/MWh which is 10% lower than the BAU case, and US\$200/MWh which is 10% higher. The third scenario describes a situation of a decline in investment costs for renewable energies by 5%, 10%, and 15%, respectively. The last scenario proposes a government policy of introducing carbon tax for electricity generation from coal. The carbon tax is set to US\$ 0.504/MWh.

III. RESULTS AND DISCUSSION

- **Business as usual scenario**

The dynamic optimization process described in the previous section results in three significant values. First is the option value which is equal to the maximized value of either investing in renewables or continuing to use coal. Second is the value of waiting as described by the vertical distance between option value curves: initial period (dotted) and terminal period (bold) of investment. This value approximates the gains of an investor if investment is delayed or postponed to some period. The last estimated value is the optimal timing of investment denoted by the trigger prices of coal for shifting electricity source from coal to renewables. This trigger price is illustrated as the intersection of the two option value curves, and indicates the threshold where the value of waiting is zero and that an investor has no benefit to delay the investment to renewables.

Figure 1 shows the dynamics of option values at different prices of coal in the business as usual scenario. The first point of interest is the positive option values. It indicates that investment in renewable energy incurs positive returns at the current energy situation in the Philippines. This contradicts with the result of Detert and Kotani [19] where the optimization yields negative option values describing a government controlled, operated, and subsidized energy regime. The next point of interest is option value curves sloping downward. This indicates that option values decrease with increasing cost for input fuel. At certain point on the curves, the option values become constant. These are the prices of coal where investment in renewable is a better option than continuing to use coal for electricity generation. The positive values further indicate positive NPV_R for investing in renewables. In this scenario, the result shows that the trigger price of coal for shifting technologies is US\$ 129/short ton. This trigger price is higher than the current price of coal US\$93.13/short ton (year 2016), and implies that delaying investment in renewables is a better option. However, at the current coal price, the value of waiting to invest is -US\$105.4 million. This negative value indicates possible losses incurred from delaying investment in renewables.

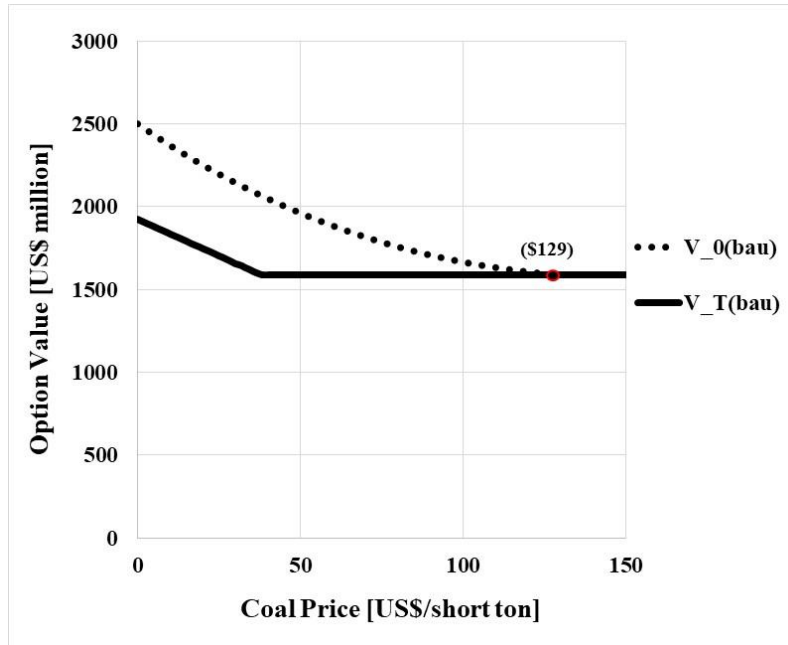


Fig. 1. Option values at the business as usual scenario

- **Growth rate of renewable energy investment scenario**

This scenario describes an accelerated growth of investment in renewable energy sources. While the country is aiming to increase the current share of energy generation from renewables from 25% to 60% by 2030 at 4% annual growth rate [5], this goal seems unattainable as the country's electricity demand is increasing at a faster rate than renewable investments [4]. This scenario examines how changing the rate of growth in renewable energy investment affects the option values and trigger prices.

The results of dynamic optimization at various growth rates are shown in Figure 2. It can be observed that option value curves shift upwards. This implies that increasing investment in renewables incurs higher returns from economies of scale. Doubling of wind farms could result in price reductions as the costs can be spread over large production of electricity [23]- [25]. It can be noticed that the trigger prices of coal have also decreased from US\$129/short ton in the BAU scenario, to US\$120, US\$113, and US\$105 at 4%, 6%, and 8% growth rates. Finally, the value of waiting to invest varies from -US\$105.4M at BAU scenario, to -US\$139.5M at 4% growth, -US\$146M at 6%, and -US\$153.7M at 8% growth rates. These results suggest that accelerating the current growth rate from business as usual prevents potential losses from waiting to invest in renewables.

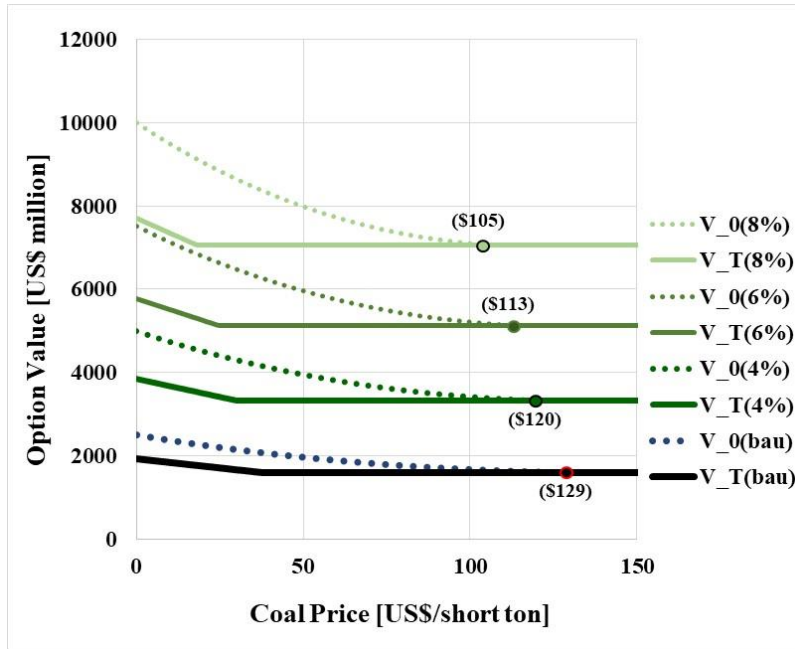


Fig. 2. Option values at different rates of renewable energy investment

- **Price of electricity from renewable energy**

In this scenario, the effect of changing electricity prices from renewables on option values and trigger prices is analyzed. Currently, the Philippines is one of the countries with the highest electricity rates in the Asia-Pacific region. Compared with neighboring countries including Thailand, Malaysia, South Korea, Taiwan, and Indonesia, the prices are lower as the government subsidized the cost through fuel subsidy, cash grants, additional debt, and deferred expenditures. In the Philippines, electricity prices are higher due to no government subsidy, fully cost reflective, imported fuel-dependent, and heavy taxes across the supply chain [26], [27]. By changing the value broadly, this scenario presents how potential government actions regarding electricity prices affect investment conditions in renewable energy.

Figure 3 illustrates the optimization outcomes with varying electricity prices. The result shows an upward shift of option values at higher electricity prices. This result is expected as higher price increases the revenues and the net present value of electricity generation from renewable energy. On the other hand, the result shows the inverse relationship of electricity prices and trigger prices from US\$129/MWh in BAU to US\$100/MWh at 10% higher and US\$159/MWh at 10% lower electricity price. The values of waiting to invest also show a similar trend from -US\$105.4M at BAU to -US\$25.9M at higher and -US\$241.6M at lower electricity price. This implies that setting the price of electricity generated from renewables higher than current tariff provides a better environment for renewable energy investments. Nevertheless, this study also considers the possibility that extensive electricity generation from renewable energy sources has significant impact on the electricity prices as stated in previous literatures [28-30].

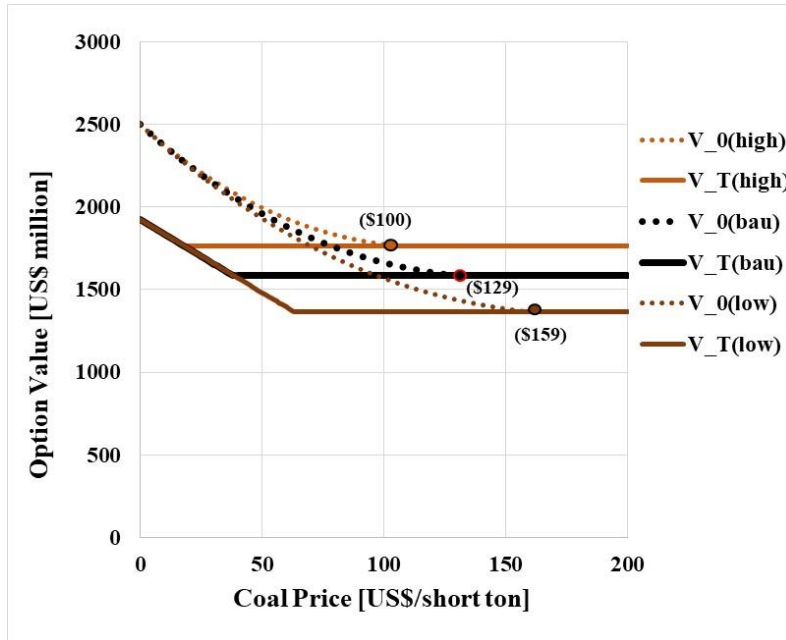


Fig. 3. Option values at various electricity prices from renewable sources

- **Investment cost scenario**

This scenario describes how decline in overnight cost affects investment in renewables. In the recent years, growth in renewable energy investments is driven by several factors including the improving cost competitiveness of renewable technologies, policy initiatives, better access to financing, growing demand for energy, and energy security and environmental concerns [2], [31] This scenario focuses on the effect of renewable energy cost on investment option values and trigger prices of coal for shifting technologies.

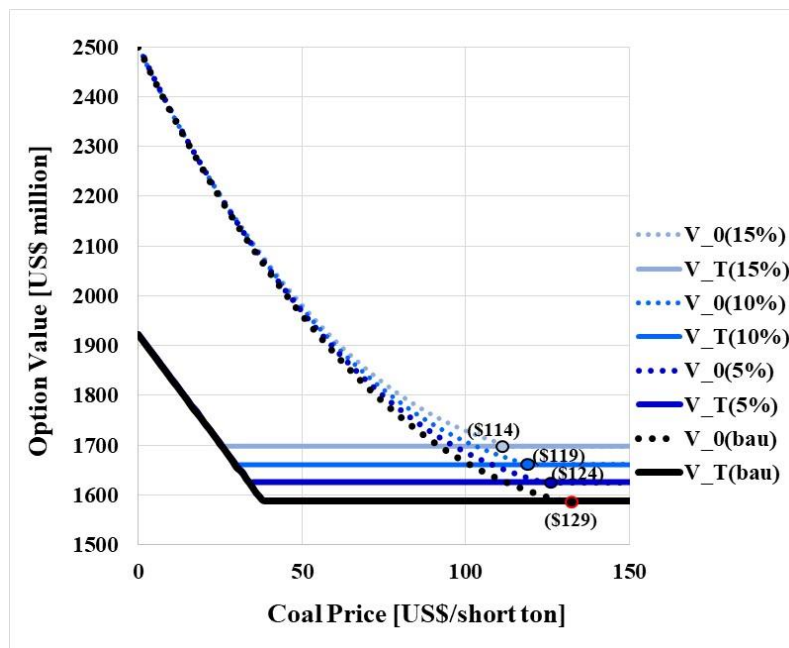


Fig. 4. Option values at different decline of renewable investment cost

Figure 4 shows the dynamics of option values at various investment cost scenarios. The result shows an upward shift in the option value curves. This outcome is evident as lower investment cost incurs higher net present value for renewable energy, leading to higher option values. The trigger prices decrease from US\$129 in BAU to US\$124, US\$119, and US\$114 at 5%, 10%, and 10% cost reduction. The value of waiting also decreases from -US\$105.4M in BAU to -US\$86.5M, -US\$68.6M, and -US\$52.2M, respectively. This result confirms the rapid growth in investment as caused by the sharp decline in renewable technology costs.

- **Externality scenario**

The last scenario discusses the effect of carbon prices for electricity generation from coal. Currently, there are no carbon prices in the Philippines. This study evaluates the effect of imposing carbon tax as proposed in previous literatures [32]- [34]. As shown in Figure 5, the option values and trigger prices decrease with the addition of externality cost. This result is anticipated as additional cost decreases the value of electricity generation from coal. It can also be noted that the trigger price is lower than the current price of coal equal to US\$93/short ton (year 2006). This implies that investing in renewables is a better option than continuing to use coal if carbon tax is imposed. Furthermore, with carbon tax, the demand for carbon-intensive inputs, including coal and oil, will decrease, while less carbon- and carbon free energy inputs eventually increase. This finally supports the research aim of analyzing renewables as a cleaner and more sustainable source of energy and a better alternative to coal.

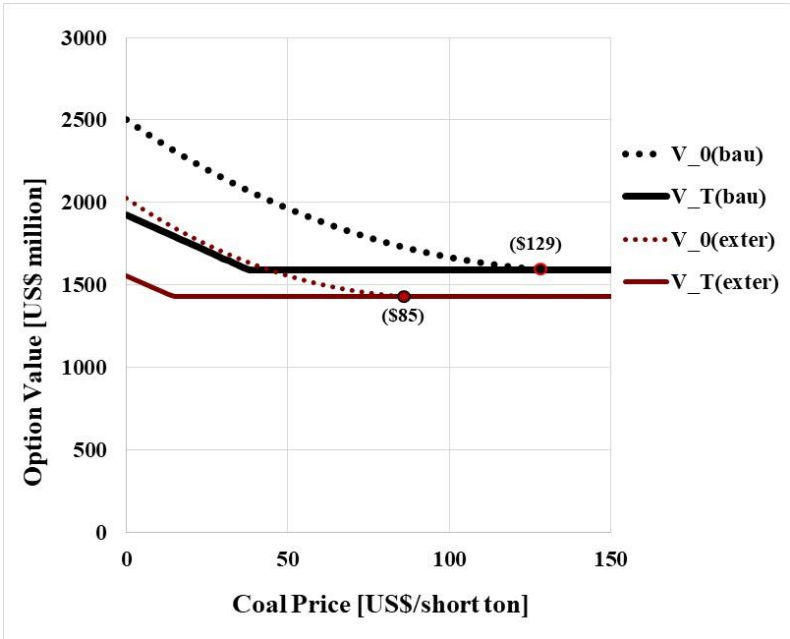


Fig. 5. Option values with externality cost for using coal

IV. CONCLUSION

This study presented various investment scenarios that represent energy switching decisions that apply to developing countries. By taking the case of the Philippines, this study employed real options approach to evaluate the maximized option values of investing in renewables, value of delaying investment, and trigger prices of coal for shifting technologies from coal to renewable sources. While numerous studies applied this approach to analyze renewable energy investments, this study expanded the existing body of research by considering a multi-period investment and taking account of uncertainties in input fuel prices, renewable technology cost, growth of investment in renewables, and externality cost for using coal.

The analyses conclude that renewable energy is a better option than continuing to use coal for electricity generation in the Philippines. Delaying the investment in renewables may lead to possible welfare losses. Shifting from fossil-based to renewable sources is very timely as the costs of renewable technologies have decreased immensely throughout the years and expected to continuously fall. To support investments in renewable energy, the government must set higher FIT rates than business as usual and impose carbon tax for using carbon-intensive fuels. Further, the growth in investment in renewables should be increased to meet the country's goal of 60% energy generation from renewable sources and decrease its dependence on imported fossil fuels.

While this study compared coal and renewables, particularly wind energy, for electricity generation, future studies may also analyze other sustainable energy sources including hydropower, solar, geothermal, biomass, tidal/ocean, and other technologies designed to improve energy efficiency. Further, environmental uncertainty, such as climate variability and weather disturbances, that affects energy generation may also be included to further capture investment scenarios relevant to climate change policy.

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Supplementary Information

REAL OPTIONS ANALYSIS OF RENEWABLE ENERGY INVESTMENT SCENARIOS IN THE PHILIPPINES

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Table 1. List of Variables and Estimation Parameters

V_t	Option value of investment at each price of coal at each period t, US\$
π_R	Profit for investing in renewable energy, US\$
$\pi_{C,t}$	Profit of using coal for electricity generation, US\$
NPV_C	Net present value of using coal for electricity generation, US\$
NPV_R	Net present value of investing in renewable, US\$
PV_R	Present value of renewable energy, US\$
P_{ER}	Price of electricity from renewable energy, US\$/MWh
P_{EC}	Price of electricity from coal, US\$/MWh
$P_{C,t}$	Stochastic price of coal, US\$/short ton
Q_R	Quantity of electricity from renewable/coal, MWh
Q_c	Quantity of coal needed to produce Q_R , short ton
C_c	Annual marginal operations and maintenance cost for electricity generation using coal, US\$
C_R	Annual marginal operations and maintenance cost for electricity generation from renewable, US\$
$C_{C_CO_2}$	CO_2 cost from coal, US\$
I_R	Investment cost for renewable energy, US\$
r	Installment periods of renewable energy investment
T_R	Lifetime of electricity generation from renewable energy, years
T	Total period of investment, years
τ	Period where investor decides to invest in renewable
ρ	Discount factor
α	GBM rate of drift of coal prices
σ	GBM variance of coal prices
φ	Growth of renewable energy investment cost
$\mathbb{1}_{\tau \leq T}$	Indicator equal to 1 if switching to renewable or energy is made, otherwise, equal to 0
J	Number of times for Monte Carlo simulation process
V_0	Option value at the initial period of investment
V_T	Option value at the terminal period of investment

Table 2. Augmented Dickey-Fuller Unit Root Test result for Coal Prices (1987-2016)

Null Hypothesis: LNPRICE has a unit root
 Exogenous: Constant
 Lag Length: 3 (Automatic - based on SIC, maxlag=7)

	t-Statistic	Prob.*
Augmented Dickey-Fuller test statistic	-1.119480	0.6924
Test critical values:		
1% level	-3.711457	
5% level	-2.981038	
10% level	-2.629906	

*MacKinnon (1996) one-sided p-values.

Augmented Dickey-Fuller Test Equation
 Dependent Variable: D(LNPRICE)
 Method: Least Squares
 Date: 09/11/17 Time: 16:48
 Sample (adjusted): 1991 2016
 Included observations: 26 after adjustments

Variable	Coefficient	Std. Error	t-Statistic	Prob.
LNPRICE(-1)	-0.103245	0.092226	-1.119480	0.2756
D(LNPRICE(-1))	0.226008	0.205954	1.097368	0.2849
D(LNPRICE(-2))	-0.377858	0.199774	-1.891430	0.0724
D(LNPRICE(-3))	0.557382	0.213207	2.614279	0.0162
C	0.414604	0.356738	1.162208	0.2582
R-squared	0.359108	Mean dependent var		0.032027
Adjusted R-squared	0.237033	S.D. dependent var		0.249409
S.E. of regression	0.217853	Akaike info criterion		-0.038947
Sum squared resid	0.996662	Schwarz criterion		0.202994
Log likelihood	5.506316	Hannan-Quinn criter.		0.030723
F-statistic	2.941702	Durbin-Watson stat		1.563558
Prob(F-statistic)	0.044650			

Table 3. Summary of Estimation Parameters for Dynamic Optimization

Parameter	Value	Unit	Description
alpha	0.032027		estimated myu value of GBM unit root test of coal prices
sigma	0.249409		standard deviation of GBM unit root test of coal prices
rho	0.91		discount factor
Pmin	0	US\$/short ton	base-level for price of coal
Pmax	200	US\$/short ton	maximum limit for price of coal
Pstep	1	US\$/short ton	the value between each price node
P_e	182.2	US\$/MWh	price of electricity
Q_e	1409.4	GWh	average annual electricity generated from coal
Q_e1	939.6	GWh	annual electricity generated from coal after first installment of renewables
Q_e2	469.8	GWh	annual electricity generated from coal after second installment of renewables
Q_c	862241	short ton	average annual quantity of coal used to generate Q_e
Q_c1	574827	short ton	average annual quantity of coal used to generate Q_e1
Q_c2	287414	short ton	average annual quantity of coal used to generate Q_e2
C_c	28.2M	US\$	annual O&M cost to generate Q_e from coal
C_c1	18.8M	US\$	annual O&M cost to generate Q_e1 from coal
C_c2	9.4M	US\$	annual O&M cost to generate Q_e2 from coal
Q_w1	469.8	GWh	average annual electricity generated from renewables after the first installment period
Q_w2	939.6	GWh	average annual electricity generated from renewables after the second installment period
Q_w3	1409.4	GWh	average annual electricity generated from renewables after the third installment period
C_w	6.2M	US\$	annual O&M cost for Q_w1
I_w1	561M	US\$	investment cost of renewables on the first installment
I_w2	323M	US\$	investment cost of renewables on the first installment
I_w3	298M	US\$	investment cost of renewables on the first installment
LL	30	years	time horizon for dynamic optimization problem
T_c	15	years	number of periods for NPV of coal
T_r	30	years	time horizon for renewable energy generation
C_CO2	0.504	US\$	Carbon cost
	160, 182.2(BAU), 200	US\$/MWh	Prices of electricity from renewables
	2%(BAU), 4%, 6%, 8%		Growth rate of renewable energy investment
	0%(BAU), 5%, 10%, 15%		Decline in renewable technology cost