International Journal of Sustainable Energy and Environmental Research

2017 Vol. 6, No. 2, pp. 50-62
ISSN(e): 2306-6253
ISSN(p): 2312-5764
DOI: 10.18488/journal.13.2017.62.50.62

COAL, RENEWABLE, OR NUCLEAR? A REAL OPTIONS APPROACH TO ENERGY INVESTMENTS IN THE PHILIPPINES

Casper Agaton[1]

[1]*Institute of Development Research and Development Policy, Ruhr University of Bochum, Universitaetsstr., Germany*
Email: Casper.Agaton@rub.de Tel: +4915777985839

Article History
Received: 26 September 2017
Revised: 22 November 2017
Accepted: 5 December 2017
Published: 18 December 2017

Keywords
Renewable energy
Nuclear energy
Nuclear accident
Coal prices
Dynamic optimization
Investment under uncertainty.

ABSTRACT

The Philippines is making a significant step to become energy independent by developing more sustainable sources of energy. The country sees investments in renewable energy and nuclear energy as promising alternatives to address the country's problem in energy security. This paper evaluates the comparative attractiveness of either investing in alternative energy sources or continuing the use of coal for electricity generation in the Philippines. Applying the real options approach under coal price uncertainty, this study analyzes investment values and optimal timing of switching technologies from coal to renewable or nuclear energy. It also examines how negative externality and the risk of nuclear accident affect investment decisions. Results identify possible welfare losses from waiting or delaying investing in alternative energy. Negative externality favors investment in nuclear energy over coal, whereas the risk of nuclear accident favors investment in renewable energy.

Contribution/Originality: This study contributes in the existing literature by applying real options approach to analyze investment strategies of shifting energy source from coal to renewable or nuclear energy considering the uncertainty in coal prices, risk of nuclear accident, and negative externality.

1. INTRODUCTION

The rapid economic development in the Philippines causes dramatic increase in country's energy demand in the recent decades. As the country's electricity sector was highly dependent on imported coal as a source of energy for power generation, the country's energy security has been vulnerable to various crises and unstable coal prices. To address the increasing energy demands and decreasing dependence on imported coal, the government started its nuclear program during the world oil crisis in 1973. However, due to numerous protests related to nuclear disasters, controversies, and nuclear safety, the succeeding administration discontinued the program (Beaver, 1994). In the recent years, the government is considering rehabilitating the mothballed plant and construct four additional nuclear power plants as a long-term option for energy source in the country (IAEA, 2016). Renewable energies (RE), on the other hand, remain the most promising alternatives to suffice the country's energy demand. At present, RE sources, particularly geothermal and hydropower, account to 25% of the country's power capacity (DOE, 2016). The country is aiming to increase this capacity to 60% and become energy independent by 2030 by developing localized RE resources (DOE, 2012). However, competitive prices of coal, economic downturns, political instability, natural calamities, and skepticism challenge the investments on these alternatives. This study takes this motivation to suggests a strategy whether to invest or not, and when to invest on alternative energy source to address the country's problem on energy security and sustainability.

Recent studies discuss renewable energy investments in the Philippines. Hong and Abe (2012) use multiple correspondence analysis to deal with the technical, economic, and social aspects of developing RE projects to promote energy sustainability; Meller and Marquardt (2013) present a holistic approach to calculate the costs of RE and compare their competitiveness with conventional sources of fuel; and Sovacool (2010) proposes an analytical framework to evaluate RE support mechanisms such as renewable portfolio standards, green power programs, public research and development expenditures, systems benefits charges, investment tax credits, production tax credits, tendering, and feed-in tariffs in Southeast Asia including the Philippines. However, the methodologies in these literatures do not capture important characteristics of investment such as irreversibility, uncertainty, and flexibility in timing of investment (Baecker, 2007). Real options approach (ROA) overcomes these limitations by combining uncertainty and risk with flexibility of investment as potential factors that give additional value to the project (Brach, 2003).

Myers (1977) referred the term "real options approach" (ROA) to the application of option pricing theory to valuate non-financial or "real" assets. It is useful in project appraisal when revenues from investment contain uncertainty in the future cash flow and when there is a possibility to choose the timing of investment (Yang *et al.*, 2008). Recent studies use ROA to analyze investment decision particularly with renewable energy. These include (Zhang *et al.*, 2016) on the application of real options to solar photovoltaic power generation in China; Kitzing *et al.* (2017) on the analysis of wind energy investments under different support schemes; and Kim *et al.* (2017) on analyzing uncertainty variables affecting investment in developing countries with a case in Indonesia. Several studies also use this approach to analyze nuclear energy investments including the works of Rothwell (2006) on evaluating new nuclear power plants in the United States of America; Shi and Song (2013) on evaluating how risks and uncertainties affect the development of new power plants in China; Tian *et al.* (2016) on analyzing the influence of carbon market on nuclear investment in China; and Cardin *et al.* (2017) on the flexibility analysis for nuclear power plants with uncertainty in electricity demand and public acceptance. This research tries to contribute to these literatures by analyzing energy switching problem from coal to renewable energy or nuclear energy, involving uncertainty in coal prices, negative externality, and the risk of nuclear accident.

This paper presents a framework of energy investment strategy that applies to developing countries which are highly dependent on imported fuel for electricity generation. The main goal is to provide an example of a framework of full-system switch investment decision by applying the case of the Philippines. Although this acknowledge having diverse options for energy investments in the Philippines, this study only focuses on the problem of switching to renewable energy and nuclear energy in line with the country's long-term energy plan (DOE, 2012) and the Philippine nuclear power development program (IAEA, 2016). Specifically, this study aims to evaluate the option values of energy investment and identify the trigger price of shifting technologies from coal to these alternative energies. This further aims to present investment environments where investing in renewable energy is a better alternative than nuclear. These environments include scenarios where externality and risk of nuclear disaster affect the dynamics of option values of trigger price strategy. This finally aims to recommend various government actions to address environmental problem, supply chain, and national security regarding energy.

2. METHODOLOGY, DATA, AND SCENARIOS

This study uses ROA to analyze investment decisions whether to continue using coal for electricity generation or shift to alternative energy sources. Matlab programming is used to (a) generate transition probability matrix that describe stochastic prices of coal, (b) Monte Carlo simulation to calculate the expected net present value of using coal and expected net present value of nuclear energy considering the probability of an accident, and (c) dynamic optimization that maximizes the value of investment at each price of coal from initial period to final period of investment. From this optimization, the trigger prices of coal for shifting technologies from coal to renewable or nuclear are then identified. To describe a more realistic situation where investors, policy makers, and the people are skeptical in investing in nuclear energy due to its risks, this study poses a scenario of the possibility of having a nuclear accident. Finally, negative externality of using various types of energy is incorporated in the ROA model to reflect national energy security and environmental concerns such as water and air pollution, greenhouse gas emission, and ecosystem and biodiversity loss.

2.1. Dynamic Optimization

This study adopts the work of Detert and Kotani (2013) on making investment decisions under uncertainty using dynamic optimization. In this research, ROA is used to describe a model of an investor that maximizes the value of investment of either investing in alternative energy or continuing the use of coal for electricity generation as shown in equation 1 (see Table 1 for an overview of all model parameters and variables).

$$\max_{0\leq\tau<T+1}\left[\left\{\sum_{t=0}^{\tau}\rho^t\pi_{c,t}+\left\{\rho^{T_c}\mathbb{E}NPV_{c,t}\langle 1-\mathbb{1}_{\tau\leq T}\rangle\right\}\middle|P_{c,t}\right\}+\left\{NPV_A\langle\mathbb{1}_{\tau\leq T}\rangle\right\}\right] \quad (1)$$

where

$$\pi_{c,t}=P_EQ_E-P_{c,t}Q_c-C_c-E_c \quad (2)$$

$$NPV_{c,t}=\sum_{t=T}^{T_c}PV_{c,t}=\sum_{t=T}^{T_c}\rho^t\pi_{c,t}=\left(\frac{1-\rho^{T_c+1}}{1-\rho}\right)\left(P_EQ_E-P_{c,t}Q_c-C_c-E_c\right) \quad (3)$$

$$NPV_A=\begin{cases}\sum_{m=0}^{T_R}\rho^m\pi_R-I_R-E_R=\left(\frac{1-\rho^{T_R+1}}{1-\rho}\right)[P_EQ_E-C_R]-I_R-E_R\\ \sum_{m=0}^{T_N}\rho^m\pi_N-I_N-E_N=\left(\frac{1-\rho^{T_N+1}}{1-\rho}\right)[P_EQ_E-C_{NF}-C_N]-I_N-E_N\end{cases} \quad (4)$$

Using dynamic programming, the option value of investment for each period as shown in equation 5.

$$V_t(P_{c,t})=max\left[\pi_{c,t}+\rho\mathbb{E}\left(V_{t+1}(P_{c,t+1})\middle|P_{c,t}\right),NPV_A\right] \quad (5)$$

The option value, $V_t(P_{c,t})$, is calculated by maximizing the investment at each price of coal, $P_{c,t}$ from 0 to US$500/short ton. The dynamic optimization process is set to 40 years to represent a situation where an investor is given a period to make an investment decision. After such period, he has no other option but to continue using coal for electricity generation. The choice is valued for another 40 years to represent the lifetime of power plant using coal.

From the dynamic optimization results in equation 5, the dynamics of option values are analyzed and the trigger price are identified. The trigger price in this model is described as the optimal timing for switching technologies from coal to alternative energy as shown in equation 6. From the given equation, the trigger price is evaluated as the minimum price of coal where the option value at the initial period equals the terminal period of investment.

Table-1. Description of Variables

Variable	Description, unit
V_t	Option value of investment at each price of coal at each period t, US$
NPV_A	Net present value of using coal for electricity generation, US$
NPV_A	Net present value of investing in renewable or nuclear, US$
$\pi_{c,t}$	Profit of using coal for electricity generation, US$
π_R	Profit for investing in renewable energy, US$
π_N	Profit for investing in nuclear energy, US$
P_E	Price of electricity in the Philippines, US$/MWh
$P_{c,t}$	Stochastic price of coal, US$/short ton
Q_E	Quantity of electricity demand from coal, MWh
Q_c	Quantity of coal needed to produce Q_E, short ton
C_c	Annual marginal cost for electricity generation using coal, US$
C_R	Annual marginal cost for electricity generation from renewable, US$
C_N	Annual marginal cost for electricity generation from renewable, US$
C_{NF}	Annual marginal fuel cost for electricity generation from renewable, US$
I_R	Investment cost for renewable energy, US$
I_N	Investment cost for nuclear energy, US$
C_D	Decommissioning cost for closing nuclear power plant, US$
C_A	Cost of nuclear accident, US$
E_c	Externality cost of generating electricity from coal, US$
E_R	Externality cost for renewable energy generation, US$
E_N	Externality cost for nuclear energy generation, US$
T_R	Lifetime of electricity generation from renewable energy, years
T_N	Lifetime of electricity generation from nuclear energy, years
T_C	Lifetime of electricity generation using coal, years
T	Total period of investment, years
τ	Period where investor decides to invest in renewable or nuclear, years
ρ	Discount factor
$\mathbb{1}_{\tau \leq T}$	Indicator equal to 1 if switching to renewable or nuclear energy is made, otherwise, equal to 0
J	Number of times for Monte Carlo simulation process

Source: author assigned variables and estimation parameters for the proposed real options model, 2017

$$\hat{P}_c = min\{P_{c,t} | V_0(P_{c,t}) = V_T(P_{c,t})\} \quad (6)$$

2.2. Geometric Brownian Motion and Monte Carlo Simulation

In line with previous studies (Xian *et al.*, 2015; Tietjen *et al.*, 2016; Wang and Du, 2016) this study assumes that the price of coal is stochastic and follows Geometric Brownian motion (GBM) with a drift. Using discretized specification for GBM, the price of coal as shown in equation 7

$$P_{c,t+1} = P_{c,t} + \alpha P_{c,t} + \sigma P_{c,t} \varepsilon_t \quad (7)$$

where α and σ are the drift and variance rates of time series of prices of coal (Dixit and Pindyck, 1994). This equation illustrates that the previous price affects the current price of coal. Applying the work of Insley (2002) the values of α and σ are estimated using augmented Dickey-Fuller (ADF) test. The annual average prices of coal from 1970 to 2016 from World Bank-Global Economic Monitor are used to run the ADF test. The result in table 2 implies that the null hypothesis that p_t has a unit root cannot be rejected at all significant levels. Therefore, coal prices conform with GBM. The estimated GBM parameters are $\alpha = 0.011133$ and $\sigma = 0.250153$ and are used to approximate stochastic prices of coal for each investment period $t = 0$ to $t = T_c$ at each initial price of coal from $P_c = 0$ to $P_c = US\$300/short\ ton$ at an increment of US$ 1/ short ton.

Table-2. Augment Dickey-Fuller unit root test of coal prices

Test statistic and significance levels for critical values		t-Statistic	Prob*
Augmented Dickey-Fuller test statistic		-2.338239	0.1648
Test critical values:	1% level	-3.581152	
	5% level	-2.926622	
	10% level	-2.601424	

Source: author computation using Eviews, 2017

This study applies Monte Carlo simulation to estimate the expected NPV of using coal for electricity generation in equation 1. In this process, the computation of NPV from equation 3 is repeated in a sufficiently large number of J =10000 times to approximate the expected NPV at each initial price of coal and take the average as shown in equation 8.

$$\mathbb{E}\{NPV_{c,J}|P_{c,0}\} \approx \frac{1}{J}\sum_{j=1}^{J} NPV_{c,J} \approx \mathbb{E}\{NPV_c|P_{c,0}\} \quad (8)$$

2.3. Risk of Nuclear Accident

Recent literatures discuss the probability of nuclear accident using classical probabilistic models, simple empirical approach, Poisson distribution, Poisson Exponentially Weighted Moving Average (PEWMA), Least Squares Monte-Carlo(LSM), and infinite mean model (Kaiser, 2012; Zhu, 2012; Hofert and Würthrich, 2013; Rangel and Lévêque, 2014). However, these do not fit with the ROA model described in this study where the decision to invest in nuclear energy is evaluated in an annual basis and so the probability of nuclear accident. This study proposes a ROA model considering a risk of having a nuclear accident. This study assumes that an accident may happen only once, at most, in the entire lifetime of nuclear energy generation. The energy generation terminates once the accident occurs, hence, accident cannot be repeated.

Assuming an independent and identically distributed (i.i.d.) random variable $x_i \sim Bernoulli$ for $i = \tau, \tau + 1, \ldots, \tau + T_N$ as shown in equation 9.

$$x_i = \begin{cases} 0 & \text{with probability } q(\tilde{t}) \quad \text{if no disaster} \\ 1 & 1 - q(\tilde{t}) \quad \text{otherwise} \end{cases} \quad \text{where } q(\tilde{t}) < 0 \qquad (9)$$

Stopping time, $\tilde{t}$, describes the period which nuclear accident happens subject to

$$\tilde{t} = min\{T_N: x_\tau + x_{\tau+1} + x_{\tau+2} + \cdots + x_{\tau+T_N} = 1\} \qquad (10)$$

The probability mass function of this Bernoulli distribution over possible outcomes of k, is

$$Pr(\tilde{t} = \tau + k) = [1 - q(\tilde{t})][q(\tilde{t})]^k \quad for\ k = 0, 1, 2, \dots, T_N \qquad (11)$$

The accident may happen after the switch to nuclear energy with t equal to $\tau, \tau + 1, \tau + 2, \dots, \tau + T_N, \dots, \infty$. Then the probability of a nuclear accident

$$Pr(\tilde{t} = \tau) + Pr(\tilde{t} = \tau + 1) + Pr(\tilde{t} = \tau + 2) + \cdots + Pr(\tilde{t} = \tau + T_N) = 1 \quad (12)$$

Using equation 11, the equation 12 can be expressed as

$$[1 - q(\tilde{t})] + [1 - q(\tilde{t})][q(\tilde{t})] + [1 - q(\tilde{t})][q(\tilde{t})]^2 + \cdots + [1 - q(\tilde{t})][q(\tilde{t})]^{T_N} + \cdots = 1 \quad (13)$$

Then the probability of having no accident in the lifetime of nuclear energy generation is described as $Pr(\tilde{t} > T_N) = 1 - Pr(\tilde{t} \le \tau + T_N)$. Therefore, the probability of having no nuclear accident decreases over time. The reason behind this is the assumption that nuclear plant increases the risk of an accident, as it gets older especially during a continued operation beyond the end of its useful years. The expected net present value of nuclear energy investment as follows

$$\mathbb{E}\{NPV_N\} = \mathbb{E}\{[NPV_N](1 - \mathbb{I}_{\{\tilde{t} \le T_N\}}) + [NPV_N](\mathbb{I}_{\{\tilde{t} \le T_N\}})\} \qquad (14)$$

where $(\mathbb{I}_{\{\tilde{t} \le T_N\}})$ is an indicator function equal to 1 if nuclear accident occurs, otherwise 0. Expanding the equation 14 with probability function for nuclear accident at each period gives

$$\mathbb{E}\{NPV_N\} = Pr(\tilde{t} > T_N)\left[\sum_{t=\tau}^{\tau+T_N} \rho^{\tau}\pi_N - \rho^{\tau+T_N}(C_D) - I_N\right]\left(1 - \mathbb{I}_{\{\tilde{t} \le T_N\}}\right)$$
$$+ \left\{ Pr(\tilde{t} = \tau)\left[\rho^{\tau}\pi_N - \rho^{\tau+\tilde{t}}(C_D + C_A) - I_N\right] \right.$$
$$+ Pr(\tilde{t} = \tau + 1)\left[\sum_{t=\tau}^{\tau+T_N} \rho^{\tau}\pi_N - \rho^{\tau+1}(C_D + C_A) - I_N\right]$$
$$+ Pr(\tilde{t} = \tau + 2)\left[\sum_{t=\tau}^{\tau+T_N} \rho^{\tau}\pi_N - \rho^{\tau+2}(C_D + C_A) - I_N\right] + \cdots$$
$$\left. + Pr(\tilde{t} = \tau + T_N)\left[\sum_{t=\tau}^{\tau+T_N} \rho^{\tau}\pi_N - \rho^{\tau+T_N}(C_D + C_A) - I_N\right]\right\}\left(\mathbb{I}_{\{\tilde{t} \le T_N\}}\right) \quad (15)$$

Using Monte Carlo simulation, binomial numbers are generated to represent the probability of having no accident. The process is repeated several times (10000) and get the average to estimate the expected probability value $\mathbb{E}Pr(\tilde{t} = \tau + t)$for each period of nuclear energy generation. These estimates are used to calculate the expected net present value of nuclear investment, $\mathbb{E}\{NPV_N\}$ in equation 1 to determine the option values of investment using the dynamic optimization process.

2.4. Data and Scenarios

To determine a suitable set of parameter values for the baseline scenario, this study uses data from Department of Energy (DOE, 2016) Energy Information Administration (EIA, 2017) and Nuclear Energy Agency (NEA, 2015). From these sources, the domestic electricity price, and the quantity of electricity generated from coal are determined. Using the 2015 electricity production from coal of 36,686GWh, the quantity of coal and the operations and management cost needed to generate this amount of electricity, as well as the investment costs, annual operations and management costs, and fuel costs for nuclear and RE are estimated. The decommissioning cost is incorporated in the investment cost of nuclear energy (NEA, 2016a). The country data for wind energy is used to represent the RE investment. The number of years of nuclear energy generation is set to 50 years while 30 years for RE. The social discount rate is 7.5%. In the base scenario, all externality values are set to zero to provide an initial estimate of comparison in later scenarios. This also describes the current situation in the country where externalities from various sources are not valued.

In the scenario of nuclear accident, the probability is set to 0.01% per year with damage cost comparatively higher than the values reported at the NEA (2016b). The accident cost is set greater than the values reported in literature to describe a more realistic maximum potential for nuclear damages. The last scenario incorporates the externality cost of electricity generation from various sources. The values used here are in line with the external cost of generating electricity in the Philippines (Meller and Marquardt, 2013) and average external costs for electricity generation technologies (EEA, 2010). The externality values are first set to US$6/MWh for renewable energy, US$1/MWh for nuclear energy to US$1/MWh while zero for electricity generation from coal (as described in base scenario). The value of externality for using coal are then adjusted from 0 to US$100/MWh at US$25/MWh increment. In this scenario describes how increasing externality cost from coal affects the options values and trigger prices of shifting technology from coal to alternative energies. This scenario also finds the threshold of externality cost for shifting technologies from coal to alternatives.

3. RESULTS

3.1. Base Scenario

Figure 1 shows the result of our estimation for the baseline scenario. The curves in Figure 1 illustrate the maximized option values of either continuing the use of coal for electricity generation or investing in renewable energy (blue curves) or nuclear energy (red curves). The first point of interest in this figure is that the option values decrease with coal price. This implies that the value of any investment decreases with higher cost of input fuel. Second, the straight line at the end of the curves indicate a situation where there is no better option but to shift technology from coal to renewable or nuclear. These lines also describe the net present values of renewable and nuclear energy investment. The results show that investment in RE gains higher NPV equal to US$31.525 billion than in nuclear energy with US$30.880 billion. However, note that NPV is not the sole determinant of investments in a ROA. We must also account for the optimal timing that maximize the value of investment opportunity (Dixit and Pindyck, 1994).

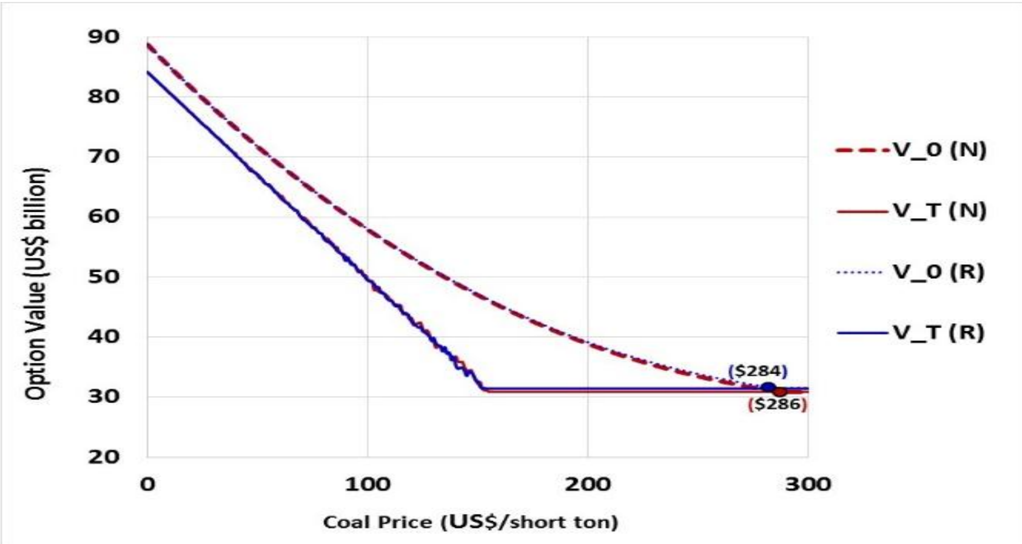

Figure-1. Option values of renewable and nuclear energy investments at base scenario
Note: V_0(N)-option value of investment in nuclear at initial period, V_T(N)-option value of investment in nuclear at terminal period, V_0(R)-option value of investment in renewable at initial period, V_T(R)-option value of investment in renewable at terminal period

The optimal timing of investment in this study is described as the trigger price of shifting technologies from coal to renewable or nuclear. In figure 1, the intersection of the two curves, option value at the initial period of investment (V_0) and at the terminal period (V_T), illustrate the trigger price of coal. At this price, an investor has no better option but to invest in any of the alternative energies. The result in Figure 1 shows that the trigger price of coal for investing in renewable is US$284/short ton and US$286/short ton in nuclear energy. Although renewable is slightly higher, the difference in trigger prices is not significant. Further, the value of option to wait is described as the difference between the option values at the initial period (dashed curve) and the terminal period. It can observe that option values in the initial period of investment is higher than in the terminal period resulting to a negative value of option to wait in prices of coal below the trigger price. This indicates that waiting to invest in renewable or nuclear energy incurs losses.

3.2. Risk of Nuclear Accident Scenario

Figure 2 shows the comparison of the option values for nuclear energy investment with the probability of nuclear accident (black curves) and the baseline scenario for both nuclear and renewable. The results reveal that option values of nuclear decrease with the risk of nuclear accident. This result is expected as nuclear accident incurs huge costs to cover the reparation of damages, evacuation of affected residents, rehabilitation, and decommissioning. While this is the case, the trigger price increase from US$286/short ton to US$307/short ton of coal. This marginal increment suggest that it is more optimal to wait longer until the nuclear risk is resolved, or when the nuclear energy technology has advanced to the point of significantly reducing the probability of nuclear accident. Also from the figure, the difference in trigger prices between RE investment and nuclear energy with probability of nuclear accident becomes larger. Further, the options values for renewable is comparably higher than nuclear energy with the risk of accident. This suggests that it more optimal to invest in RE considering the possibility of having nuclear accident.

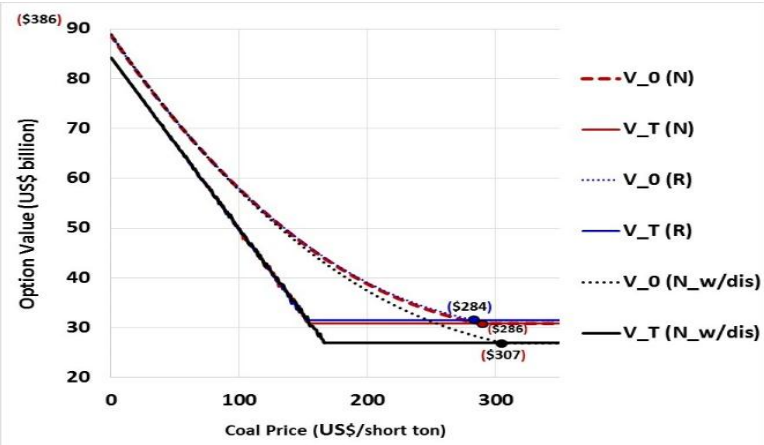

Figure-2. Option values with the risk of nuclear accident

Note: V_0(N)-option value of investment in nuclear at initial period, V_T(N)-option value of investment in nuclear at terminal period, V_0(R)-option value of investment in renewable at initial period, V_T(R)-option value of investment in renewable at terminal period, V_0(N_w/dis)-option value of investment in nuclear at initial period with accident risk, V_T(N_w/dis)-option value of investment in nuclear at terminal period with accident risk

3.3. Negative Externality Scenario

In this scenario analyzes the sensitivity of options values and trigger prices with the addition of negative externality to the base model. Figures 3 and 4 illustrate the dynamics of options values with negative externality for renewable energy and nuclear energy investments. The results reveal that option values decrease with increasing externality values for both renewable and nuclear energy investments. These results are foreseeable as negative externality incurs additional costs. It is also observed much decrease in the option values for renewable than nuclear energy.

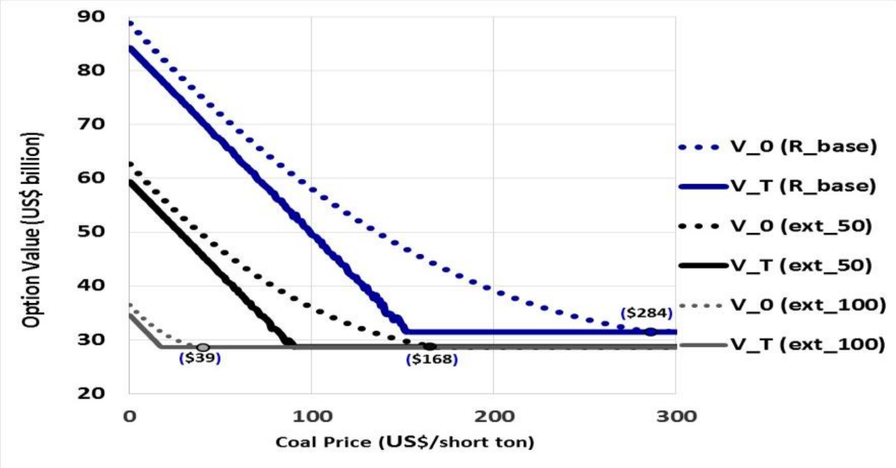

Figure-3. Option values of renewable energy investment with negative externality

Note: V_0(R_base)-baseline option value of investment in renewable at initial period, V_T(R_base)-baseline option value of investment in renewable at terminal period, V_0(ext_50)- option value of investment in renewable at initial period with US$50/MWh coal externality, V_T(ext_50)- option value of investment in renewable at terminal period with US$50/MWh coal externality, V_T(ext_100)- option value of investment in renewable at terminal period with US$100/MWh coal externality

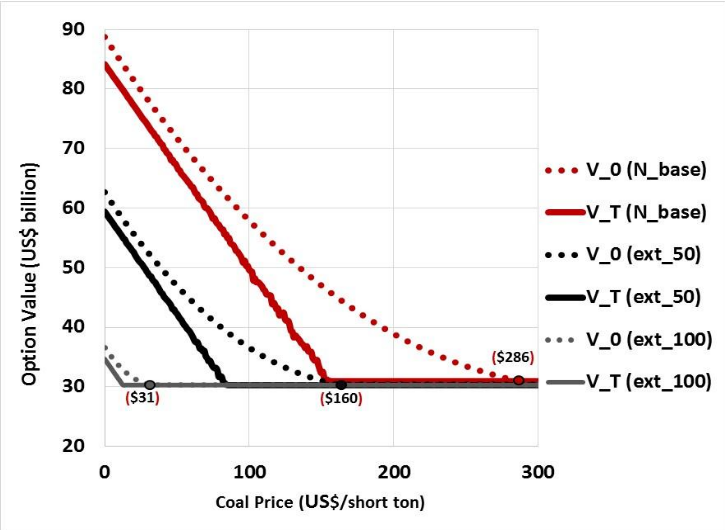

Figure-4. Option values of nuclear energy investment with negative externality

Note: V_0(N_base)-baseline option value of investment in nuclear at initial period, V_T(N_base)-baseline option value of investment in nuclear at terminal period, V_0(ext_50)- option value of investment in nuclear at initial period with US$50/MWh coal externality, V_T(ext_50)- option value of investment in nuclear at terminal period with US$50/MWh coal externality, V_T(ext_100)- option value of investment in nuclear at terminal period with US$100/MWh coal externality

Figure 5 shows the curves of trigger price of coal for shifting technologies from coal to renewable (blue) or nuclear (red) at various externality values of using coal. The results reveal declining trends in the trigger prices for both energy investments with increasing externality values. This suggests that it is more optimal to shift technology earlier from coal to renewable or nuclear energy considering negative externality costs. Also from the figure are the thresholds of externality costs of coal for each investment. This suggests that if the government is eager to attract investors and power producers to shift technologies, the government must set external cost for using coal in a form of externality tax equal to US$88.93/MWh for renewable energy and US$85.05/MWh nuclear energy. This result is also in line with the estimated average EU external costs for electricity generation technologies (EEA, 2010).

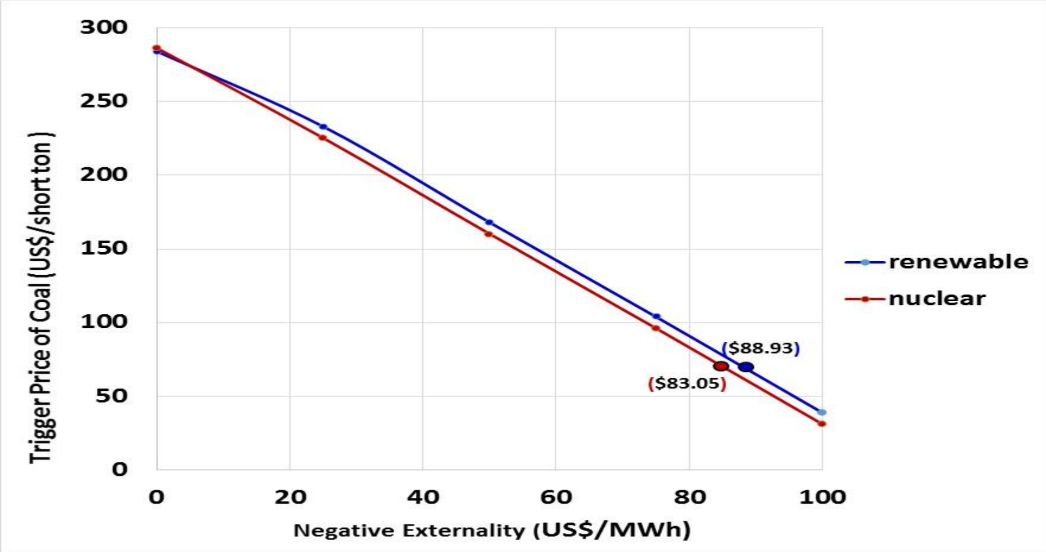

Figure-5. Trigger prices of renewable and nuclear energy investment at various negative externalities of using coal.
Source renewable(blue curve)-trigger prices of coal for shifting energy source from coal to renewable; nuclear(red curve)-trigger prices of coal for shifting energy source from coal to nuclear

4. CONCLUSION

This study examined various scenarios that represent energy switching investment decisions that apply to developing countries. Although numerous studies explore the effect of input price uncertainty in investment decisions, this study expands the existing body of research by considering switching options to nuclear or renewable energy, incorporating negative externality for using various types of energy, and the risk of nuclear accident.

This study used ROA to evaluate the option values that maximize the net present value of each alternative investment, and the trigger prices of coal for shifting technologies from coal to renewable or nuclear. Dynamic optimization results showed that flexibility in decision timing is important in making irreversible investment under uncertainty. This highlights the important characteristic of ROA in valuing financial options that timing is essential in considering investment decisions. Despite the risk of having nuclear accident, investment in nuclear energy seemed to be attractive in the Philippines. Yet, the question on building new nuclear power plant will still be highly debatable as Filipino people are still skeptical from its radiation and health risks due to the recent nuclear accident in Fukushima in 2011. With the long-term reliability, nuclear energy may only serve as a transition technology from coal to renewable as the concerns of the public about safety issues, proliferation of nuclear material, long-term nuclear waste disposal, and risks of using nuclear energy needs to be considered first. Finally, the inclusion of externality cost for using coal makes the option for renewable or nuclear energy investments more valuable than continue using coal for electricity generation. Being nonrenewable and exhaustible, the concerns on coal's limited supply, price volatility, national security problems, and the environmental effects associated with its continued use serve as an impetus of finding better and more sustainable sources of energy.

To develop a general model of energy investment decision in developing countries, the study made several simplifying assumptions leading to various limitations in the analyses. It is therefore important to note that the given estimates must be taken with great caution. While the assumptions in this study are sufficient for the main objective of providing qualitative guidance and general scenario of energy investment, it should be noted that thorough identification of parameter estimations requiring calculations with more tailored numerical methods are necessary in real decision-making process. This research focus on ROA under uncertainty in coal prices, negative externality, and risk of nuclear accident. Future studies may consider other uncertainties associated with energy investments. These include technological innovation that may lower the overnight cost for renewables and safer nuclear energy generation; environmental uncertainty such as climate variability and weather disturbances that affect energy systems; and policy uncertainty to further, capture the underlying political and environmental processes essential to climate change policy.

Funding: This study received no specific financial support.
Competing Interests: The author declares that there are no conflicts of interests regarding the publication of this paper.

REFERENCES

Baecker, P.N., 2007. Real options and intellectual property: Capital budgeting under imperfect patent protection. Berlin Heidelberg: Springer.

Beaver, W., 1994. Nuclear nightmares in the Philippines. Journal of Business Ethics, 13(4): 271-279. *View at Google Scholar* | *View at Publisher*

Brach, M.A., 2003. Real options in practice. Hoboken, New Jersey: John Wiley & Sons, Inc.

Cardin, M.A., S. Zhang and W. Nuttall, 2017. Strategic real option and flexibility analysis of nuclear power plants considering uncertainty in electricity demand and public acceptance. Energy Economics, 64: 226-237. *View at Google Scholar* | *View at Publisher*

Detert, N. and K. Kotani, 2013. A real options approach to energy investments in Mongolia. Energy Policy, 56: 136-150. *View at Google Scholar* | *View at Publisher*

Dixit, A.K. and R.S. Pindyck, 1994. Investment under uncertainty. New Jersey: Princeton University Press.

DOE, 2012. Philippine energy plan 2012-2030. Philippines: Department of Energy. Retrieved from https://www.doe.gov.ph/sites/default/files/pdf/pep/2012-2030_pep.pdf. [Accessed 20 March 2017].

DOE, 2016. Philippine power statistics. Philippines: Department of Energy. Retrieved from https://www.doe.gov.ph/sites/default/files/pdf/energy_statistics/power_statistics_2015_summary.pdf. [Accessed 20 March 2017].

EEA, 2010. Estimated average EU external costs for electricity generation technologies in 2005. European Environmental Agency. Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/en35-external-costs-of-electricity-production/en35-external-costs-of-electricity-production [Accessed 16 April 2017].

EIA, 2017. Annual energy outlook 2017. United States of America: Energy Information Administration. Retrieved https://www.eia.gov/outlooks/aeo/pdf/0383(2017).pdf. [Accessed 20 March 2017].

Hofert, M. and M.V. Würthrich, 2013. Statistical review of nuclear power accidents. Asia-Pacific Journal of Risk and Insurance, 7(1): 1-18. *View at Google Scholar* | *View at Publisher*

Hong, G.W. and N. Abe, 2012. Sustainability assessment of renewable energy projects for off-grid rural electrification: The Pangan-an Island case in the Philippines. Renewable and Sustainable Energy Reviews, 16(1): 54-64. *View at Google Scholar* | *View at Publisher*

IAEA, 2016. Nuclear power development program in the Philippines. International Atomic Energy Agency. Available from https://cnpp.iaea.org/countryprofiles/Philippines/Philippines.htm [Accessed 16 April 2017].

Insley, M., 2002. A real options approach to the valuation of a forestry investment. Journal of Environmental Economics and Management, 44(3): 471-492. *View at Google Scholar* | *View at Publisher*

Kaiser, J.C., 2012. Empirical risk analysis of severe reactor accidents in nuclear power plants after Fukushima. Science and Technology of Nuclear Installations: 1-6. *View at Google Scholar* | *View at Publisher*

Kim, K., H. Park and H. Kim, 2017. Real options analysis for renewable energy investment decisions in developing countries. Renewable and Sustainable Energy Reviews, 75: 918-926. *View at Google Scholar* | *View at Publisher*

Kitzing, L., N. Juul, M. Drud and T.K. Boomsma, 2017. A real options approach to analyse wind energy investments under different support schemes. Applied Energy, 188: 83-96. *View at Google Scholar* | *View at Publisher*

Meller, H. and J. Marquardt, 2013. Renewable energy in the Philippines: Costly or competitive? Facts and explanations on the price of renewable energies for electricity production. Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ)

GmbH. Retrieved from http://star-www.giz.de/fetch/1of2Q1F01X0Ck000g0/giz2013-0483en-renewable-energy-philippines.pdf [Accessed 16 April 2017].

Myers, S.C., 1977. The determinants of corporate borrowing. Journal of Financial Economics, 5(2): 147–175. *View at Google Scholar* | *View at Publisher*

NEA, 2015. Projected cost of generating electricity. Nuclear Energy Agency, Organisation for Economic Co-operation and Development. Retrieved from https://www.oecd-nea.org/ndd/pubs/2015/7057-proj-costs-electricity-2015.pdf [Accessed 16 April 2017].

NEA, 2016a. Cost of decommissioning nuclear power plants. Nuclear Energy Agency, Organisation for Economic Co-operation and Development. Retrieved from https://www.oecd-nea.org/ndd/pubs/2016/7201-costs-decom-npp.pdf [Accessed 16 April 2017].

NEA, 2016b. Cost of major accidents: An introduction. Nuclear Energy Agency, Organisation for Economic Co-operation and Development. Retrieved from https://www.oecd-nea.org/ndd/workshops/cost-electricity/presentations/docs/6a-cometto.pdf [Accessed 16 April 2017].

Rangel, L.E. and F. Lévêque, 2014. How Fukushima Dai-ichi core meltdown changed the probability of nuclear accidents? Safety Science, 64: 90-98. *View at Google Scholar* | *View at Publisher*

Rothwell, G., 2006. A real options approach to evaluating new nuclear power plants. Energy Journal, 27(1): 37-53. *View at Google Scholar* | *View at Publisher*

Shi, H.Y. and H.T. Song, 2013. Applying the real options approach on nuclear power project decision making. Energy Procedia, 39: 193-198. *View at Google Scholar* | *View at Publisher*

Sovacool, B.K., 2010. A comparative analysis of renewable electricity support mechanisms for Southeast Asia. Energy, 35(4): 1779-1793. *View at Google Scholar* | *View at Publisher*

Tian, L., H. Shan and N. Naiping, 2016. Analysis of the real options in nuclear investment under the dynamic influence of carbon market. Energy Procedia, 104: 299-304. *View at Google Scholar* | *View at Publisher*

Tietjen, O., M. Pahle and S. Fuss, 2016. Investment risks in power generation: A comparison of fossil fuel and renewable energy dominated markets. Energy Economics, 58: 174-185. *View at Google Scholar* | *View at Publisher*

Wang, X. and L. Du, 2016. Study on carbon capture and storage (CCS) investment decision-making based on real options for China's coal-fired power plants. Journal of Cleaner Production, 112(5): 4123-4131. *View at Google Scholar* | *View at Publisher*

Xian, H., G. Colson, B. Mei and M.E. Wetzstein, 2015. Co-firing coal with wood pellets for US electricity generation: A real options analysis. Energy Policy, 81: 106-116. *View at Google Scholar* | *View at Publisher*

Yang, M., W. Blyth, R. Bradley, D. Bunn, C. Clarke and T. Wilson, 2008. Evaluating the power investment options with uncertainty in climate policy. Energy Economics, 30(4): 1933–1950. *View at Google Scholar* | *View at Publisher*

Zhang, M.M., P. Zhou and D.Q. Zhou, 2016. A real options model for renewable energy investment with application to solar photovoltaic power generation in China. Energy Economics, 59: 213-226. *View at Google Scholar* | *View at Publisher*

Zhu, L., 2012. A simulation based real options approach for the investment evaluation of nuclear power. Computers & Industrial Engineering, 63(3): 585-593. *View at Google Scholar* | *View at Publisher*