

OPTIMAL INVESTMENT SCHEMES FOR RESIDENTIAL SOLAR PHOTOVOLTAIC PROJECT IN THE PHILIPPINES

Casper Boongaling Agaton^{1,2*}, Charmaine Samala Guno³, Resy Ordon Villanueva⁴, and Riza Ordon Villanueva⁴

¹ Utrecht University School of Economics, Kriekenpitplein 21-22, 3584 EC Utrecht, The Netherlands (corresponding author)

² Copernicus Institute of Sustainable Development, Utrecht University, Princetonlaan 8a, 3584 CB Utrecht, The Netherlands

³ Mindoro State College of Agriculture and Technology, Masipit, Calapan City 5200, Philippines

⁴ St. Paul University - Manila, 680 Pedro Gil St, Malate, Manila 1004, Philippines

ABSTRACT

This paper applies the real option approach (ROA) to analyze the economic viability of residential solar photovoltaic (PV) investment in the Philippines. From the point of view of a household (HH) owner, this approach evaluates the option values and optimal timing of investment to compare the attractiveness of investing in solar PV over continuing to use electricity from the grid. This further analyzes how various investment schemes and electricity prices uncertainty affect investment decisions. Results find that residential solar PV investment is profitable for all HH types investigated and that earlier investment in solar PV reduces the risk of opportunity loss from postponing the investment. Among the investment schemes analyzed, the distribution of solar PV cost in 5- or 10-year period without initial down payment shows to be the best investment strategy. The results are robust with various HH types investigated and with sensitivity in electricity prices.

Keywords: residential solar PV, energy investment, real options, Monte Carlo simulation, dynamic optimization, investment strategy

PP	Payback period
PV	Photovoltaic
ROA	Real options approach
<i>Symbols</i>	
α	Drift of electricity prices
σ	Volatility of electricity prices
ε_t	Random number
ρ	Discount factor
r	Discount rate
τ	Period of making investment
C	Cost of solar PV panels
$\mathbb{E}\{NPV\}$	Expected net present value
I_d	Down payment for solar PV
I_τ	Lump sum investment cost
I_t	Installment payment for solar PV
J	Number of times for Monte Carlo
P_e	Electricity price
Q_e	Electricity consumption
ROV	Real option value
T_s	Lifetime of solar PV
V_e	Value of electricity from the grid
V_s	Value of electricity from solar PV

NOMENCLATURE

Abbreviations

DOE	Department of Energy
GBM	Geometric Brownian motion
HH	Household
IRR	Internal rate of return
MERALCO	Manila Electric Company
NPV	Net present value

1. INTRODUCTION

In response to the international debate to combat climate change, solar energy has become one of the most promising sources of cleaner energy and its share in the global energy mix has been steadily increasing in the last years. While most developing countries in Asia-Pacific region have embraced solar energy, the Philippines is lagging behind in terms of investments and

policy implementation [1]. Currently, solar energy accounts to only 1.3% of the country's total energy generation [2]. With its geographic location advantage, the government is planning to tap its huge solar potential (>1528MW) [3] by awarding micro- to mini-grid solar projects and encouraging the adoption of own-use solar PV. Due to falling costs of equipment and system installation, as well as possible future savings from paying high electricity rate,¹ solar PV systems are becoming more popular with consumers particularly in far-flung areas that are rarely connected to the national electricity grid. However, the HH owners are hesitant to invest in solar PV due to budget constraints, lack of information on system providers, skepticism, compatibility issues and difficulty in using all appliances at the same time, and availability in the local market. These give an impetus to make a study that analyzes the economic viability of adopting residential solar PV and suggest investment strategies making own-use solar more attractive than continue using electricity from the grid.

Various literatures discuss residential solar PV investment using different investment models. These include a simulation on the profitability of residential PV and storage investments in Germany and Ireland considering the technological, market-based, political, and economic drivers [6]; a cost-benefit analysis of installing solar PV in residential houses in Malaysia [7]; and an integrated economics models involving net present value (NPV), internal rate of return (IRR), payback period (PP), and profitability index for residential PV systems [8-10]. However, most traditional valuation models do not capture important characteristics of energy investments such as irreversibility of investment, uncertainties in future cash-flow, and flexibility in making investment decisions. Real options approach (ROA) overcomes this limitation by combining risks and uncertainty with flexibility of investment as a potential positive factor which gives additional value to the project [5]. In a growing number of literatures applying ROA to own-use residential solar PV investments [11-13], there is a limited number of studies focusing on investment strategies [13].

This paper contributes to these literatures by proposing a ROA framework for analyzing residential

solar PV project in the context of developing countries, particularly to households (HH) in island countries that are rarely connected to the national grid. This study is predominantly relevant to low- to medium-income HH adopting capital-intensive solar PV. Using the Philippines as a case study, this research aims to evaluate whether investing in solar PV project is more profitable option than continuing the use of electricity from the local grid and identify the optimal timing of investment for different types of HH. This further analyzes how investment schemes and electricity price uncertainty affect the investment decision-making process.

2. METHODOLOGY

2.1 Simulation model

The real option model in this study takes the perspective of an investor, a household owner, who decides to shift electricity source from the grid to residential solar PV. The investor has the option to invest immediately or postpone the investment given the electricity price P_e . In line with previous studies [14,15], we assume that electricity prices are stochastic and follow Geometric Brownian motion (GBM). The evolution of prices is given by Equation 1

$$\frac{dP_e}{P_e} = \alpha dt + \sigma dz \quad (1)$$

where α and σ are parameters of drift and variance representing mean and volatility of the price process, dt is the infinitesimal time increment, and dz is the increment of the Wiener process equal to $\varepsilon_t \sqrt{dt}$ such that $\varepsilon_t \sim N(0,1)$. We describe that the current price of electricity $P_{e,t}$ depends on its previous price, the drift, and variance rates from time series of electricity prices as shown in Equation 2.

$$P_{e,t} = P_{e,t-1} + \alpha P_{e,t-1} + \sigma P_{e,t-1} \varepsilon_{t-1} \quad (2)$$

The investor maximizes the value of investment ROV_t at each decision making period as shown in Equation 3

$$ROV_t = \max\{[E\{NPV_s\}, E\{\sum_{0 \leq t \leq \tau} \rho^t V_{e,t}\}] | P_{e,t}\} \quad (3)$$

where $E\{NPV_s\}$ is the expected net present value of solar PV project, $E\{\sum_{0 \leq t \leq \tau} \rho^t V_{e,t}\}$ is the discounted

cost-reflective, monopolized, and heavily taxed across the supply chain [4,5].

¹ Compared to neighboring Asian countries, the Philippines has relatively higher electricity prices due to country's dependence on imported fuels, no government subsidy on electricity generation, fully

expected value of using electricity from the grid between the time $t = 0$ until the period of making investment τ , ρ is the discount factor equal to $(1 + r)^t$, r is the discount rate, and $V_{e,t}$ is the electricity bill at each period t . The net present value of project NPV_s is represented by Equation 4

$$NPV_s = \sum_{t=\tau}^{T_s} \rho^t V_{s,t} - C_t \quad (4)$$

where T_s is the lifetime of electricity generation from solar PV, $V_{s,t}$ is the energy saving value equal to the stochastic price of electricity from the grid $P_{e,t}$ multiplied by the electricity consumption Q_e . The cost of solar PV system C_t in various investment schemes is described in Equation 5

$$\left. \begin{array}{l} I_t \quad \text{full payment} \\ I_d + \sum_{t=\tau}^n \rho^t I_t \quad \text{installment with downpayment} \\ \sum_{t=\tau}^n \rho^t I_t \quad \text{installment without downpayment} \end{array} \right\} (5)$$

where the investor can choose to pay in full amount I_t , or on an installment basis I_t in a certain number of n years with or without down payment I_d .

The expected net present value of the project is calculated using Monte Carlo simulation. This process is done by calculating the NPV_s for each $P_{e,0}$ price path j ; repeating the estimations in a sufficiently large number of times ($J = 10000$); and getting the average of the estimations as shown in Equation 6.

$$E\{NPV_{s,j}|P_{e,0}\} \approx \frac{1}{J} \sum_{j=1}^J NPV_{s,j} \approx E\{NPV_s|P_{e,0}\} \quad (6)$$

Table 1. Investment schemes at different types of households

Household Type	annual average electricity consumption	# of panels	full payment (PhP*)	5-year installment (PhP/mo)	10-year installment (PhP/mo)
I	below 6 MWh	5	128000	2850	1680
II	6 MWh - 11.9 MWh	7	178000	3960	2550
III	12 MWh - 17.9 MWh	14	348000	7740	4990
IV	18 MWh - 23.9 MWh	21	498000	11080	7150
V	24 MWh - 30 MWh	28	658000	14640	9440

Note: Investment schemes include full payment; zero down payment at 5-year or 10-year monthly instalment; 40% down payment at 50% lower monthly rates; or (c) 20% down payment at 25% lower monthly rates.

Finally, the optimal timing τ^* is characterized by a decision to invest immediately or to postpone the investment into a more favorable period as shown in Equation 7.

$$\left. \begin{array}{l} ROV_{\tau^*}(P_{e,t}) \leq ROV_0(P_{e,0}) \quad \text{invest} \\ ROV_{\tau^*}(P_{e,t}) > ROV_0(P_{e,0}) \quad \text{delay, postpone} \end{array} \right\} (7)$$

2.2 Parameter estimation and scenarios

To estimate the parameters for the optimization problem, we use the data from Philippines' Department of Energy (DOE), Manila Electric Company (Meralco), and Solar Philippines. All calculations are done using MATLAB programming. We set the optimization period to 25 years to make the investment decision. The HH types are grouped according to the average yearly electricity consumption from less than 6MWh to 30MWh at 6MWh interval, while solar panels installed for each HH type are 2, 5, 7, 14, and 28 as shown in Table 1.² Investment schemes include full payment, or monthly installment in 5 or 10 years, with or without down payment (0%, 20%, 40%, 100%).³ The investment cash flow is discounted at 7.5% risk-free interest rate. For electricity prices, a 10-year period of average annual prices is used to run Augmented Dickey-Fuller unit root test for stochastic process. The test result confirms that P_e follows GBM with $\alpha=0.04053$ and $\sigma=0.03033$. We use these parameters to generate stochastic prices of electricity from the current $P_{e,t}=5.3\text{PHP/kWh}$. The project runs for 25-year life-time of full off-grid operation with no sell-back option. We assume that solar PV can generate electricity at an annual average of Q_e all throughout its lifetime; there are no additional costs for annual maintenance as this will be covered by the warranty from the provider; and the average consumption of electricity will be constant annually for all types of HH.

² The solar PV provider offers two more options which include 35- and 42-panel installations. However, these options are more applicable to commercial establishments which are beyond the scope of the study focusing on small to medium-type residential houses.

³ The solar PV provider gives another investment option to pay the investment according to electricity consumption. However, we do not include it in this study as it would not fit in the proposed ROA model.

3. RESULTS AND DISCUSSION

3.1 Baseline scenario

The baseline scenario describes a payment scheme where the HH owner invest in residential solar PV project at once. The optimization result using the proposed real options model discussed in previous section is illustrated in Figure 1. Each curve represents option values at every period of investment for each type of HH.

The first point of interest is the positive option values for all types of HH. These indicate positive returns to investment at a given electricity price. Among the HH owners, we identify that HH 5, who is the largest consumer of electricity, benefits most from the given investment scheme. This is due to economies of scale where the cost of investing in the project decreases with increasing number of solar panels installed [16,17]. Another point of interest is downward slope of the ROV curves which indicates a decline in the value of investment over time. This suggests that investing immediately in solar PV project is a better option as postponing or delaying investments incurs costs from paying electricity consumption from the grid.

3.2 Investment scheme scenario

In this scenario, we describe an investment scheme where the investor has the option to pay in full or pay a monthly amortization in a given number of years. We further describe a scenario of monthly installment with partial down payment and totally without down payment. Figure 2 compares the ROV of solar PV project for HH 1 at various installment schemes without down

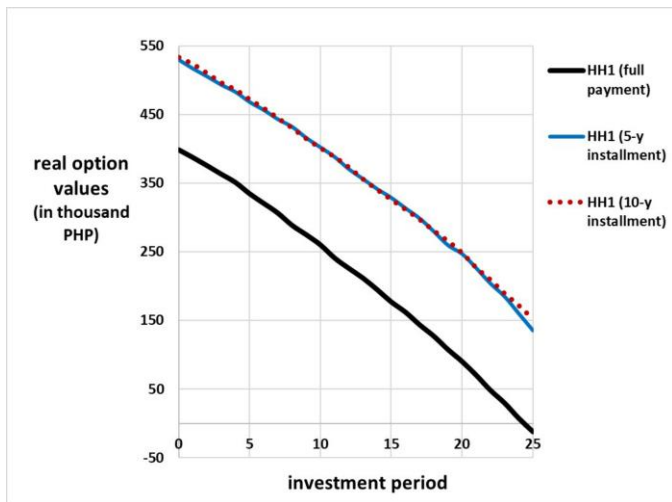


Figure 2. ROV of residential solar PV investments at various instalment schemes. 5-y and 10-y instalments has no initial down payment.

⁴ The result is robust with other HH types.

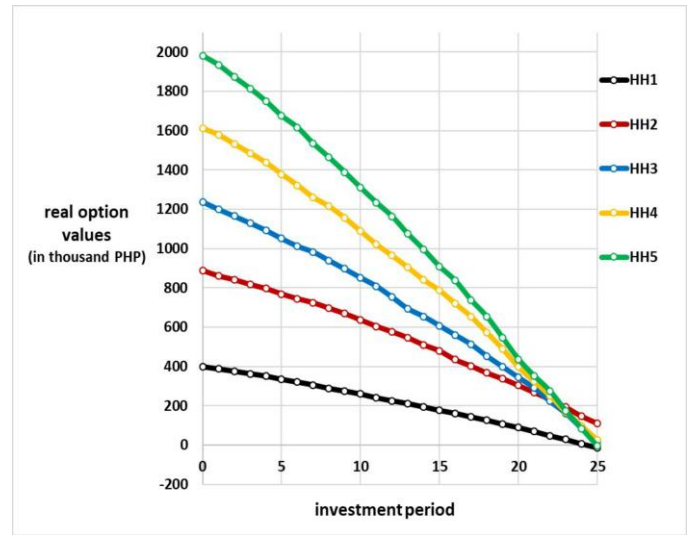


Figure 1. ROV of residential solar PV investments at different types of household in the baseline scenario. HH: household type. 10-year average exchange rate: US\$1=PHP45.85

payment. The result shows a large difference between the option values of investment with full payment and investments payed in installment.⁴ This indicates a better option to regularly pay a monthly amortization for a period of 5 or 10 years as the discounted present value of payment decreases overtime. This scheme give more benefits to the HH owners to pay the investment at a lower cost spread over a certain period. This result supports previous claims that easy payment and installment schemes address the gap between high upfront costs for solar PV systems and low paying capacity of rural HH [18,19].

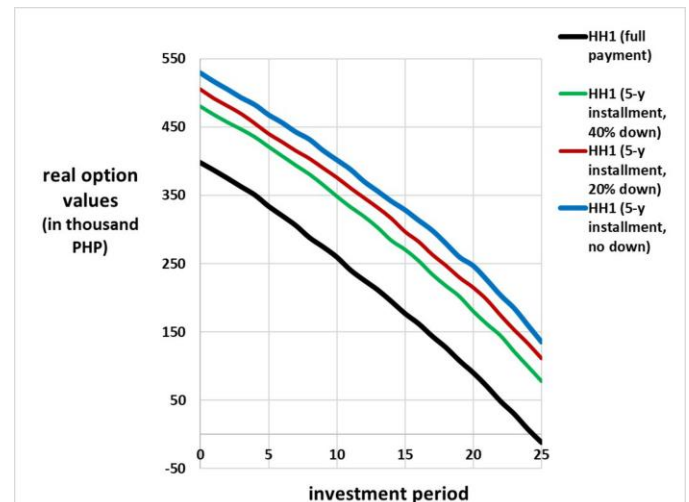


Figure 3. ROV of residential solar PV investments at various installment schemes

Another investment option is to pay an initial down payment with reduced monthly amortization as shown in Figure 3. The result shows that investment without initial down payment has the highest option values followed by 20% down payment, 40% down payment, and full payment.⁵ This suggests an optimal option to invest in solar PV project by paying a fixed monthly amortization for a given number of years without down payment. This result is highly relevant in the case of a developing country such as the Philippines, to encourage lower income and risk-averse HH owners, as cost barriers, economic status, HH income affect their decision to adopt solar PV [20,21].

3.3 Electricity price volatility scenario

In this scenario, we describe how the volatility in electricity prices affect investment decisions to adopt solar PV. Figure 4 shows the ROV at various uncertainty levels in electricity prices.⁶ The result shows higher and more stable option value curve at low price volatility σ , while a fluctuating curve at high price volatility.⁷ Lower price volatility also increases the option values at different investment periods. These results suggest a better decision to adopt solar PV at more deterministic trend in electricity retail price to avoid possible losses from investment risks [22,23]. Further, the result describes the robustness of previous implications to adopt own-use solar PV to avoid opportunity losses from postponing the investment.

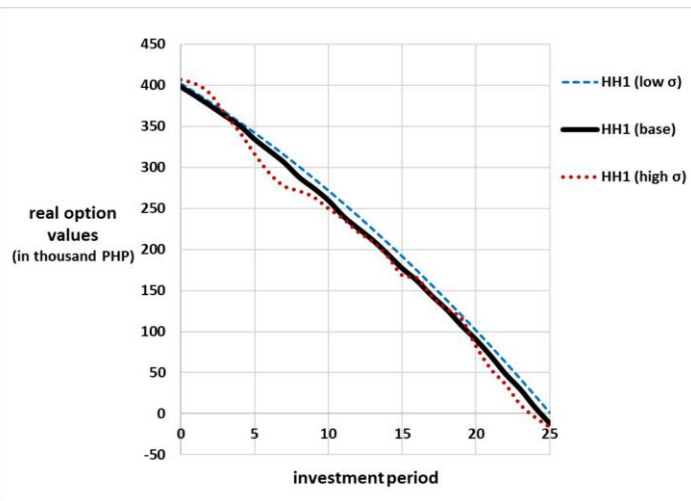


Figure 4. Sensitivity of ROV at various levels of uncertainty in electricity prices. Base $\sigma=0.03033$; low $\sigma=0.01$; high $\sigma=0.1$.

⁵ The result is robust with different types of HH and instalment periods.

⁶ We calculate the ROV using five different volatilities: low2 $\sigma=0.01$; low1 $\sigma=0.02$; base $\sigma=0.03033$; high1 $\sigma=0.05$; and high2 $\sigma=0.1$. Figure 4 presents only three main results for volatilities: low, base, and high.

4. CONCLUSION

This study discusses a ROA model to evaluate residential solar PV investments in developing countries by taking the Philippines as a case. The analyses provide important insights on how investment strategies and uncertainties affect the values of investment and the optimal timing of making investment decisions. Results suggest to adopt solar PV immediately as postponing investments incurs additional cost and opportunity losses. This further suggests investment without down payment as the most optimal strategy among the investment schemes analyzed. Results are robust with the sensitivity in electricity prices and at all HH types investigated.

While this study compares the economic attractiveness of own-use electricity from solar PV, future studies may also consider selling the excess energy generation and mixing electricity sources to optimize the value of investments. Various uncertainties such as decreasing system cost due to technological maturity and increasing demand, and government policies such as subsidy for using clean energy and carbon tax for using electricity generated from fossil can also be incorporated in the model to further capture investment decisions relevant to market and climate change policy.

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⁷ The result is robust with different types of HH, instalment periods, and payment schemes.

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