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OPTIMAL INVESTMENT SCHEMES FOR RESIDENTIAL SOLAR PHOTOVOLTAIC PROJECT IN THE PHILIPPINES

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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 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

1. INTRODUCTION

In line with global initiatives to adapt low carbon cities, both developed and developing countries are investing in greener and more sustainable sources of energy. In the recent years, solar PV dominates the renewable energy expansion accounting to more than two-thirds of the world's net electricity growth [1]. While most developing countries in Asia-Pacific region have embraced solar energy, the Philippines is lagging behind in terms of investments and policy implementation [2]. Currently, solar energy accounts to only 1.3% of the country's total energy generation [3]. With its geographic location advantage, the government is planning to tap its huge solar potential (>1528MW) [4] by awarding micro- to mini-grid solar projects and encouraging the adoption of own-use solar PV [5]. 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

[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 cost-reflective, monopolized, and heavily taxed across the supply chain [5-7].

and storage investments in Germany and Ireland considering the technological, market-based, political, and economic drivers [8]; a cost-benefit analysis of installing solar PV in residential houses in Malaysia [9]; an integrated economics models involving net present value (NPV), internal rate of return (IRR), payback period (PP), profitability index for residential PV systems [10-13]. 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 [5,7]. In a growing number of literatures applying ROA to residential solar PV investments strategies [14-17], there is a limited number of studies focusing on investment [16].

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 prices 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. We assume that electricity prices are stochastic and follow Geometric Brownian motion (GBM) [18,19] showing the evolution of prices is given by Equation 1

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

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.

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

The investor maximizes the value of investment ROV_t at each decision making period as shown in Equation 7

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

where $\mathbb{E}\{\sum_{0\le t\le\tau}\rho^t V_{e,t}\}$ is the discounted expected value of using electricity from the grid, ρ is the discount factor, $V_{e,t}$ electricity bill at period t, and $\mathbb{E}\{NPV_s\}$ is the expected net present value of solar PV project at investment period τ.

The net present value of project NPV_s is represented by Equation 4

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

where $V_{s,t}$ 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, T_s is the lifetime of electricity generation from solar PV.

The cost of solar PV system C_t in various investment schemes is shown in Equation 5

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

where the investor can choose to pay in full I_τ or installment basis I_t in n periods with or without down payment I_d .

The expected net present value of using the project is calculated using Monte Carlo simulation as described by in Equation 6.

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

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.

$$\left.\begin{array}{ll} \mathrm{ROV}_{\tau^*}(\mathrm{P}_{\mathrm{e,t}}) \leq \mathrm{ROV}_0(\mathrm{P}_{\mathrm{e,0}}) & \text{invest} \\ \mathrm{ROV}_{\tau^*}(\mathrm{P}_{\mathrm{e,t}}) > \mathrm{ROV}_0(\mathrm{P}_{\mathrm{e,0}}) & \text{delay, postpone} \end{array}\right\} \quad (7)$$

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. 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 α=0.04053 and σ=0.03033. We use these parameters to generate stochastic prices of electricity from the current $P_{e,t}$=5.3PHP/kWh. The project runs for 25-year life-time of full off-grid operation with no sell-back option. Assumptions include 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.

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 the 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

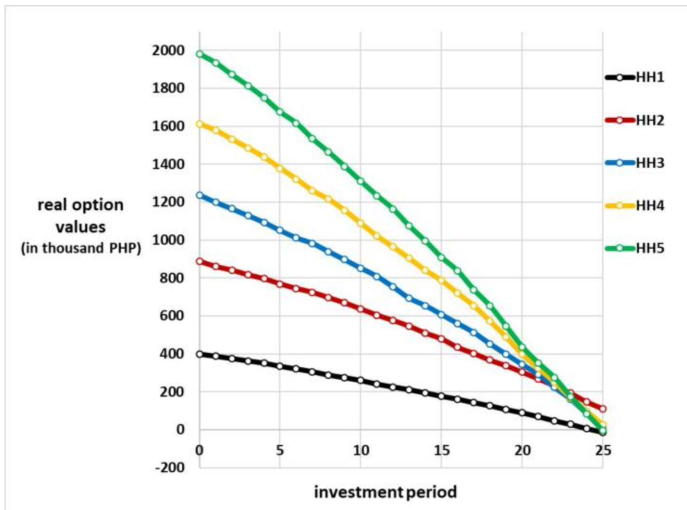

Figure 1. ROV of residential solar PV investments at different types of household in the baseline scenario. HH: household type. 10-year average exchange rate: US$1=PHP45.85

[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 according to HH electricity consumption. However, we did not include it in this study as it would not fit in the proposed ROA model.

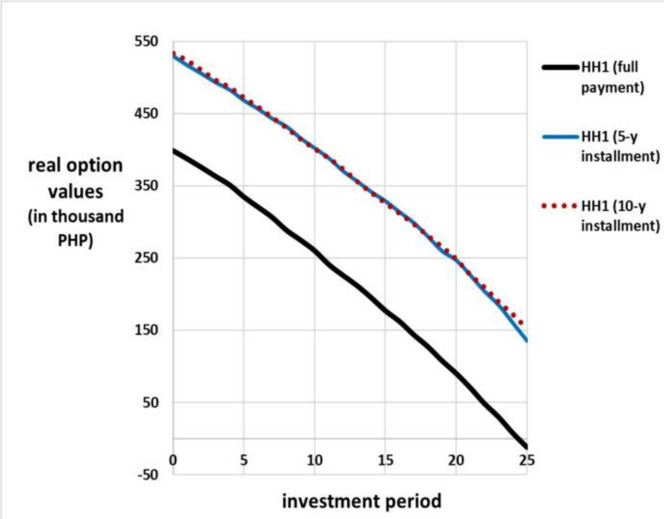

Figure 2. ROV of residential solar PV investments at various instalment schemes. 5-y and 10-y instalments has no initial down payment.

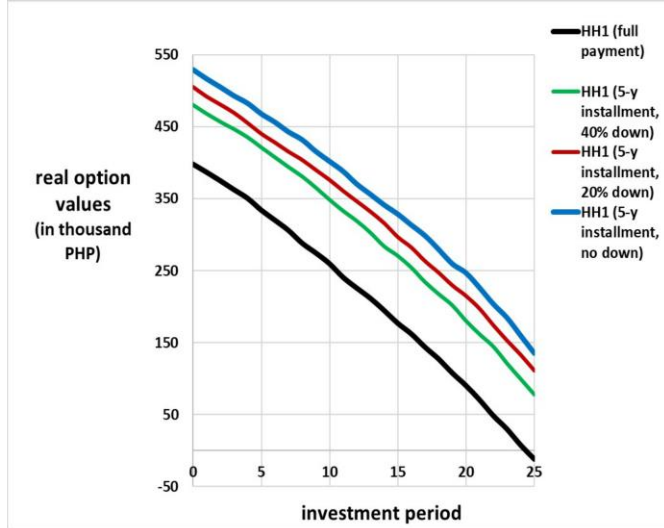

Figure 3. ROV of residential solar PV investments at various down payment schemes

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 [20,21].

Another point of interest is downward slope of the ROV curves which indicates a decline in the value of investment over time. This suggests a more optimal strategy to invest immediately in solar PV project. Contrary with ROA results from previous studies that waiting is a better option [14,16,22], our results show the otherwise as postponing or delaying investments incurs costs from paying high electricity prices 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. If the investor opt to pay monthly, he has the option to pay an initial 20% or 40% down payment and reduce the monthly rate by 25% or 50% from the rate without any down payment.

Figure 2 compares the ROV of solar PV project for HH 1 at various installment schemes without down 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 [23,24].

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 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 rent for a given number of years without down payment. This result may encourage lower income and risk-averse HH owners as cost barriers, economic status, HH income affect their decision to adopt solar PV [25-27].

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

[4] The result is robust with other HH types.

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

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

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

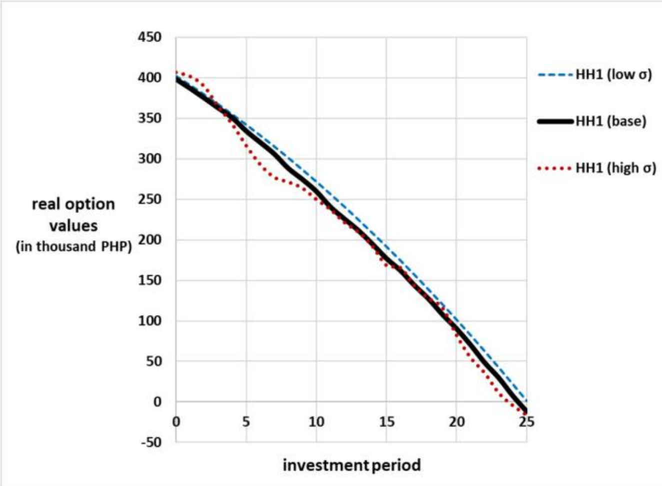

Figure 4. Sensitivity of ROV at various levels of uncertainty in electricity prices.

better decision to adopt solar PV at more deterministic trend in electricity retail price to avoid possible losses from investment risks [28,29]. Further, the result describes the robustness of previous implications to adopt own-use solar PV to avoid opportunity losses from postponing the investment.

4. LIMITATION AND DISCUSSION

To develop a ROA framework for residential solar PV investment decision, we made several simplifying assumptions leading to various limitations in the analyses. First, we assume that the electricity prices are stochastic and follow GBM with a positive drift. This indicates an increasing trend of electricity prices in the long run. We acknowledge that the recent developments in renewable energy infrastructure projects and widespread adoption of residential solar PV may eventually reduce the price of electricity in the future [5,7]. This trend in electricity prices should be accounted for. Moreover, different models to describe stochastic prices of electricity, such as mean reverting, could also be used for further comparison of results using GBM.

In this study, we apply ROA under uncertainty in electricity prices and analyze the sensitivity of results with respect to different investment schemes and volatility in electricity prices. We acknowledge that there are various uncertainties that affect solar PV investment decisions that are not covered in this study. These include the increasing demand for cleaner sources of electricity; technological maturity in storage and market competition that may lower the investment cost; and government policies such as income tax exemption, subsidy for using clean energy, or carbon tax for using electricity generated from fossil fuels [11,12,15,17,22]. The proposed ROA could be extended by incorporating these uncertainties to further capture investment decisions relevant to market and climate change policy.

Finally, in this research, we compare the economic attractiveness of own-use electricity from solar PV over continue using electricity from the grid. Future studies may also consider selling the excess electricity, mixing electricity sources, and connection to smart grid for additional revenue and optimize the value of investments [30,31]. Although there are some limitations, we believe that the ROA framework proposed in this study could be a good benchmark for further analysis of investment decisions for the adoption of cleaner and more sustainable sources of electricity.

5. 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.

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REFERENCE

[1] International Energy Agency (IEA). Renewables 2018: Analysis and Forecast to 2023.
[2] Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. It's more sun in the Philippines 2013.
[3] Department of Energy (DOE). 2018 Philippine Power Statistics.
[4] Int. Renewable Energy Agency (IRENA). Renewables Readiness Assessment: The Philippines 2017.

[5] Agaton CB. A Real Options Approach to Renewable and Nuclear Energy Investments in the Philippines. Vol. 71. Logos Verlag Berlin GmbH; 2019.
[6] Fernandez L. "Power prices: Where we are and how do we reduce the bill." DTI 2015.
[7] Agaton CB. Real Options Analysis of Renewable Energy Investment Scenarios in the Philippines. Renewable Energy & Sus. Dev. 2017; 3(3):284-292.
[8] Bertsch V, Geldermann J, Lühn T. What drives the profitability of household PV investments, self-consumption and self-sufficiency? Applied Energy 2017; 204:1-15.
[9] Muhammad-Sukki F, Ramirez-Iniguez R, Abu-Bakar S H, McMeekin SG, Stewart BG. An evaluation of the installation of solar photovoltaic in residential houses in Malaysia: Past, present, and future. Energy Policy 2011; 39(12):7975-7987.
[10] Ellabban O, Alassi A. Integrated Economic Adoption Model for residential grid-connected photovoltaic systems: An Australian case study. Energy Reports 2019; 5:310-326.
[11] Tantisattayakul T, Kanchanapiya P. Financial measures for promoting residential rooftop photovoltaics under a feed-in tariff framework in Thailand. Energy policy 2017; 109:260-269.
[12] D'Adamo I. The Profitability of Residential Photovoltaic Systems. A New Scheme of Subsidies Based on the Price of CO2 in a Developed PV Market. Social Sciences 2018; 7(9): 148.
[13] Rodrigues S, Chen X, Morgado-Dias FJEP. Economic analysis of photovoltaic systems for the residential market under China's new regulation. Energy Policy 2017; 101:467-472.
[14] Moon Y, Baran M. Economic analysis of a residential PV system from the timing perspective: A real option model. Renewable energy 2018; 125:783-795.
[15] Torani K, Rausser G, Zilberman D. Innovation subsidies versus consumer subsidies: A real options analysis of solar energy. Energy Policy 2016; 92:255-269.
[16] Gahrooei MR, Zhang Y, Ashuri B, Augenbroe G. Timing residential photovoltaic investments in the presence of demand uncertainties. Sustainable Cities and Society 2016; 20:109-123.
[17] Zhang MM, Zhou P, Zhou DQ. A real options model for renewable energy investment with application to solar photovoltaic power generation in China. Energy Economics 2016; 59:213-26.
[18] Borovkova S, Schmeck MD. Electricity price modeling with stochastic time change. Energy Economics 2017; 63:51-65.
[19] Hou Y, Liu CC, Salazar H. Electricity prices as stochastic process. In: El-Hawary ME ed. Advances in Electric Power and Energy Systems: Load and Price Forecasting, New Jersey: John Wiley & Sons; 2017, p.89-154.
[20] Ioannou A, Angus A, Brennan F. Effect of electricity market price uncertainty modelling on the profitability assessment of offshore wind energy through an integrated lifecycle techno-economic model. J Physics: Conference Series 2018;1102(1):1-11.
[21] Schepper ED, Passel SV, Lizin S. Economic benefits of combining clean energy technologies: the case of solar photovoltaics and battery electric vehicles. Energy Research 2015; 39(8):1109-1119.
[22] Cheng C, Wang Z, Liu M, Chen Q, Gbatu AP, Ren X. Defer option valuation and optimal investment timing of solar photovoltaic projects under different electricity market systems and support schemes. Energy 2017; 127:594-610.
[23] Purohit I, Purohit P, Shekhar S. Evaluating the potential of concentrating solar power generation in Northwestern India. Energy policy 2013; 62:157-175.
[24] Yadav P, Heynen AP, Palit D. Pay-As-You-Go financing: A model for viable and widespread deployment of solar home systems in rural India. Energy for sustainable development 2019; 48:139-153.
[25] Pode, R. Financing LED solar home systems in developing countries. Renewable and Sustainable Energy Reviews 2013; 25:596-629.
[26] Guta DD. Determinants of household adoption of solar energy technology in rural Ethiopia. J. of Cleaner Production 2018; 204:193-204.
[27] Palm J. Household installation of solar panels – Motives and barriers in a 10-year perspective. Energy Policy 2018; 113:1-8.
[28] Agaton CB. Use coal or invest in renewables: a real options analysis of energy investments in the Philippines. Renewables 2018; 5(1):1-8.
[29] Gazheli A, van den Bergh J. Real options analysis of investment in solar vs. wind energy: Diversification strategies under uncertain prices and costs. Renewable and Sustainable Energy Reviews 2018; 82:2693-2704.
[30] Bertolini M, D'Alpaos C, Moretto M. Do Smart Grids boost investments in domestic PV plants? Evidence from the Italian electricity market. Energy 2018; 149:890-902.
[31] McKenna E, Pless J, Darby SJ. Solar photovoltaic self-consumption in the UK residential sector: New estimates from a smart grid demonstration project. Energy Policy 2018; 118:482-91.