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Timing residential photovoltaic investments in the presence of demand uncertainties

Mostafa Reisi Gahrooei[a,*], Yuna Zhang[b,1], Baabak Ashuri[c,2], Godfried Augenbroe[d,3]

[a] Georgia Institute of Technology, Atlanta, GA 30332-0680, USA
[b] School of Architecture, Building Technology Lab, Georgia Institute of Technology, 247 4th Street Room 265, Atlanta, GA 30332-0680, USA
[c] Associate Professor & Brook Byers Institute for Sustainable Systems (BBISS) Fellow, School of Building Construction/School of Civil & Environmental Engineering, Director of Construction Research Center (CRC), Director of Economics of the Sustainable Built Environment (ESBE) Lab, Chair of the Integrated Project Delivery Systems Masters Track, Georgia Institute of Technology, 280 Ferst Drive Atlanta, GA 30332-0680
[d] Professor, College of Architecture, Georgia Institute of Technology, 247 4th Street Room 265, Atlanta GA 30332-0680

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ABSTRACT

As investment in residential photovoltaic systems is increasing at a rapid pace, it is important to investigate whether delaying or otherwise timing these investments can maximize long term investment gains. Conventional financial analysis methods for evaluating investment decisions in solar-electric system are all based on a one-time installation of the PV systems and cannot be applied to analyze the benefit of delayed and staged investment. Such benefits could be declining costs of PV systems thus tempting investors to hold off and wait for a better moment to invest. This paper proposes a decision making framework using the real option method to analyze the optimum time to invest in a residential PV system in different scenarios. A reference residential house is used to test the effect of different investment strategies. The results show the type of staged investment of installing residential PV system that maximizes the long-term payoff. This reveals when the option to delay investment is preferred. The supporting source code and data are available for download at https://github.com/reisiga2/SolarPanelInvestment.

1. Introduction

The U.S. building sector accounts for 7% of world's total energy consumption, which corresponds to 41% of the total energy usage and approximately half of the total greenhouse gas (GHG) emission in the United States (DOE, 2010; Energy Information Administration (EIA), 2011; Yudelson, 2010). This high-level of energy usage suggests that investing in building energy efficiency retrofits can effectively reduce a significant amount of energy consumption and ozone depletion caused by GHG emission at relatively low cost. In particular, investing in retrofitting residential buildings, which account for 54% of the building sector's energy consumption (DOE, 2010), can make substantial contribution to the energy reduction. From the individual homeowner perspective this will reduce the household's energy usage, environmental footprint, as well as its energy bills.

As one of the fast-growing emerging sustainable energy resources, solar energy has attracted increasing attention worldwide. Recent decades have shown an increasing trend of implementing photovoltaic (PV) systems in residential houses (Solar Energy Industries Association, 2014) as the PV system can partially or entirely fulfill the household's electricity demand from a nonpolluting energy resource. However, effective implementation of residential PV system requires the owner to make a large initial investment. The return on this investment is affected by several uncertainties, such as future energy retail price and technology costs, PV system performance, and house energy demand volatilities. These uncertainties cause difficulties in the investment evaluation exacerbated by the limitation of traditional investment techniques such as Net Present Value (NPV), Internal Rate of Return (ROR), and Discounted Cash Flow (DCF) analysis (Ashuri & Kashani, 2011; Lee, Choi, & Gambatese, 2014; Menassa, 2011; Kumbaroglu

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[*] Corresponding author. Tel.: +1 404 385 7608; fax: +1 404 894 1641.
E-mail addresses: mrg9@gatech.edu (M.R. Gahrooei), yuna.zhang@gatech.edu (Y. Zhang), baabak@gatech.edu (B. Ashuri), Godfried.Augenbroe@coa.gatech.edu (G. Augenbroe).
[1] Tel.: +1 404 713 3022.
[2] Tel.: +1 404 385 7608.
[3] Tel.: +1 404 894 1686.

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Nomenclature

p	retail price of electricity that we assumed follows a GBM model
α	the growth rate of electricity price over time
σ	volatility of electricity price
r	discount rate or market interest rate
C_t	solar panel installation cost at time t
X_t	commutative solar production
β	$2^{-\beta}$ is the progress ratio (PR), which can be considered to be between 0.7 and 0.85
γ	the growth rate of solar panel cost
z	the amount of electricity that solar panel generates in kW h, on average during a year
D	amount of electricity the household consumes in kW h on average during a year
m	average yearly maintenance cost
ε	electricity sellback ratio
$V(t,p)$	expected energy saving value if the investment appears at time t
$F(t, p)$	optimal expected value of the project at time t when the retail price of electricity is $p(t)$
V_u^t	value of energy saving for panel size u during the year t
C_{u_i,u_j}^t	cost of changing panel size from u_i to u_j at time t. That is the panel of size u_j obtained at time t
W_u^t	the optimal total value to reach size u at time t from time 0
T	project lifetime
t, τ	represents time. In Eq. (3) represents time of investment and τ represents time

& Madlener, 2012). These investment evaluation methods cannot provide an insightful analysis of the financial benefit because they only consider investing at the current moment neglecting that, in reality, the investment decision can be postponed to a future moment or implemented in multiple stages. Because of the decreasing trend in the cost of solar panels and potential increase in the retail price of electricity (Pyper, 2014), postponing the investment may bring greater benefits comparing to investing now. Therefore, providing better financial decision-making tools is becoming increasingly important. Without a suitable financial decision analysis tool, the estimation of investment risk may lack credibility to attract investor's money, even if the current investment trend is leaning strongly in favor of PV system investments.

To address the limitations of traditional investment valuation, several authors have proposed the Real Option Valuation (ROV) technique (Ashuri & Kashani, 2011; Lee et al., 2014; Menassa, 2011; Kumbaroglu & Madlener, 2012; Kashani, Ashuri, Shahandashti, & Lu, 2015; Martinez-Cesena, Azzopardi, & Mutale, 2013; Van der Maaten, 2010) to apply to the building energy domain. Real options analysis provides opportunity to cope with investment timing under uncertainty. The term real options refers to the assessment of real (non-financial) investments with strategic management flexibility features like delayed improvement (Dixit & Pindyck, 1994). This field has gone through a massive transition from a topic of modest academic interest in the 1990s to the current considerable, active academic and industry attention (Ford & Garvin, 2010; Borison, 2005). Many promising renewable energy solutions, such as PV systems, are still in the early deployment stage and hence, their costs are typically high and their efficiency and effectiveness remain to be verified in practice over time. One cannot be certain about actual energy savings of these technologies due to uncertainty about their technical performance and deterioration rate. Investors require valuation methods enabling them to determine whether they should delay an improvement and when it becomes financially sound to adopt a technology (Ellingham & Fawcett, 2006).

Real options approach provides the opportunity for appropriate investment valuation by thinking about renewable energy systems as investment options. In the context of investment in building energy systems, a building owner with an opportunity to invest in energy is holding an "Option" analogous to a financial call option—he has the right but not the obligation to adopt an emerging technology in building energy intervention at some future time of his choice. Real Options Analysis is an alternative investment valuation analysis that supplements net present value (NPV) and return on investment (ROI) calculations. Appropriate real options analysis must be based on rigorously quantified underlying uncertainties of an investment project in a specific context. Also, these uncertainties must be properly integrated in the investment valuation of the project. Fundamental research is required to quantify the uncertainties in the context of investment decision-making about PV energy systems and properly integrate these uncertainties in the process of the building energy investment valuation. For example, Lee et al. (2014), Menassa (2011), and Kumbaroglu and Madlener (2012) used real option valuation framework to evaluate the potential investment in building energy efficiency systems, such as heating, ventilation and air conditioning (HVAC) system, lighting system, and roof insulation. Ashuri and Kashani (2011), Kashani et al. (2015), and Martinez-Cesena et al. (2013) proposed a real option framework for evaluating investment in solar ready buildings under the electricity price uncertainty and concluded that delayed investment can improve the total investment benefits. Similarly, Kim, Lim, Kim, and Hong (2012) used a real option-based framework to calculate the governmental subsidy that incentivizes the implementation of solar panels in South Korea.

Although a few studies discussed the potential for staged investment in energy efficient retrofits (Menassa, 2011; Kumbaroglu & Madlener, 2012), to the best of our knowledge, no study has investigated the potential for staged investment in solar systems. In addition, studies on solar panel investment only evaluated the optimal time of investment using a real option approach, but did not provide recommendations on optimal sizing of panels. Moreover, they considered electricity price as the sole source of uncertainty and neglected the solar panels performance and building energy demand volatilities (Ashuri & Kashani, 2011; Kashani et al., 2015). This paper demonstrates an investment analysis method which uses the dynamic programming to assist decision makers in finding the optimum investment strategies (in terms of investment time and the size of solar panels) when implementing a residential PV system in the presence of building demand uncertainties and unpredictable market fluctuations.

In the next section, we will discuss the modeling scheme for each of these uncertainties and introduce a framework which considers them in the evaluation of the value of delaying investment and the value of implementing the PV panels in multiple stages.

2. Staged energy investment decision analysis platform (SIDAP)

In order to find the optimal staged investment strategy for residential PV system, we developed a staged energy investment decision analysis platform (SIDAP). Fig. 1 illustrates the schematic structure of SIDAP. In this platform, we first create an energy model of the building with integrated PV system and simulate it in EnergyPlus (Crawley et al., 2001). EnergyPlus is one of many building energy dynamic simulation software programs; it is regarded as the US "gold standard" of energy modeling versatility and