An Investment Analysis Framework for Energy Retrofit in Existing Buildings

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Energy Retrofit in Existing Buildings presents a significant role in achieving the energy reduction goal by 2020. It is projected that, through targeted government and private investment programs, as well as novel instruments, most of these retrofit solutions could be implemented widely across the nation by 2020. Given the increasing scale of investments in energy retrofit market, it is of crucial importance to offer the proper financial decision-making methodology to all stakeholders and decision-makers. Although conventional methods such as Net Present Value (NPV) have been widely used to evaluate investments in energy retrofit in existing buildings, they cannot evaluate the flexible energy retrofit solution in which investors delay adopting an emerging energy efficiency technology until the technology becomes available at a lower price, energy prices rise to higher levels, or stricter environmental regulations are put in place making the retrofit solution a necessity. Therefore, the research objective of this paper is to develop an investment analysis framework based on Real Options Theory to evaluate any proposed flexible energy retrofit solution. The proposed investment analysis framework consists of 5 functional components: the Building Energy Simulation Modeling, the Retail Energy Price Modeling, the Experience Curve Modeling, Investment Valuation Modeling, and Political and Regulatory Environments. The proposed investment analysis framework can find the optimal time to convert an existing home to a more energy-efficient home in a flexible retrofit solution. Therefore, it can be used as a policy instrument, looking at different scenarios in technology and market developments, and deciding between immediate or delayed implementation of energy retrofit for existing buildings.

Key Words: Energy Retrofit, Buildings, Investment Analysis, Real Options

Introduction

The total energy consumption by the U.S. housing stock was 10,880 Trillion BTUs in 2008, and is expected to rise to 11,410 Trillion BTUs in 2020 (including new homes) if business-as-usual continues. The total emissions from the existing homes were 1,270 Megatons CO_2e in 2008 and are projected to increase to 1,350 Megatons CO_2e in 2020 if the status quo is maintained (EIO AEO 2008). Retrofitting existing homes is the only way to break this trend. Advances in building technologies offer many promising retrofit solutions that can make houses more energy efficient. It is projected that by 2020, through targeted government and private investments, as well as novel instruments, such as energy mortgages, most of these retrofit solutions can be implemented widely across the nation.

Given the increasing scale of investments in energy retrofit markets, it is necessary to offer proper financial decision-making tools to the stakeholders and decision-makers. Without proper tools, the risk that funds are misappropriated is imminent, e.g., by choosing wrong energy technologies or by timing the implementation of energy retrofit solutions incorrectly. Conventionally, methods like Net Present Value (NPV) and Return on Investment (ROI) have been used to evaluate investments in energy retrofits for existing buildings. These methods cannot evaluate flexible energy retrofit solution in which investors delay adopting an emerging energy efficiency technology until it becomes available at a lower price, energy prices rise to higher levels, or stricter environmental regulations that make its application a necessity are in place. The market for building energy retrofit solutions is dynamic and subject to great uncertainty. A large number of emerging technologies can be considered for a retrofit project; some of which enable renewable energy production while others improve energy efficiency. Many of these promising technologies are still in their infancy and, hence, their prices are typically high and their efficiency and effectiveness remain to be verified in practice over time. One cannot be certain about actual energy savings potential of these technologies due to uncertainty about their technical performance and deterioration rate. Conventional valuation metrics like NPV do not systematically treat these issues in the financial analysis of a retrofit project and, hence, these opportunities are simply dropped from the investment list. This ignores the fact that many investors like to keep the option of using these technologies on the table since they see enormous energy savings potentials once their prices go down and they become more mature. Thus, investors require valuation models that can help them

determine whether they should delay a retrofit solution and when it becomes financially sound to adopt a technology.

The described limitations of conventional investment valuation methods can be overcome by using a different approach for financial valuation of energy retrofit solutions. The Real Options Analysis approach can be utilized to fulfill these expectations. The objective of this research was to develop an investment analysis framework based on Real Options Theory to evaluate flexible energy retrofit solutions. The proposed framework can find the optimal time to exercise the option embedded in a flexible retrofit solution and convert an existing home to a more energy-efficient home. This investment analysis framework puts a fair price tag on a flexible retrofit solution; for instance, it can establish the correct market-value of a solar-ready house. Thus, it effectively informs homeowners and investors and promotes competition in the retrofit provider market.

Research Background: Real Options Analysis

Generally, the financial assessment of a delayed retrofit solution is performed under the uncertainty about whether and when a retrofit solution should be implemented. Real Options Analysis properly meets this objective. The term "Real Options" refers to the application of financial option pricing techniques such as the Black and Scholes (1973) formula to assessment of non-financial or "Real" investments with strategic management flexibility features like delayed retrofit solutions (see Dixit and Pindyck (1994) for a detailed overview of real options analysis). This field has gone through a significant transition from a topic of modest academic interest in 1990s to considerable, active academic and industry attention (Borison 2005). However, the applications of real options in building design and engineering have not been numerous. (Greden et al. 2006; Greden and Glicksman 2005; Ashuri 2010; Ashuri et al. 2010). To the best of authors' knowledge, real options analysis has not been applied to evaluate energy retrofit investments. Considering the high level of investments in energy retrofit, creating more appropriate investment valuation models in order to avoid under- and over-investments is crucial and the application of the real options theory from finance/decision science can result in significantly improvements in the investment valuation of energy retrofit solutions.

Investment Analysis Framework for Energy Retrofit

Figure 1 present an overview of the proposed energy retrofit investment analysis framework, which is applicable to energy retrofit solutions considered for an existing building. An Investment Valuation Model based on Real Options Theory is at the core of this framework. It receives input from external modeling components, which generates the information that proper financial analysis of a proposed energy retrofit solution requires. The first component is Building Energy Simulation Modeling, which is used to assess the energy performance of a proposed energy retrofit solution in an existing building under all major sources of uncertainty. The module determines the energy savings potential of the proposed retrofit solution and characterizes how the energy performance evolves over time due to changes in physical system degradation. It delivers probability distributions of obtainable energy savings over time which is used as inputs to the real options investment valuation model. The second component is Retail Energy Price Modeling, which shows future projected paths for the energy price. The financial benefit of a proposed retrofit solution will be calculated based on these energy price models. The third component is Experience Curve Modeling, which is used to characterize how price and efficiency of a proposed retrofit solution evolve over time. This is critical in finding the optimal investment time for a proposed energy retrofit. Finally, the proposed investment valuation framework real options model requires inputs from Political and Regulatory Environments, which characterize specific incentive programs and energy efficiency targets. The modeling process is described in the following sections.
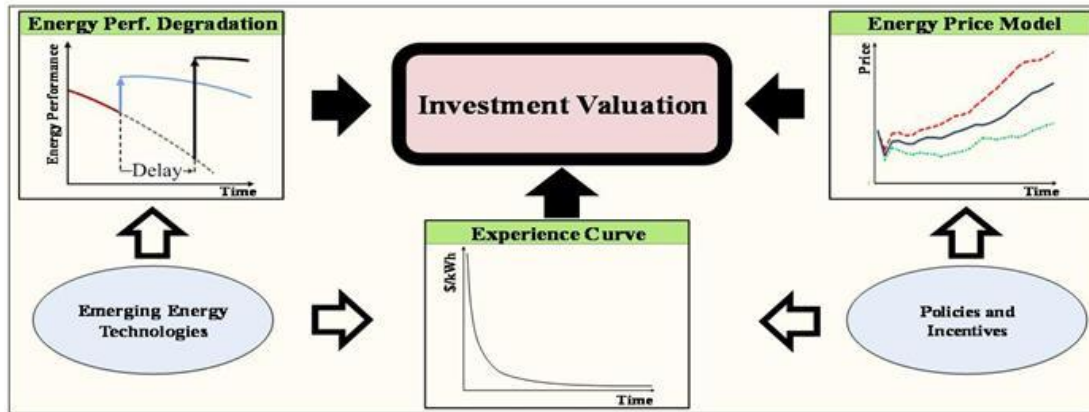
Figure 1: Overview of the Investment Analysis Framework for Energy Retrofit
Building Energy Simulation Modeling: Characterize Energy Savings Performance

The Building Energy Simulation Modeling component explicitly addresses the uncertainty and degradation in energy savings performance of a proposed energy retrofit solution. Uncertainty analysis can be conducted using two well-established whole building simulation environments: EnergyPlus and TRNSYS. The analysis starts with the identification of sources of uncertainty and their quantification including the meteorological, urban and micro climate uncertainties, related to the environmental conditions around the building. Uncertainties about the long-term meteorological fluctuations is captured in new weather files as reported in (Crawley 2007; Hopfe 2009). Uncertainty Quantification (UQ) on these scales is based on available literature on urban influences (Robinson et al. 2007), studying mainly airflow, urban heat island effects and wind pressure coefficients in urban surroundings. Table 1 (Hu 2009) gives a small sample of the results of an UQ exercise, in this case for the risk analysis of an off-grid solar house. It shows the range (Min, Max) and the typical value (Ref) used in deterministic simulation. Uncertainties caused by degradation are the main focus of the work.

The ranking of parameters with highest impact on uncertainty in predicted energy consumption is a major outcome of this task. Rank-ordering the sources of uncertainty is useful because it helps in streamlining the uncertainty analysis by considering the most important sources first and study their impact on considered retrofit solution. The Morris method (Morris 1991) is the prime candidate for the parameter ranking. When all model uncertainties are quantified, uncertainty analysis is conducted typically using Monte Carlo simulation (Saltelli 2008) with EnergyPlus or TRNSYS. The outcome of this activity is a probability distribution of energy savings potential over time. The effect of several sequential interventions can be studied in a similar fashion leading to results as sketched in Figure 2. The figure depicts the uncertainty profile of predicted energy savings of a proposed energy retrofit solution. To quantify the financial benefit of implementing the energy retrofit solution, the future retail of energy should be characterized in order to calculate the extent of energy saving benefits.

Table 1

Example of Uncertainty Intervals (Min, Max) and Best Estimates

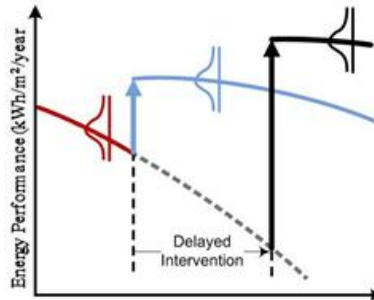|	Min	Max	Ref
Roof - Solar Transmittance	0.14	0.22	0.18
Internal Heat Transfer Coefficient - Wall	1.59	4.1	2.5
Normalized Leakage Area (NL)	0.08	0.52	0.3
PV – Environmental Factor	0.667	0.994	0.84
Inverter	0.92	0.97	0.96
Change Regulator	0.9	0.95	0.95
Battery –Efficiency	0.7	0.84	0.84
Ground – Albedo	0.15	0.3	0.17
Thermal Bridge - U	66.4	99.6	66.4

Figure 2: Uncertainty about Energy Performance Degradation

Retail Energy Price Modeling: Create a Stochastic Model for Energy Price

Retail Energy Price Modeling explicitly addresses uncertainty about energy price as a major benefit driver of an energy retrofit investment. Financial benefits of energy savings depend on the price of energy in the utility retail market. Although average energy price rises over time, it is subject to considerable short-term variations (Figure 3). A Binomial Lattice model (See Hull (2008) for detailed descriptions) can be created to characterize the energy price uncertainty. A binomial lattice model is a simple, discrete random walk model, which has been used to describe evolving uncertainty about energy price (Liski and Murto 2010; Ellingham and Fawcett 2006). The modeling choice of binomial lattice is also consistent with the general body of knowledge in real options (Hull 2008; Luenberger 1998). In economics and finance, binomial lattice is an appropriate model to capture uncertainty about a factor like energy price that grows over time plus random noise (Dixit and Pindyck 1994).

Binomial Lattice Model

To define a binomial lattice (Figure 4) for energy price (S), a basic short period with length Δt will be considered. Suppose the current energy price is S_0. Energy price in the next period is one of only two possible values: $u \times S_0$ or $d \times S_0$ where both u and d are positive rates with u>1 and d<1. The probabilities of upward and downward movements are p and 1-p, respectively. This variation pattern continues on for subsequent periods until the end of investment time horizon. Binomial lattice parameters can be determined using data on the expected annual growth rate of energy price (α) and the annual volatility of energy price (σ) as explained by Hull formulation (2008). This binomial lattice can be used as a basis to generate future random paths for energy price.
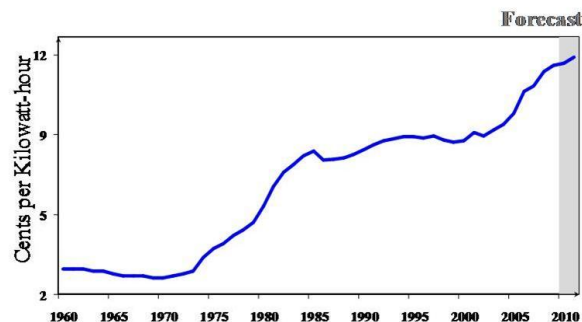

Figure 3: Annual Average Residential Electricity Price (EIA 2010)

Monte Carlo Simulation

Next, Monte Carlo simulation technique can be applied to generate several random paths for energy price S – from the time that an energy retrofit solution is applied until the end of investment time horizon – based on the described binomial lattice. Considering the binomial lattice formulation, energy price in any period of the lattice is a random variable that follows a discrete binomial distribution; this is the basis of applying Monte Carlo simulation technique for generating a large number of random energy price paths along the investment time horizon (Figure 4). Random energy price paths are used to compute respective energy savings series. In addition to benefits, it should be specified how the initial cost of an emerging technology changes over time to find when it is optimal to invest in. This is discussed in the following section.
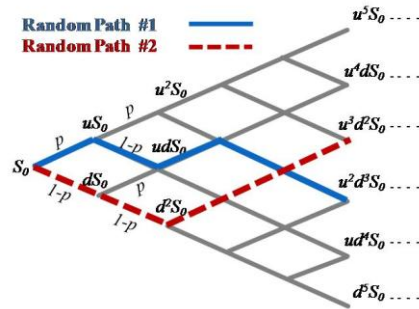
Figure 4: Random Energy Price Paths along the Binomial Lattice

Experience Curve Modeling: Create an Experience (Learning) Curve for the Proposed Emerging Technology

The concept of Experience Curve describes how the marginal costs decline with cumulative production over time (Hartley et. al 2010; Weiss et al. 2010). Typically, this relationship is characterized empirically by a "Power Law" of the form: $Pt = P_0 X^{-\alpha}$ where P_0 is the initial price (\$ cost of first Megawatt MW of sales), X is the cumulative production in MW up to year t, and $2^{-\alpha}$ is Progress Ratio (PR); for each doubling of the cumulative production (sales) the cost declines to PR% of its previous value. For instance, Figure 5 shows an experience curve created for PV modules. The apparent decline in costs may be due to several reasons, including process innovation, learning-by-doing, economies of scale, R&D expenditures, product innovation/redesign, input price declines, etc. (Hartley et. al 2010; Yu et al. 2010). The parameter α in the experience curve – i.e., $P_t = P_0 X^{-\alpha}$ – is defined using historical data of marginal costs and cumulative productions of the emerging technology. α can be estimated by a standard Ordinary Least Square (OLS) method. However, it is not easy to forecast whether α remains constant or change over time (Yeh et al. 2009). Research has been focused on development of models that incorporate such uncertainties (Yeh et al. 2009; Gritsevskyi and Nakicenovic 2000). The best engineering judgment for the future level of decline in price of a technology can be used in these circumstances to characterize the cost trend of an emerging technology.
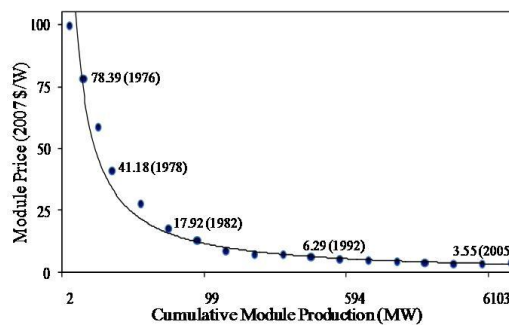

Figure 5: Experience Curve of PV Modules 1968 to 2006

Investment Valuation Modeling based on Real Options Analysis

With the input from above three steps, Investment Valuation Modeling will determine the optimal investment time to implement an energy retrofit and embedded price flexibility in a delayed energy retrofit solution.

A probabilistic NPV analysis can be conducted to describe the financial risk profile of an immediate investment for a proposed energy retrofit. This is carried out under the assumption that investors adopt the proposed emerging technology right away at the current price and efficiency rate. Randomly generated energy saving streams are used to characterize investors' NPV distribution of an immediate Energy Retrofit (Figure 6). Investors' cost of capital or required rate of return can be the discount rate in NPV analysis.
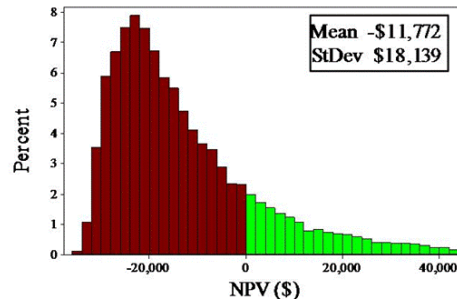
Figure 6: Investor's NPV Distribution of Immediate Energy Retrofit

In addition, using the risk-neutral valuation method – developed in mathematical finance for pricing options and derivatives –the correct market-based value of a delayed energy retrofit solution can be determined. In this technique, the probabilities of upward and downward movements in the initial energy price binomial lattice are modified – as described by (Luenberger 1998; Hull 2008) – to conduct option valuation. Risk-neutral binomial lattice can then be used as Decision Tree to determine the optimal energy retrofit time. Hence, investors' NPV distribution is calculated considering this optimal retrofit time. The difference between expected investors' value under immediate and delayed energy retrofit represents the expected value of optimal delayed energy retrofit (Figure 7).
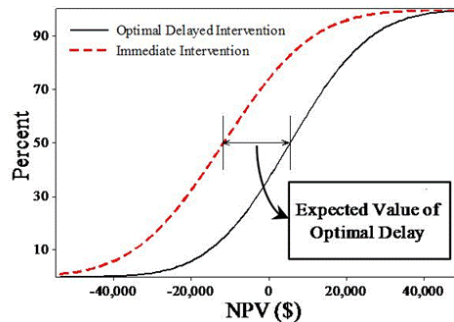

Figure 7: Investment Value of Optimal Delayed Energy Retrofit

Impact of the Political and Regulatory Environments

Political and Regulatory Environments component encompass the impact of energy efficiency policies and incentive programs on investment valuation. Scenario analysis should be applied to specify possible energy targets and their likelihoods. Random upgrade scenarios, e.g., regulatory, political, technical, and/or market environments, in which an energy retrofit solution takes place should also be generated. Each scenario can be investigated with respect to its impact on future level of energy price, as well as its contribution to cost reductions of the proposed energy technology. Through what-if analyses, the impact of the regulatory conditions on the investment timing for an energy retrofit solution can be evaluated.

Validation of Investment Analysis Framework

The validation of the proposed investment analysis framework was carried out by applying the framework to valuation of the investment in PV panels for a residential building. Based on the proposed investment analysis framework, the financial performance of the flexible retrofit solution 'Solar-Ready House' was compared with the financial performance of the fixed retrofit solution 'Solar House'. The initial cost of preparing electrical, structural, and roofing systems for PV panels was considered to be $10,000. This is the additional cost of embedding flexible features in a solar-ready house. Also, it was supposed that the purchase price of PV panels with the service life of 20 years is currently $4/W and is anticipated to decrease every year due to experience curve effect (PR=0.46329). It means that when the cumulative production of the PV modules is doubled, the price of the PV panels ($/W) is going to be reduced by the magnitude of 46.329%. Solar panels for this house were required to provide 6,300W power and to generate 12,000 kWh per year for electricity consumption in the house. It is expected that the performance of the installed PV panels will decrease by a magnitude of 1% on an annual basis (Ishii et al 2010). The initial retail price of electricity was also assumed to be $0.1031/kWh; this unit price changes over time with the expected annual

growth rate 4% and the volatility of 20%. These values were used to create a binomial lattice to model electricity price variations. Financial benefits of PV panels are in terms of energy savings, which must otherwise be purchased from the utility company. Federal and State tax benefits are $5,000 and the homeowner's discount rate is 7%/year. Under these circumstances, the real options analysis methodology was applied and the financial performance of solar house and solar-ready house under uncertainty about the electricity price were evaluated. It was also determined whether and when it is optimal to convert a solar-ready house to a solar house and how much embedded flexibility in a solar-ready house is worth investing.

Figure 8(a) shows the optimal electricity price, which triggers conversion from a solar-ready house to a solar house; the increasing boundary effect is due to the option expiration in 2030. Below the price threshold, an investor or homeowner should delay the installation of PV panels. When the electricity price rises to a substantially high level, the value of waiting becomes lower than the energy savings benefits of the immediate PV panels installation; therefore, the solar-ready house should be converted into the PV house. Figure 8(b) shows the likelihood profile of the optimal conversion year; this is the probability of the event that the random electricity price path reaches the optimal investment threshold specified in (a) for the first time in the current year. It can be seen that initially waiting is more valuable than immediate exercise; but, as the time passes, the opportunity cost of waiting becomes large enough that triggers investment. Figure 8(c) shows the NPV distribution of a solar-ready house under uncertainty about energy savings. Figure 8(d) shows the NPV Cumulative Distribution Functions (CDFs) of solar and solar-ready houses. The expected NPV of the solar house is $-11,772 and the chance of investment loss, i.e., Probability (NPV<0), is approximately 75%, which make the solar house an unattractive retrofit solution. Delayed retrofit decision-making can enhance the value of solar upgrade. The two-phase development of the solar-ready house represents the hidden value of flexibility in the solar upgrade. It can be seen that the expected NPV of the solar-ready house is $5,480, which is much larger than the expected NPV of the solar house $-11,772. Therefore, the expected price of flexibility in the solar-ready house is $5,480-($-11,772)=$17,252. Also, due to the two-stage installation of PV systems, the chance of investment loss for the solar-ready house is approximately 35%, which is much lower than 75% for the solar house.
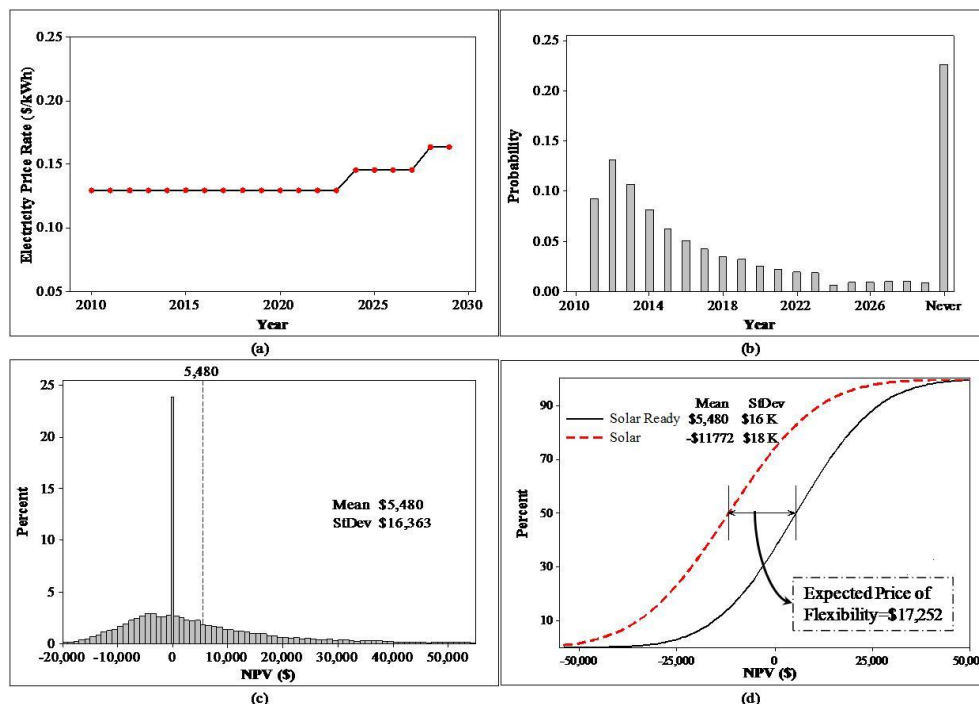

Figure 8: (a) Optimal Retail Price of Electricity ($/kWh) Triggering the installation of Solar Panels; (b) Installation Likelihood of PV Panels Over the House Service Life; (c) NPV Distribution of Solar Ready Home; (d) NPV Cumulative Distribution Functions (CDFs) of the Solar House and Solar Ready House and Price of Flexibility

Conclusion

Better investment decision models can facilitate achievement of energy savings through increasing the efficiency and effectiveness of private investments in energy retrofit. The proposed investment analysis framework will enlighten investors about the economic and environmental inefficiencies that conventional fixed energy retrofits produce and provide delayed solutions to mitigate such inefficiencies. Explicit pricing of flexibility is significant for systematic energy retrofit decision-making beyond the current energy target; embedded options in delayed retrofit solutions reflect on the possibility to meet future stricter targets and prepare for future upgrades.

The proposed investment framework can be used as a policy instrument, looking at different scenarios in technology and market developments, and deciding between immediate or delayed implementation of energy retrofit. Thus, it can become an instrument in the selection of the right government incentives over time. As a corollary, the methodology will be used to single out the type of retrofit solution and technologies that are ripe in the expected market of competing energy retrofit technologies.

References

Borison, A. (2005) "Real Options Analysis: Where Are the Emperor's Clothes?" Journal of Applied Corporate Finance, 17(2), pp. 17-31.

Crawley, D.B. (2007) "Creating Weather Files for Climate Change and Urbanization Impacts Analysis". Proceedings of the 10th International IBPSA Conference, Beijing, China.

Dixit, A., and Pindyck, R. (1994) Investment Under Uncertainty, Princeton University Press, Princeton, NJ.

Draper, N.R. and Smith, H., (1998) Applied Regression Analysis, 3rd ed., Wiley, New York.

Greden, L. V., Glicksman, L. R., and Lopez-Betanzos, G. (2006) "A Real Options Methodology for Evaluating Risk and Opportunity of Natural Ventilation." Journal of Solar Energy Engineering, 128(2), pp. 204-212.

Greden, L., and Glicksman, L. (2005) "A Real Options Model for Valuing Flexible Space." Journal of Corporate Real Estate, 7(1), pp. 34-48.

Gritsevskyi, A. and Nakicenovic, N. (2000) "Modeling Uncertainty of Induced Technological Change", Energy Policy, 28, pp. 907–921.

Hartley, P., Medlock, K. B., Temzelides, T. and Zhang , X. (2010) "Innovation, Renewable Energy, and Macroeconomic Growth". Prepared in conjunction with an energy study sponsored by The James A. Baker III Institute for Public Policy and The Institute of Energy Economics, Japan

Hopfe, C., Augenbroe, G.. Hensen, J. Wijsman, A. and Plokker, W. (2009) "The impact of climate scenarios on Decision making in building performance simulation: a case study". EuropIA 12 Conference, Paris, March, 2009.

Hu, H. (2009) Risk-Conscious Design of a Zero Energy House. Ph. D. dissertation, Georgia Institute of Technology.

Hull, J. C. (2008) Options, Futures, and Other Derivatives, Prentice Hall, New Jersey.

Ishii, T., Takashima, T., Otani, K. (2010) Long-term performance degradation of various kinds of photovoltaic modules under moderate climatic conditions. Progress in Photovoltaics: Research and Applications. Article first published online on 14 July 2010.

Luenberger, D. G. (1998). Investment Science, Oxford University Press, New York.

McGraw-Hill Construction (2010) "SmartMarket Report: Green Building Retrofit & Renovation".

Morris, M.D., (1991) "Factorial Sampling Plans for Preliminary Computational Experiments," Technometrics, 33(2) pp. 161-174, 1991.

Robinson D., Campbell N., Gaiser W., Kabele K., Le-Mouel A., Morel N., Page J., Stankovic, S., and Stone, A. (2007). "Suntool - A New Modeling Paradigm for Simulating and Optimizing Urban Sustainability", Solar Energy, 81(9), pp. 1196-1211.

Rye, C. (2008). "Solar Ready Houses." Solar Power Authority the Dirt on Clean, July 21, 2008.

Saltelli, A., Ratto, M., Andres, T., Campolongo, F., Cariboni, J., Gatelli, D., Saisana, M., and Tarantola, S. (2008). Global Sensitivity Analysis: The Primer. John Wiley & Sons, Chichester.

SBI Energy (2010) "Global Green Building Materials and Construction", 2nd Edition.

Van Sark, W. G. J. H. M. E., Alsema, A. , Junginger, H. M., de Moor, H. H. C., and Schaeffer, G. J.(2008) "Accuracy of Progress Ratios Determined From Experience Curves: The Case of Crystalline Silicon Photovoltaic Module Technology Development" Progress in Photovoltaics: Research and Applications, (16), pp. 441–453.

Weiss, M., Junginger, H. M., Patel, M.K. and Blok, K. (2010) "Analyzing Price and Efficiency Dynamics of Large Appliances with the Experience Curve Approach", Energy Policy, 38, pp. 770–783.

Yeh, S., Rubin S., Hounshell, D.A. Taylor, M. R. (2009) "Uncertainties in Technology Experience Curves for Integrated Assessment Models", available at: http://repository.cmu.edu/epp/77

Yu, C.F., van Sark, W.G.J.H.M., Alsema, E.A. (2010) Unraveling the photovoltaic technology learning curve by incorporation of input price changes and scale effects, Renewable and Sustainable Energy Reviews, Article in Press.