A TOOL FOR THE ANALYSIS OF REAL OPTIONS IN SUSTAINABILITY IMPROVEMENT PROJECTS

A Thesis

by

NAPON BOONCHANTA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

August 2012

Major Subject: Civil Engineering

A Tool for the Analysis of Real Options in Sustainability Improvement Projects

A TOOL FOR THE ANALYSIS OF REAL OPTIONS IN SUSTAINABILITY IMPROVEMENT PROJECTS

A Thesis

by

NAPON BOONCHANTA

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

Approved by:

Co-Chairs of Committee,	David N. Ford
	Ivan Damnjanovic
Committee Member,	Zofia K. Rybkowski
Head of Department,	John Niedzwecki

August 2012

Major Subject: Civil Engineering

ABSTRACT

A Tool for the Analysis of Real Options in Sustainability Improvement Projects.

(August 2012)

Napon Boonchanta, B.E., Chulalongkorn University

Co-Chairs of Advisory Committee: Dr. David N. Ford
Dr. Ivan Damnjanovic

The major challenges in sustainable implementation are the financial issue and uncertainties. The traditional financial budgeting approach that is commonly used to evaluate sustainable projects normally neglects future decisions that might need to be made over the course of a project. The real options approach has been suggested as a tool for strategic decision making because it can provide flexibility which can increase the project value. Researchers have been trying to identify the potential of the real options approach, and provide the frameworks for a real options evaluation and flexible strategy in sustainability improvement. However, some important variables and financial impacts explanation of real options are missing. Models can be improved to show the variation of possible project values along with its behavior. This work aims to improve the real options model in sustainable projects to provide understanding about the financial impacts of flexible strategy to sustainable improvement projects and to be used as a tool to assist decision making. The results showed that real options can have a positive financial impact to the project. The extension of this model can assist the analysis and development of decision policies.

DEDICATION

To my family

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Ford and Dr. Damnjanovic, for their continuous support, guidance and patience through the course of this research. I am so grateful to them for helping me through the difficulties not only in academic but also in other issues.

I also thank my committee member, Dr. Rybkowski, for her guidance and support throughout the course of this research.

Thanks also to my friends and colleagues and the department faculty and staff for making my time at Texas A&M University such a great experience.

Finally, thanks to my mother and father for their patience, love and support. I would also like to thank every teacher in my life. I owe my success to them.

NOMENCLATURE

AEC	Architecture, Engineering and Construction
BCR	Benefit to cost ratio
LCCA	Life Cycle Cost Analysis
LEED	Leadership in Energy and Environmental Design (refers to rating system of high performance green building)
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
O&M	Operation and Maintenance
PV	Photovoltaic (refers to photovoltaic or solar energy system)
U.S. DOE	U.S. Department Of Energy
U.S. EIA	U.S. Energy Information Administration
USGBC	U.S. Green Building Council

TABLE OF CONTENTS

Page

ABSTRACT iii

DEDICATION iv

ACKNOWLEDGEMENTS v

NOMENCLATURE vi

TABLE OF CONTENTS vii

LIST OF FIGURES ix

LIST OF TABLES xi

1. INTRODUCTION 1

2. REAL OPTIONS IN SUSTAINABILITY IMPROVEMENT 5

2.1 Real options principle and flexible strategy 5
2.2 Real options valuation 7
2.3 Previous work on real options in sustainability improvement 9

3. RESEARCH OBJECTIVES AND SCOPE OF STUDY 15

3.1 Problem description 15
3.2 Research objectives 18
3.3 Scope of study 18

4. HYPOTHESES 20

4.1 Hypothesis statement 20
4.2 Expected contribution 20

5. RESEARCH METHODOLOGY 22

5.1 Model development to investigate impacts of real options 22
5.2 Model development to use as an analysis tool 24

6. THE MODEL DEVELOPMENT 26

Page

6.1 Model assumptions 26
6.2 Model structure 27
6.3 Simulation model of uncertainty scenarios 29
6.3.1 Uncertainty in electricity price 30
6.3.2 Uncertainty in photovoltaic price 33
6.3.3 Performance degradation 35
6.4 Financial calculation 40
6.5 Real option analysis 41
6.6 Validation 43
6.6.1 Structure validation 43
6.6.2 Behavior validation 46
6.7 Model use 48
6.7.1 The steps for using with the PV installation case study 50
6.7.2 Modifications for other projects 60

7. RESULT 62

7.1 Simulation by assigned investment year 64
7.2 Simulation by assigned criteria 72
7.3 Model analysis 74

8. CONCLUSION 79

8.1 Impacts and behavior of real options in sustainable improvement according to the case study 79
8.2 Impacts of real options in sustainable improvement in practice 80
8.3 Future works 81

REFERENCES 82

APPENDIX A: MODEL CODE 87

APPENDIX B: VALIDATION RESULT 89

APPENDIX C: PRICE HISTORICAL DATA 93

LIST OF FIGURES

FIGURE Page

1 Integrative investment framework for ecology-driven real options 11

2 Overview of investment analysis framework for energy retrofits 12

3 The distribution function of NPV resulted from delayed decision 13

4 The retail electricity price and the cost of electricity produced from renewable energy trend 16

5 Average retail price of electricity in commercial building 16

6 The modeling procedure 22

7 Real options simulation model structure 28

8 Historical average retail prices of electricity 30

9 Exponential simulation trend of electricity price 32

10 Linear simulation trend of electricity price 32

11 Historical data of PV module price with linear fitted trend line 33

12 Historical data of PV module price with exponential fitted trend line 34

13 PV module price model graph 35

14 The comparison between exponential degradation and linear degradation model of PV output 37

15 Histogram of reported degradation rates from literatures 38

16 Degradation simulation of PV output 39

17 Model structure and inputs of financial calculation section 40

18 Real options analysis model structure 42

19 Cumulative cost graphs in 3 study cases based on ideal condition 45

20 Content sheet 51

FIGURE Page

21 Screenshot of analysis option user interface 52

22 Screenshot of simulation sheet 54

23 Solar Isolation Map for Texas 62

24 Average project value by the time of exercising the option (year) if electricity price trend is exponential...65

25 Average project value by the time of exercising the option (year) if electricity price trend is linear 69

26 Cumulative distribution chart of project NPV for exponential electricity trend case 70

27 Cumulative distribution chart of project NPV for linearl electricity trend case 71

28 Project NPV when an option was exercised at different assigned electricity price ratio decision policy...73

29 Project NPV when an option was exercised at different assigned PV price ratio decision policy...73

30 Sensitivity analysis of exogenous variables 75

31 Impact of volatility to project value...77

LIST OF TABLES

TABLE Page

1 Concept of analogy between financial options and real options 5

2 Types of real options and their contribution to management flexibilit 6

3 Model Variables 19

4 Model scenario assumptions 26

5 Fitted trend line equation and standard deviation of historical data for historical trajectory 31

6 Extreme condition test parameters 47

7 Spreadsheets model description. 49

8 Simulation sheets detail 55

9 PV system sizing assumptions and calculation 62

10 Model parameters and input 63

11 Comparison of results from simulation 64

12 Comparison of NPV in first 2 years between the decisions to invest in year 0 and year 1 67

13 Impact of exogenous variables 76

1. INTRODUCTION

Currently, sustainability has become one of the most important aspects in AEC industry. The demand for sustainable development has been increasing globally because of the growth in population, limited resources, climate change, economy and market trend (Kibert, 2007). Defined by the USGBC (2011), three key aspects or "the triple bottom line" of sustainability is economics, environment and social responsibility. These are the main objectives which serve as a foundation of sustainable development in today's business world (Weber and Savitz, 2006). Green buildings, also refer to as energy-efficient buildings, are buildings which constructed to satisfy the three bottom lines in the building environment. Numerous owners and clients, from both public and private sectors have invested more than ever in these types of buildings because of the primary benefits in financial, environmental, health and market (Kubba, 2010; Durmus-Pedini and Ashuri, 2010). Although there are many advantageous aspects, in practice, sustainable development is still mainly driven by financial reasons. According to McGraw-Hill Construction's survey (2009), over 73% of motivation in green building adoption in American corporate is the financial incentive. The other two aspects of the three bottom line, environment and social responsibilities, are not major concerns.

This thesis follows the style of *Journal of Construction Engineering and Management*.

However, one of the major challenges in sustainable implementation is also the financial issue. Investors still doubt whether sustainable investment in such buildings would give them good return on investment within the desired period. In order to make an effective investment decision on sustainable development alternatives, financial evaluation is needed. Traditional financial budgeting approach normally neglect future decisions that might need to be made over the course of a project. One of the most common methods is discounted cash flow method or Net Present Worth (NPV). Decision makers shall make a decision based on negative or positive value of NPV. Although, NPV method is a very useful tool to evaluate investment alternatives as it considers discounted cash flows over a project life cycle, it still presents some limitations. First, NPV assumes that alternatives require a now-or-never type of decision making which means that an investment is irreversible (Dixit et al., 1995; Ashuri et al., 2011). This assumption ignores the value of future opportunities. Second, NPV method also considers all cash flows as a known variable. This provides an error when evaluating a project investment uncertainty involved. Also, Ford and Bhargav (2006) claimed that firms which have used a traditional discounted cash analysis may undervalue a project.

Another difficulty in sustainable development investments is uncertainties in the project life cycle including uncertainty over reliability of green technologies, the costs of developing of green real estates, economic benefits and performance over time (Secretariat of the Commission for Environmental Cooperation, 2008). Due to the nature of technology related to sustainability, most technologies will be improved and likely to be cheaper in the future. For sustainable building retrofit, owners rank energy price and volatility as their main concerns (Menassa and Rexrode, 2010). Therefore, ability to make changes to the project when future events or uncertainties become clear might be economically sensible.

The real options approach has been suggested as a tool for strategic decision making and capital budgeting because it can provide future flexibility which can add value to the project (Amram and Kulatilaka, 1999). Real options can be defined as "the right, but not the obligation, to make a particular business decision" (Berk et al., 2009). The term "real" usually refers to tangible assets. It allows decision makers to resolve uncertainty over the passage of time and make better decisions in a dynamic environment later on in a project, not limiting decisions to the pre-project planning stage (Mun, 2010; Johnson et al., 2006). Real option is an analogous to financial options: a put option and a call option. Similar to a call option, owners pay a premium to acquire the right to defer, expand or delay a decision to put sustainable features to their properties which depends on the strike (exercise) price of the features. In other word, the owners pay the premium or buy the right to have flexibility in the project. Correctly modeled flexible strategies have the ability to add value to a project by delaying decisions during a time of vague uncertainties (Ford et al., 2002). Although the real options approach has potential gains, it has had limited use in the AEC industry (Johnson et al., 2006; Ford and Bhargav, 2006; Ford and Garvin, 2010). Ford and Garvin (2010) recommended that challenges can be overcome by improving the real option models to better reflect the nature of the project. This work aims to improve the real options model in sustainable projects to identify the results and use as a preliminary tool to assist decision making.

2. REAL OPTIONS IN SUSTAINABILITY IMPROVEMENT

Recently, many researchers have identified the potential of the real options approach in uncertainty management of engineering projects. The real option models have been developed according to projects' nature to assist the decision making process. Selected papers on real options and the application in sustainability improvement are discussed in this section.

2.1 Real options principle and flexible strategy

Most of the business projects contain real options which allow decision makers to choose the most attractive alternative when new information has been learned or uncertainties have become clear. Real options theory is based on the financial option principle. A financial option is a contract that gives its owner a right but not obligation to purchase or sell an asset at a fixed price in the future. The concept of real options in capital budgeting is analogous to financial options in several ways. Brach (2003) summarized the analogy concept between financial options and real options in Table 1.

Table 1 Concept of analogy between financial options and real options (after Brach, 2003)

Variable	Financial Option	Project Investment/ Real Options
K	Exercise Price (Strike Price)	The cost to acquire the asset
S	Stock Price	The present value of future cash flows from the assets
t	Time to Expiration	Length of time that option is viable
σ^2	Variance of Stock Return	Riskiness of the asset: variance of the best and worst case scenario
r	Risk-free Rate of Return	Risk-free Rate of Return

For application of real options in the managerial field, Amram and Kulatilaka (1999) defined option as the opportunity to make a decision after events become clearer. They categorized the application of within investment decisions into five types: option to defer, option to grow, option to extend, option to switch, and option to abandon. Busch and Hoffmann (2009) extended their research and provided the managerial flexibility and descriptions for each type of option as shown in Table 2.

Table 2 Types of real options and their contribution to management flexibility (after Busch and Hoffmann, 2009)

Types of option	Management flexibility	Description
Option to defer	Deferring the exercise date into the future	An option to defer allows the management to postpone the start of an investment. This applies to investments that are not profitable under current conditions but might become profitable at a later stage
Option to grow	Flexible adjustment of project's scope	Growth options can be adequate in situations where an initial investment turns out to be profitable. While building on this investment, further investments generate additional revenues at a later stage
Option to extend	Broadening the utilization of gained knowledge	Considering options to extend, firms are able to utilize an initial investment in related areas afterward if the conditions are favorable. Management is able to transfer technologies or knowledge gained to other projects
Option to switch	Flexible choice of path	Within a project's lifetime, management may have the option to move back and forth between different possibilities to utilize the initial investment, depending on each possibility's profitability

Table 2 (Continued)

Types of option	Management flexibility	Description
Option to abandon	Stop project	An option to abandon describes the possibility to stop a project at a later stage while retaining the ability to capture a remaining value of the initial investment. A reason for stopping a project could be a change in market conditions

Triantis (2003) presented five key of the flexible or “option-based” strategies for creating value as follows:

- Investment opportunities should not always be viewed as now-or-never decisions as a better opportunity may present itself in the future when some uncertainties become clear.
- The decision makers should create flexibility to allow them to alter the project in the future instead of focusing on the most likely scenario.
- Investments should be made in stage rather than all at once.
- Diverse sets of future alternatives should be developed when planning an investment strategy.
- Creating or purchasing real options may be profitable when uncertainty is high.

2.2 Real options valuation

In order to calculate the value for an option, several main techniques are generally used: the partial differential equation or Black-Scholes formula, binomial option valuation and simulation approach.

First, Black and Scholes (1973) presented the well-known formula for valuing financial options called the Black-Scholes Options Pricing formula which was derived to value a European-style call option for a non-dividend-paying stock. The formula consists of only one equation and five inputs which makes it very simple to use. The equation can be simply written as:

$$\text{Call Option} = \text{Stock Price} \times N(d_1) - PV(\text{Strike Price}) \times N(d_2)$$

The present worth is calculated using the risk-free rate. The expression $N(d_1)$ and $N(d_2)$ are probabilities, and d_1 and d_2 are the inputs that contain necessary variables which are volatility, time to decision date, risk free interest rate, value of underlying asset, exercise price.

However, according to Brach (2003), Black-Scholes formula does not always work for real options case because project volatility is not constant over time, the expiration date is not definitive and the asset value, as well as exercise price, behave stochastically.

The second approach is the binomial option pricing model. The model assumes that in each time period, the underlying asset can take only one or two possible values. Such binomial movement sequence generates a large set of a "binomial tree" and the probabilities of achieving these values and the expected payoff can be calculated. This approach has an assumption that the decision makers are risk indifferent or risk-neutral. Although the option values can be varied by individual's risk taking preference, the risk neutral assumption of binomial approach can simplify the calculation.

Third, more complex decision problems may be solved by a simulation approach. The simulation model can generate a number of different values and thousands of paths of the underlying asset during the viable time to the decision. The Monte Carlo simulation is commonly used and generates a number of possible values based on the probabilities in a risk-neutral environment. The current value of the option is determined by averaging the payoffs and then discounting the average back to the present (Amram and Kulatilaka, 1999). The expected value of the option is then calculated, and a risk-free rate is used to discount this expected value back to the initial date. According to Triantis (2003), one of the principle advantages of the simulation approach is the ability to deal with multiple uncertainties. Simulation approach can also be done as a dynamic programming in order to see when the current decision policy influences the future payoffs. In this work, simulation approach is used to value real options. The previous works on the simulation approach framework on are discussed in next section.

2.3 Previous work on real options in sustainability improvement

Cortazar et al. (1998) conducted research on an investment in environmental technologies under varying output price levels. This paper presented a mathematical model that can determine which and when the optimum point to invest in environmental technologies is, and what the variables that can affect the decision are. They utilized three types of real options in the research: option to defer, expand and abandon. The result showed that the parameters which affect the decision are interest rate, output price and profitability. The higher interest rate can reduce optimal environmental investment while price volatility and potential profit can dictate whether a firm should make such investment.

Further study by Busch and Hoffman (2009) on real options approach for sustainable development was to investigate the ecology-driven real options as a conceptual approach for incorporating uncertainties in the context of the environment. They derived six areas of ecology-driven uncertainties, and combined them with the investment framework to illustrate with carbon constraint case. The framework combines the major steps as follow:

- Change in the business environment both natural constraints and institution actions aimed to improve the environment.
- Perceived uncertainties.
- Determinants of investments' profitability which require analysis of underlying investment conditions, volatilities and assignment of time to invest.
- Ecology-driven real options in five options type. The investment framework for ecology-driven real options from this work is presented in Figure 1.

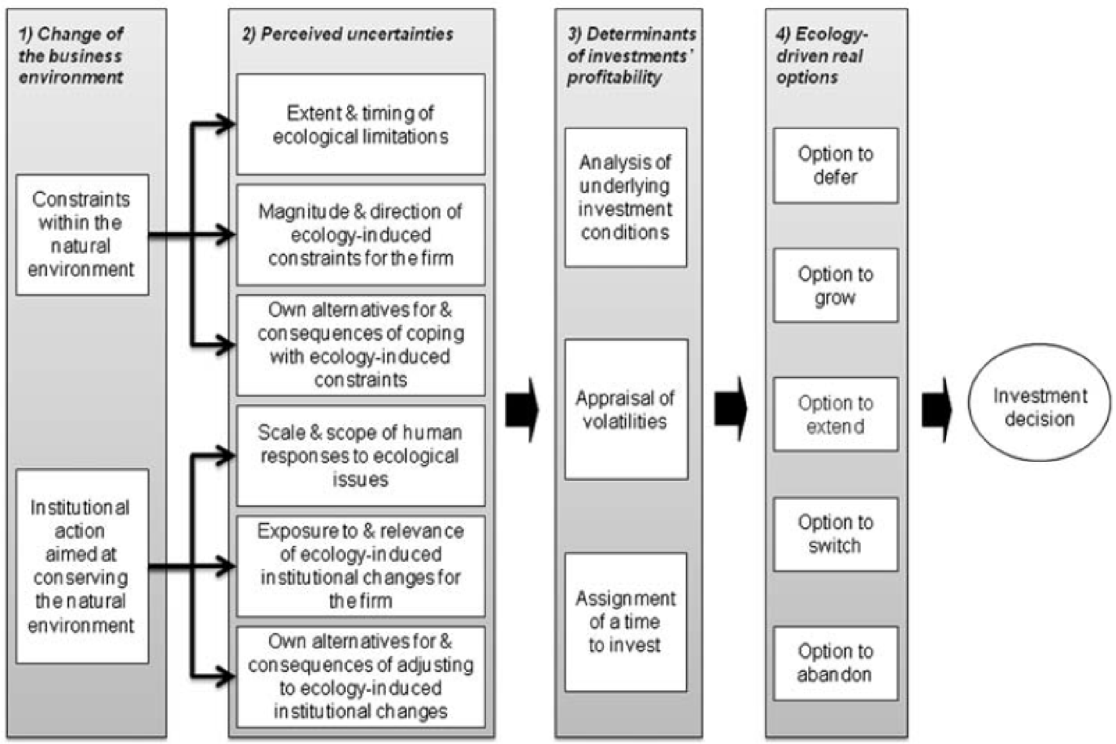


Figure 1 Integrative investment framework for ecology-driven real options (Busch and Hoffmann, 2009)

Menassa and Rexrode (2010) conducted research on the application framework of Life Cycle Cost Analysis (LCCA), real options theory and potential application to improve sustainability. The paper suggested that LCCA should be integrated with real options approach to effectively evaluate an investment alternatives and add value to the project.

Ashuri et al. (2009) presented a novel approach of incorporating flexibility to a building or building systems. They noted that flexibility strategy can transform traditional building development to become sustainable buildings while confronting risks and challenges. Ashuri et al. (2010) summarized the risk factors of sustainable development in existing buildings into five categories: financial, performance, legislative, market, and industry. Based on previous two literatures, Ashuri et al. (2011) proposed a real options approach framework to evaluate an investment in building energy retrofit. The proposed investment analysis framework consists of five 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 framework is shown in Figure 2.

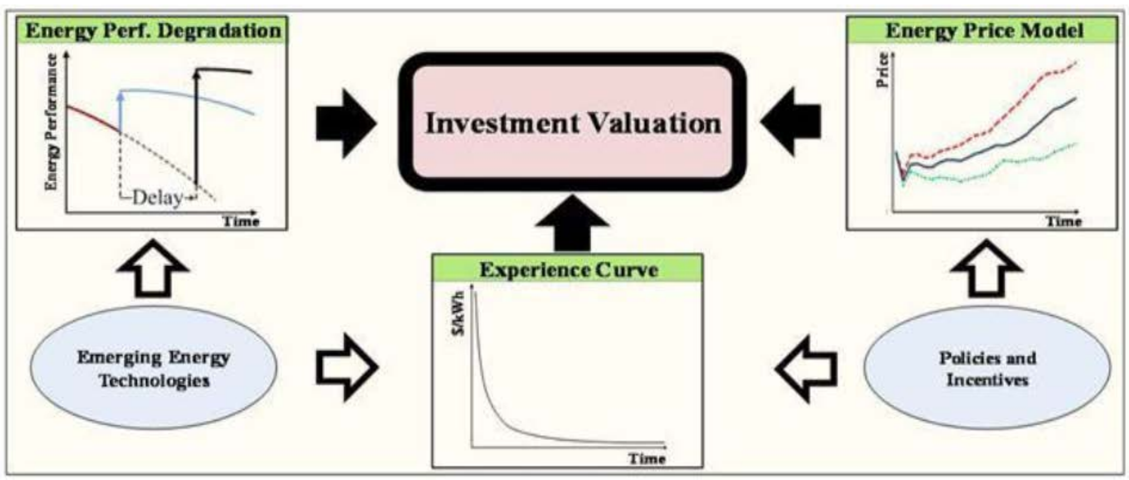


Figure 2 Overview of investment analysis framework for energy retrofits (Ashuri et al., 2011)

Ashuri et al. (2011) also illustrated an analysis in the case of a solar-ready building investment. The model considered only uncertainties in the price of energy, Photovoltaic technology efficiency and price volatility in Photovoltaic technology. Future retail energy price was modeled using the Binomial Lattice model while Photovoltaic price and efficiency was modeled with experience curve. Their model is the simulation approach which averages the value of the options by generating possible outcomes from Monte Carlo Simulation. The result presentation is shown in Figure 3.

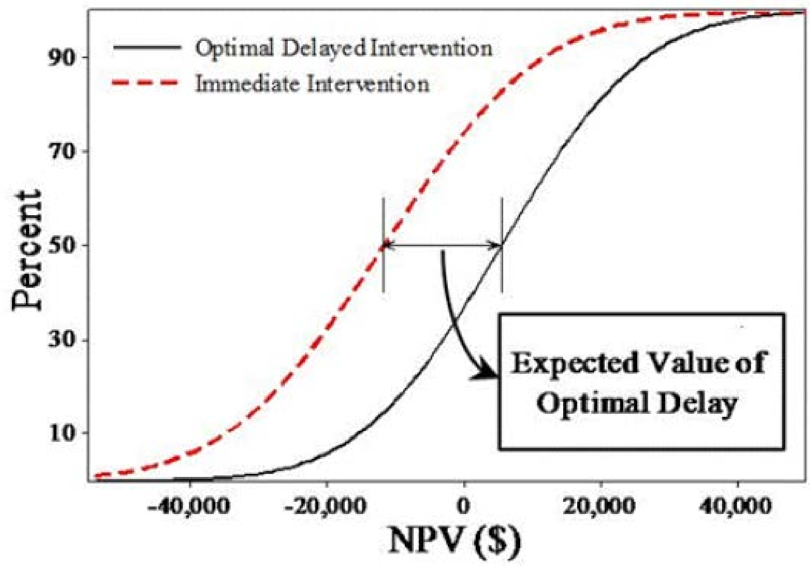


Figure 3 The distribution function of NPV to show investment value result from delayed decision (Ashuri et al., 2011)

Although the framework is useful, the illustrated model could be improved in order to be utilized in the decision making process. First, it did not consider the higher life cycle cost from sustainable technology operation and maintenance. Second, the simulation approach that was used did not show all the possible values that can be varied due to a decision policy. Lastly, system degradation was not taken into account in the calculation despite being mentioned in the framework.

Yang and Blyth (2007) presented a methodology and developed a model to quantify the impacts of uncertainties on an investment in energy technologies using the real options approach. The methodology includes project net present value calculation, stochastic simulation to capture the characteristics of uncertain variables, and real options to capture the investors' flexibility to optimize the timing of their investments. The model was developed in MS Excel environment.

3. RESEARCH OBJECTIVES AND SCOPE OF STUDY

3.1 Problem description

Sustainable improvement in buildings can be in several ways. One of the features that are significant and subjected to high uncertainties is an improvement in energy efficiency. According to U.S. DOE (2010), over 40% of U.S. primary energy was consumed in the building sector. Improving the energy efficiency in buildings is not only benefit the financial aspect but also reduce the impact to the environment.

The first challenge here is that the decision on sustainability implementation is still subjected to the uncertainties. In the improvement of building's energy aspect, electricity price and technology cost are that key variables that keep changing over time. According to historical electricity price data from U.S. EIA (2010), the unit price per kWh has been increasing 4% per year on average in the past 10 years and has increased in a fluctuating form since the date that data were collected. The technology cost, obviously, will be cheaper over time from the demand, technological advance and other factors. At one point of time, technology price will be able to decrease the overall initial investment cost, and the energy price will be high enough to have a shorter payback period. Figure 4 and 5 are good examples of this case. The production cost of solar electricity has been decreasing while the average retail electricity price has been rising.

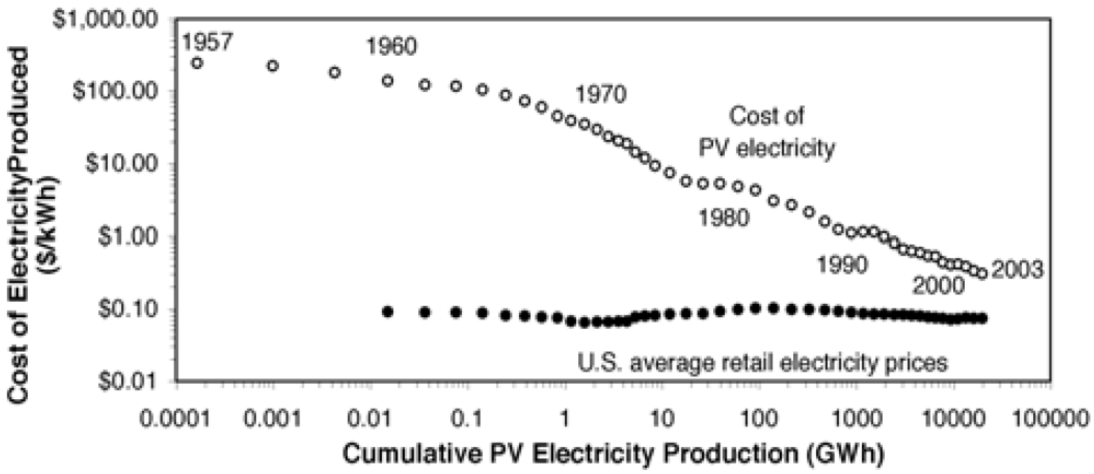


Figure 4 The graph shows that the retail electricity price has been increasing while the cost of electricity produced from renewable energy source such as PV system has been decreasing (Nemet, 2006)

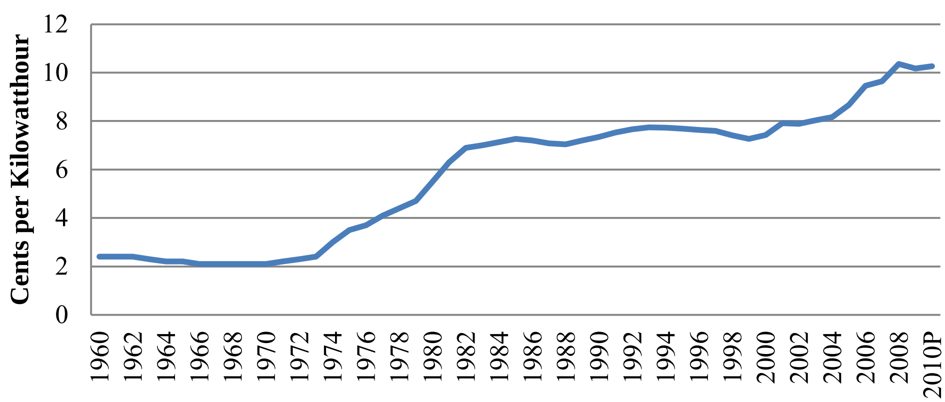


Figure 5 Average retail price of electricity in commercial building (after U.S. EIA, 2010)

Second, in practice, buildings are rarely designed for flexibility. Investments in buildings and sustainable features are usually evaluated with traditional discounted cash flow method; hence, the future changeability is limited. Previous work on this topic can have some improvements by incorporating important variables that were left out in order to model the system to reflect the nature of project.

Consider an illustrated case of a new commercial building. During the planning stage, the owner wants to install a solar energy system that will produce enough electricity for the entire building. His benefits would be cost reduction from energy saving and a higher property value. However, with the uncertainty of electricity prices and the cost of solar energy system, the investment might have a long payback period. The flexible strategy would give him an option to delay his decision and reevaluate his investment. By designing the building for the future installation, he will have the choices to install, abandon or delay his decision further. The challenges are when would be a good time to invest and how could this flexible strategy add value to the building? If he decided to delay his decision, he will lose the opportunity to earn the benefits from installing a solar energy system at the beginning as well.

In order to overcome a challenge, it is crucial to provide a good understanding about the real options approach and develop a model to be used as a preliminary tool for decision making. According to Mun (2010), it is important to understand that real options analysis is an entire decision making process, not just a model. The correct tools that can always have a room for expansion are important. Ford and Garvin (2010) also suggested that the real option models can be an effective tool for decision making process if it was developed to better reflect the nature of the project. This work intent is to incorporate flexibility strategy into the sustainable development in built environment with the real options principle. In conclusion, the research questions are:

- How a real option will perform in sustainability improvement projects in terms of investment return and the project's value?
- How to optimize the sustainable investment decision while having uncertainties involved by using the real options approach as a tool.

3.2 Research objectives

The overall objectives of this work are:

- To determine the financial impacts of flexible strategy to an investment in sustainable improvement of the building environment.
- To develop and validate a real options simulation model and propose evaluation process to assist investors to optimize the sustainable investment decision with the uncertainties involved.

3.3 Scope of study

In this study, a model was developed as a real option analysis tool to determine the financial impact of flexible strategy to the project and assess what are good periods of time and decision policies to invest in sustainability improvement. The model represents the consequences of decisions in construction projects and the outcomes these decisions will have on the net present value of project cost. In order to identify real options performance and use the model as an investment decision tool, the model needs to be developed with current information and nature of sustainable development project.

This study explicitly focuses on the building's energy improvement by adding an on-site renewable energy source. Some variables in the real system are neglected such as uncertainty in discount rate, site condition, change in climate and variation of property value to the market. Also, the residual value is assumed to be zero and the replacement cost is assumed to be out of interested period. Variables are shown in Table 3.

Table 3 Model Variables

Category	Variables
Cost	- Initial investment/ installation/retrofit/construction cost - Exercise cost/Prime cost (the cost to be paid to have flexibility) - Operation and maintenance cost
Benefit	- Incentives - Energy savings
Uncertainties	- Volatility of energy price - Cost and effectiveness of sustainable technologies - System degradation
Other: To model the nature of investment	- Discount rate - Inflation rate - Future incentives
Financial Index	- Present worth - Benefit - Cost ratio

The information in this study is based on literatures and historical data. No real data survey or simulation of the building's energy was conducted.

4. HYPOTHESES

In an investment decision on sustainable development, it is beyond the decision makers' capability to control over uncertainties such as energy price, sustainable technology price, and technology efficiency. However, the decision makers can reduce the overall risks by considering a flexible strategy. Such strategy can be incorporated into the building design and planning stage to allow owners to have future options to improve the building's sustainability whenever the current uncertainties are unfolded favorably. This flexible strategy should have a positive financial impact on a sustainable improvement project by increasing the project value.

4.1 Hypothesis statement

Hypothesis 1: When comparing to the base case, if exercise the option at the favorable conditions and periods, flexible strategy should increase the value of a sustainable project.

Hypothesis 2: The real option model analysis can improve the decision maker's ability to determine under what condition and when he should exercise the option to improve project sustainability and value.

4.2 Expected contribution

This research can help investors, professionals and future researchers understand the impacts and significance of flexible strategy to the sustainable improvement projects. The approach and the model can provide the application of real options analysis that can be utilized as a tool for decision makers by improving the decision makers' ability to determine whether and when they should invest in the technologies for sustainability improvement Also, they could be a starting point for future researches on the real options approach to improve sustainability.

5. RESEARCH METHODOLOGY

A real option model was developed according to the research objectives. The model was used to simulate the result in a scenario case study to illustrate the impact of flexible strategy on sustainable development. The case study was also used as a basis to validate the model for future applications. The chosen scenario was a decision to invest in a solar energy system in commercial building. According to U.S. DOE (2011), the studied trend indicated that energy consumption in residential buildings has not changed significantly since the 1980's data. By contrast, the consumption in commercial and office buildings has been increasing.

5.1 Model development to investigate impacts of real options

To obtain the results that will show the impacts and provide understanding of real options, the research process was developed and summarized as shown in Figure 6.

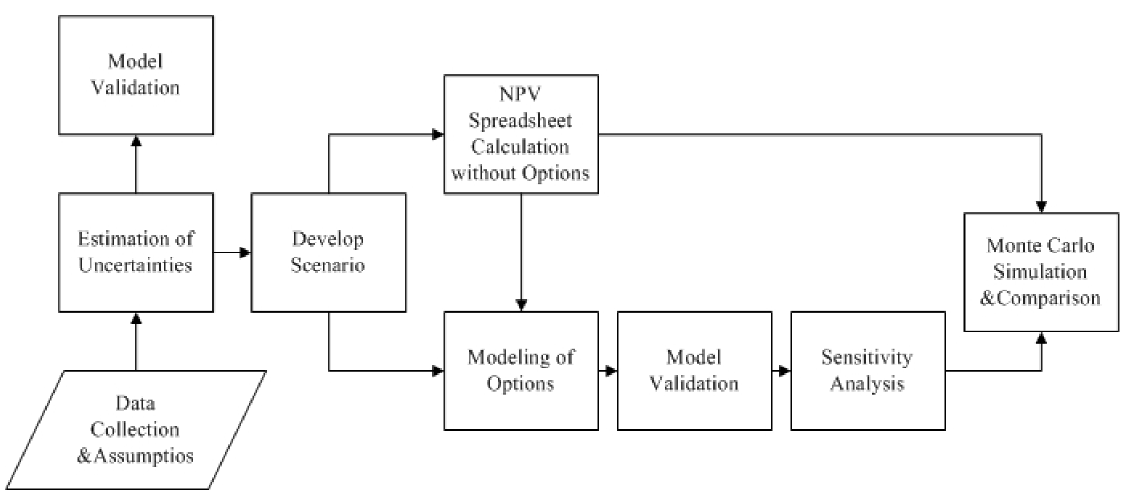


Figure 6 The modeling procedure

From Figure 6, the process was developed to test the hypotheses. Six key steps are explained as follow:

1. Establish common assumptions and data collection. In this process, common assumptions were developed and the historical data of uncertainties were collected.
2. Estimation of uncertainties. The model generated the random path with a stochastic behavior of electricity price, PV modules price and PV output degradation based on historical trend to assimilate the uncertainty behavior in the real world.
3. Develop scenario and NPV calculation. Assumptions were based on the scenario when the owner was deciding to invest in PV system. This process adapted LCCA key steps from Fuller and Petersen (1995) which are establishing common assumptions, estimating cost and time of occurrence, computing discount future costs and then compare the project financial index of each strategy. To understand the impact of flexibility on an investment decision, the project value was quantified in three cases.
   a. The building was built as a conventional building. No option or investment on sustainability improvement.
   b. The base case, the building that invest on sustainability improvement "now". The building was built as a conventional building with a decision to integrate

a sustainable feature at the beginning with no future option. Discounted cash flow evaluation was used along with LCCA.

c. The building was constructed to be ready for future retrofit, in other word, to have the rights or options to defer, grow and abandon. The interest period was limited at 30 years which is the technical lifespan of PV panel (Battisti and Corrado, 2005) in order to be able to compare the project value from a flexible strategy with the base case.

4. Model validation. The model was validated to test if it works as expected. The validation process was based on an assessment process recommended by Sterman (2000) to test a dynamic model.
5. Monte Carlo simulation and comparison. The project value was simulated with different exercise timing, decision policies and different uncertainty paths. The comparison of project value and financial index were made in the end. All in all, it was an analogy of three identical buildings with same lifespan that are planned to be built under the same condition.
6. Analysis of impacts and behaviors. Analysis can be made based on understanding of real option behaviors and the impact of exercise timing, decision policies, uncertainties and exogenous variables.

5.2 Model development to use as an analysis tool

The model was developed as an MS Excel spreadsheet with Macro-enabled. The main reasons to choose spreadsheet modeling system are the adaptability, popularity and capability to handle simulations and large amount of data. First, an Excel spreadsheet is easier to change calculation code and modify to analyze in case-by-case basis. Second, Excel-based spreadsheet is very common and easy to use. Therefore, it could be a useful tool to assist decision makers or managers. Lastly, MS Excel is the most common software that is able to program, such as VBA or basic Macro, to extend the capability of the model.

This work provided a guideline and step to utilize model with the base case and future modification.

6. THE MODEL DEVELOPMENT

6.1 Model assumptions

The model assumptions were identified according to the scope of study. The overall model assumptions are as follow:

- The model represents a single project decision. The project value is quantified in three cases to understand the impact of flexible strategy on an investment decision.
- Three major uncertainties are concerned: investment cost, energy price and system performance.
- Value of uncertainties and other variables are based on literatures and historical data.

For the illustrated case, the model was developed based on the following scenario in Table 4.

Table 4 Model scenario assumptions

Scenario	**Assumptions**
Type/size of the facility	Office, low rise
Project location	Bryan, Texas
Sustainability improvement	Energy efficiency improvement: Solar energy system
System inefficiency (for calculating system size)	20%

The sustainability improvement in this case is an energy efficiency aspect. The scenario is to decide on the investment of solar energy system into the building. The type and size of facility are assumed to be able to estimate energy consumption. System inefficiency and project location are assumed for the calculation of desired system size.

6.2 Model structure

The final product of this model is financial index, in this case, NPV and BCR. The project investment is evaluated from year 0 to the final year or the end of the designed life cycle whether the sustainable feature is invested or not. The investment scheme can be separated into two parts. The scenario part represents the conditions and the nature of sustainable project. The scenario includes uncertainties and variables which are calculated based on project data and assumptions. The uncertainties are energy price, sustainable technology cost and system degradation. Scenario simulation produces the uncertainty value each year. Those values, along with assumptions, are the inputs for the second part which is the financial evaluation. The financial evaluation will incorporate costs and benefits over the project life cycle and calculate the project value and BCR.

The model structure adapted Yang and Blyth (2007) real options model framework and modified to reflect an investment scheme of sustainable improvement. It provides the financial analysis for energy efficiency retrofit option, and can be adapted into investment financial evaluation of energy efficiency retrofit such as wind power, Energy Star appliances and higher efficiency HVAC system. In this research, the model was structured to evaluate an investment of the solar energy system in the building as an illustrated case. The conceptual model structure is shown in Figure 7.

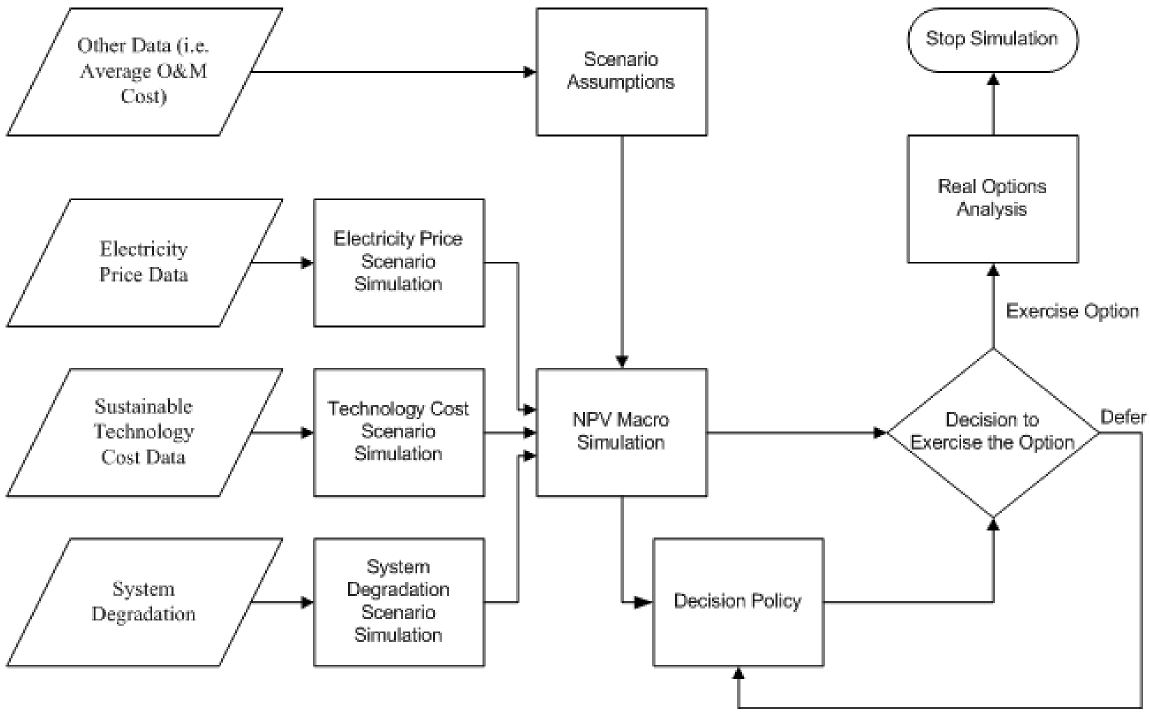


Figure 7 Real options simulation model structure

The real options model consists of three main sections:

1. Simulation model of uncertainties
    a. Energy price model (Electricity price). This is modeled in two characteristics to reflect the future uncertainty: Linear and exponential trend
    b. Technology investment cost model
    c. Performance degradation over time
2. Financial calculation spreadsheet
    a. LCCA of the building with sustainable feature added from the start to represent the irreversible investment

b. LCCA of the building that was built with options. Incentives will be added in this section.

3. Real options analysis: A dynamic programming model utilizes the Monte Carlo Simulation to test on different decision policies.

6.3 Simulation model of uncertainty scenarios

There are three major uncertainties that were modeled to test the hypothesis with the illustrated case are uncertainty in electricity price, solar module cost and solar energy system degradation. The simulation requires the historical data to develop the model of uncertainties. The general equation for the future value of uncertainties is:

$$F(t) = f(t) + \Delta$$

where:

F(t) = The future value of interested variable as the function of time

f(t) = The function of fitted trend line indicates the change of value in the future from historical data.

Δ = Deviation from trend line

For linear function $f(t) = P_i + tg$ when P_i is the initial value from historical data, t is time and g is the slope of historical data trend

Delta (Δ) is used in this equation to represent the stochastic behavior. However, if this parameter creates total random path, the simulated value can be unrealistic. Therefore, this “noise” should be generated randomly within the deviation from historical data. The fluctuation was modeled to be normalized with the fitted trend function.

6.3.1 Uncertainty in electricity price

First, for the electricity price, historical data retrieved from U.S.EIA (2010) was used to create the price trend and deviation in the future scenario. The data shows the trend of electricity price over time of nominal prices, prices unadjusted for the effects of inflation. Full historical data are shown in Appendix C. Linear and exponential functions were chosen to fit the trend as shown in Figure 8.

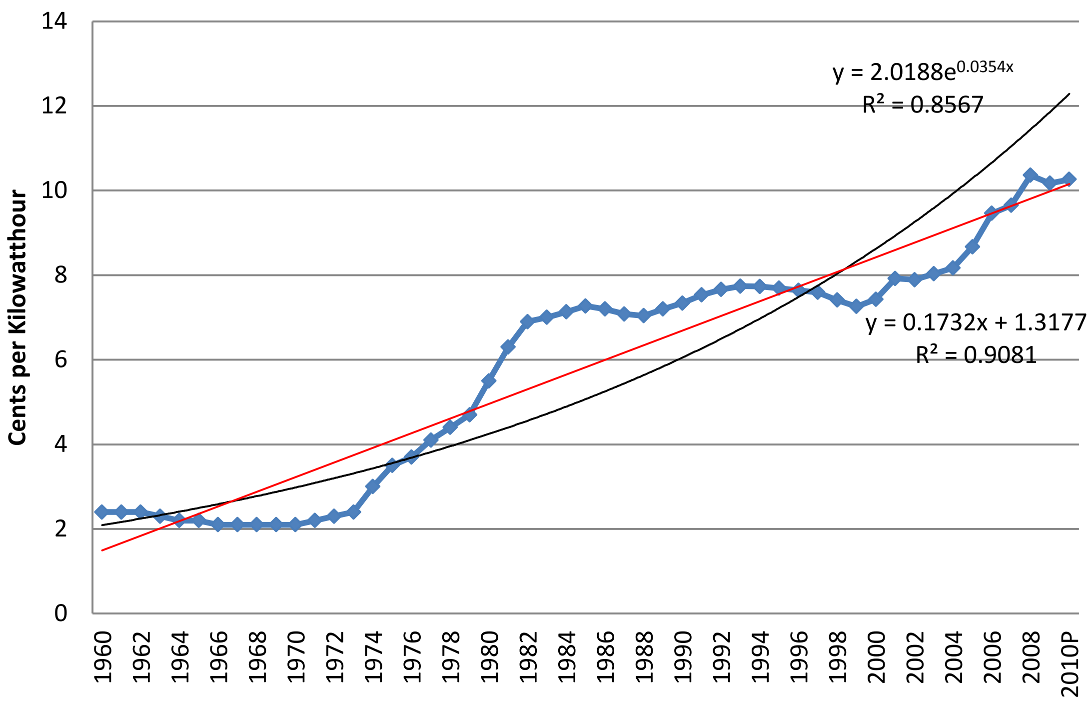


Figure 8 Historical average retail prices of electricity (plus taxes) with the fitted trend from 1960-2010 (after U.S. EIA, 2010)

According to trajectories, the future trend could be either linearly growth or exponentially growth as both possess the goodness of fit with a trend with positive R-squared value of 0.91 and 0.86. This indicates the uncertainties in the growth in electricity prices in the future.

Table 5 shows the exponential and linear fitted trend line equation and the standard deviation of historical data for fitting trend.

Table 5 Fitted trend line equation and standard deviation of historical data for historical trajectory

Forecast trend line	Fitted trend line equation	SD from fitted trend line
Exponential function	$P = 2.0188e^{0.0354t}$	1.215
Linear function	$P = 0.1732t + 1.3177$	0.8193

MS Excel function "NORMINV(RAND(),Mean,SD)" was utilized to generate the deviation from the trend line. In this case, mean value equals to zero which means that the simulated trend shall be normalized and fluctuated around the trend line. Examples of simulated future electricity price in exponential and linear trend are shown in Figure 9 and 10, respectively. Each chart represents one simulation sample.

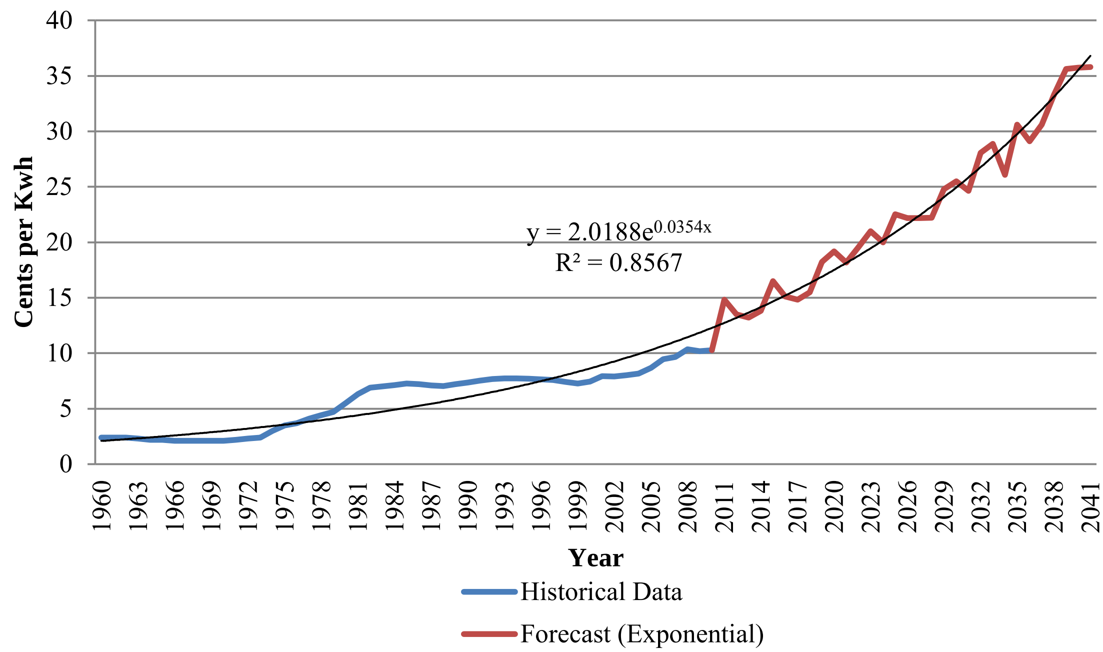


Figure 9 Exponential simulation trend of electricity price from year 2011-2041

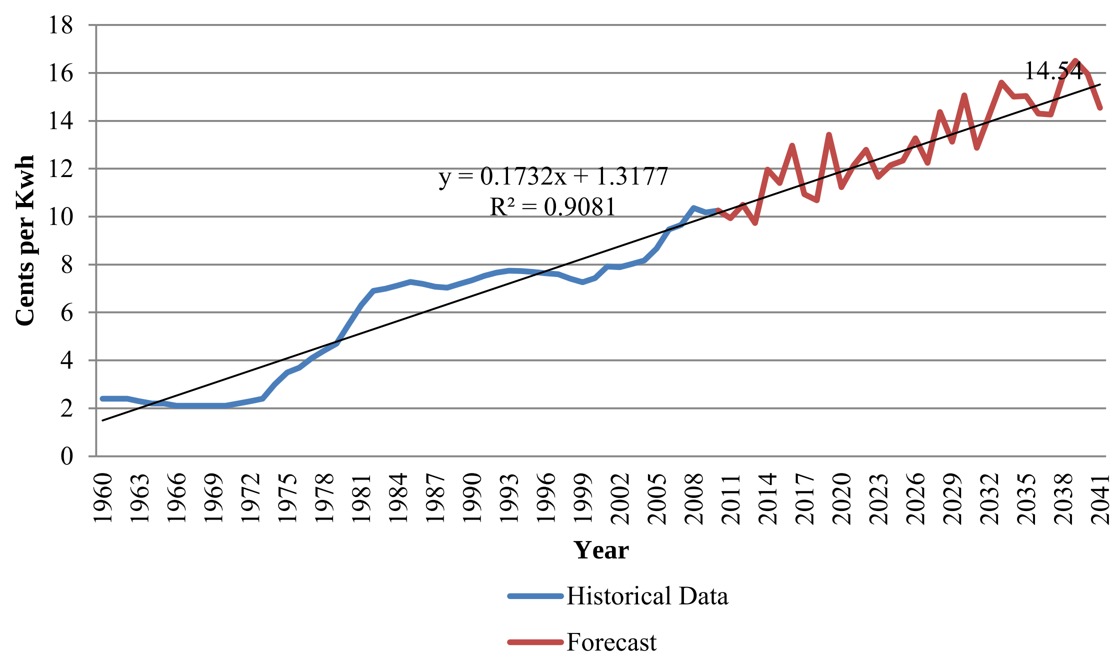


Figure 10 Linear simulation trend of electricity price from year 2011-2041

6.3.2 Uncertainty in photovoltaic price

According to historical data since 1989 from U.S. EIA (2010), the historical average price of solar module per watt-peak is shown with linear and exponential fitted trend line in Figure 11 and 12.

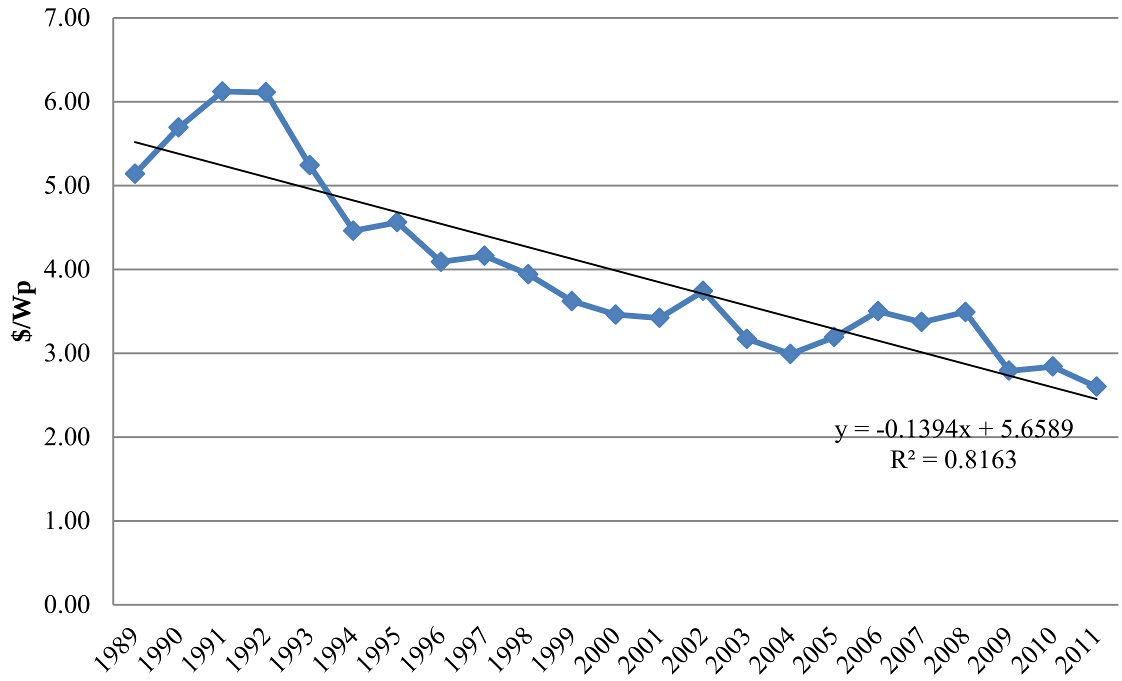


Figure 11 Historical data of PV module price ($ per Watt peak) with linear fitted trend line from 1989-2010 (after U.S. EIA, 2010)

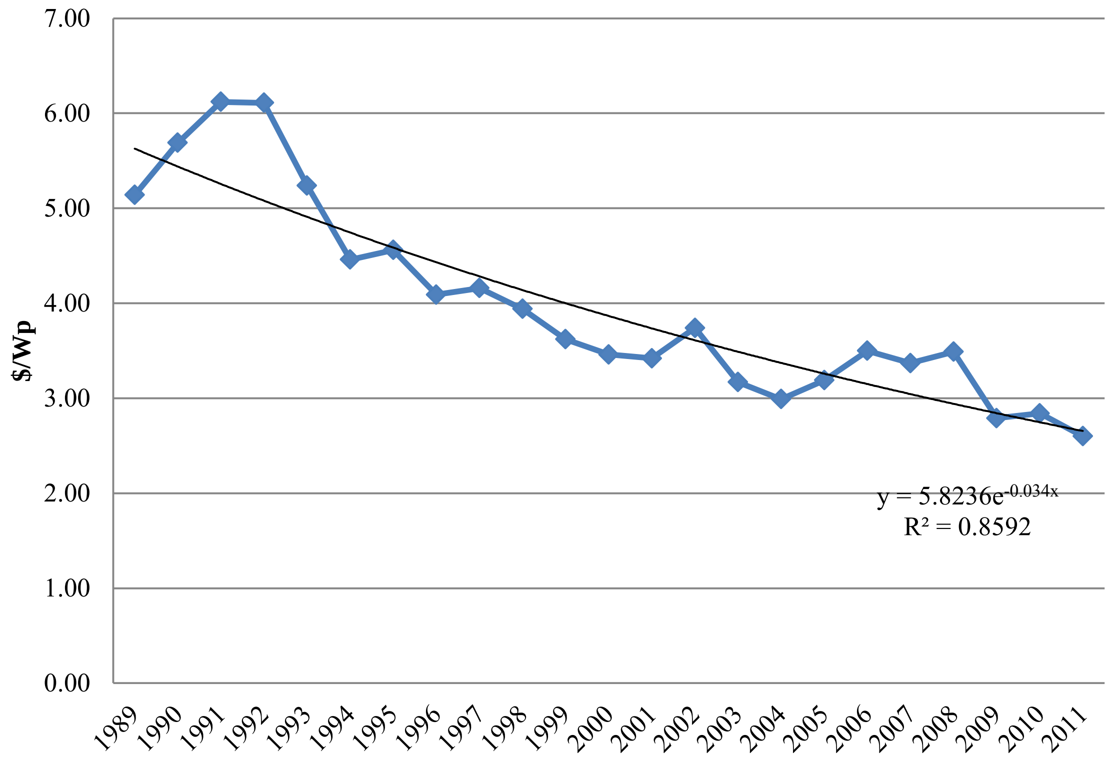


Figure 12 Historical data of PV module price ($ per Watt peak) with exponential fitted trend line from 1989-2010 (after U.S. EIA, 2010)

From the trend estimation, again, both linear and exponential functions have high R-squared value which indicates a good fit. However, according to researches, solar technology price is likely to decrease exponentially (NREL, 2010; Ashuri et al., 2010; International Energy Agency, 2011). Hence, the exponential trend was selected in this study. With the same approach to model other uncertainties, future value of uncertainties is $F(t) = f(t) + \Delta$. From the historical data, exponential regression trend equation equals to $5.8236e^{-0.034x}$. Deviation (Δ) from trend line was generated randomly with standard deviation = 0.41 from the regression line. Detailed historical data and simulated value are shown in Appendix C. The graph of simulated result is shown in Figure 13.

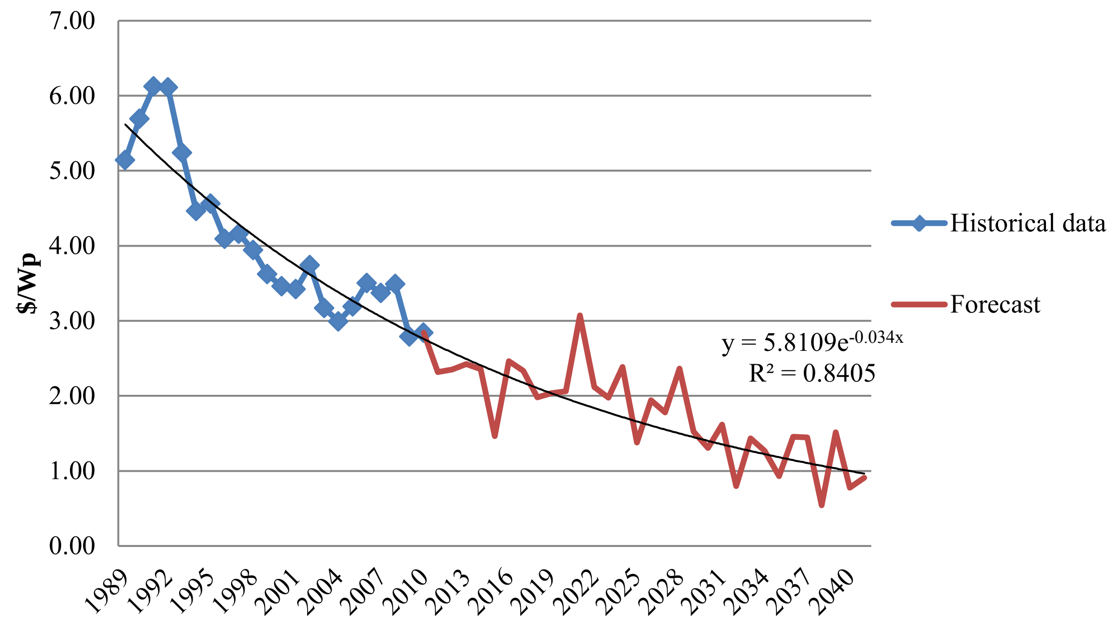


Figure 13 PV module price model graph

6.3.3 Performance degradation

Like other technology, photovoltaic (PV) output performance can decreased over time. According to Borenstein (2008), PV cell production declines over time, approximately 1% of original capacity per year due to aging and soiling effect. There are other factors that can affect the degradation rate such as time of operation, weather and the time of installation (Brooks and Dunlop, 2011). This work would not consider further on the causes but more on the effects on project financial decision. PV output degradation uncertainty may not play the big part in decision making process; however, degradation rate can represents financial risks to PV investors. Also, it needs to be integrated into the model in order to lessen the gap of model scenario and real situation. Forecasting the degradation of technology performance can be difficult and mostly inaccurate and this section does not intend to do such thing as it is out of the study scope. Instead, this work tries to simulate the degradation behavior of PV system based on the historical field results.

According to Jordan and Kurtz (2010), the degradation rates in PV, especially in the initial phase, can be non-linear. However, Va´zquez and Rey-Stolle (2008) study acknowleged that there are an argument that non-linear regression is more suitable to model the technology reliability over time.They studied the trend line equations in both linear and non-linear and noted that both trend exibit similarly as shown in Figure 14. The recommendation from the study is to model with linear regression and assume that the PV output degradation rate is constant over time. This work was also supported by the field test results that the PV output tends to decrease linearly with stochastic behavior over time (Marion and Adelstein, 2003; Raghuraman, et al., 2006; Reis, et al., 2002; Dunlop and Halton, 2005).

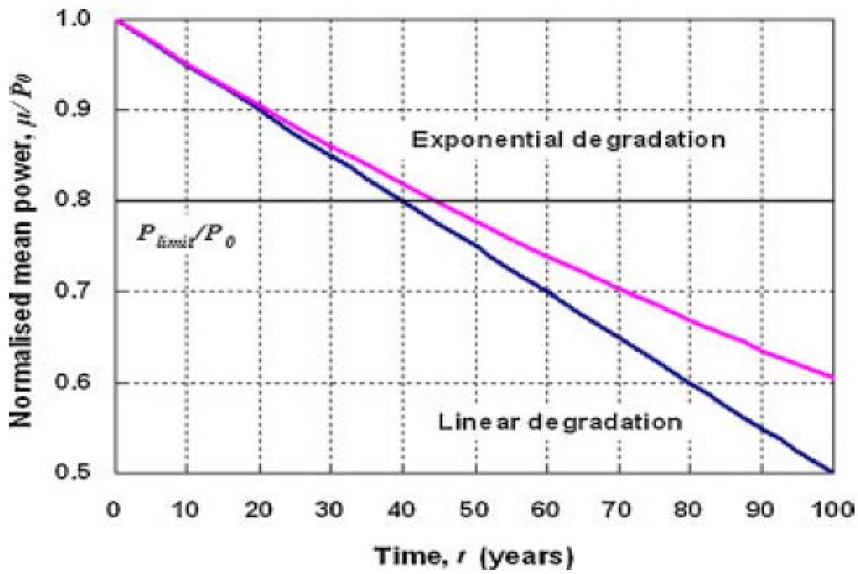


Figure 14 The comparison between exponential degradation and linear degradation model of PV output. The behavior in an interested period (30 years) is similar (Va´zquez and Rey-Stolle, 2008)

This work acknowledges both sides of argument will not increase the complexity of the discussion. The linear regression is chosen as the model reference mode to imitate results from field study and to estimate the value to be more pessimistic.

According to linear regression model from Va´zquez and Rey-Stolle (2008), the equation for the average power of the PV modules is:

$$\mu(t) = P_0 - At$$

where:

$\mu(t)$ = The average power of the PV modules at time t

P_0 = The average power at time t = 0

A = Degradation rate per year

t = Time (years)

Obviously, the validity of this equation is limited to time less than P_0 /A

According to Jordan and Kurtz (2010), the degradation rate can be varied due to technologies, age, manufacturers, and geographic locations. They presented PV degradation rate based on 1920 data from over a hundred publications worlwide. The histogram in shown in Figure 15.

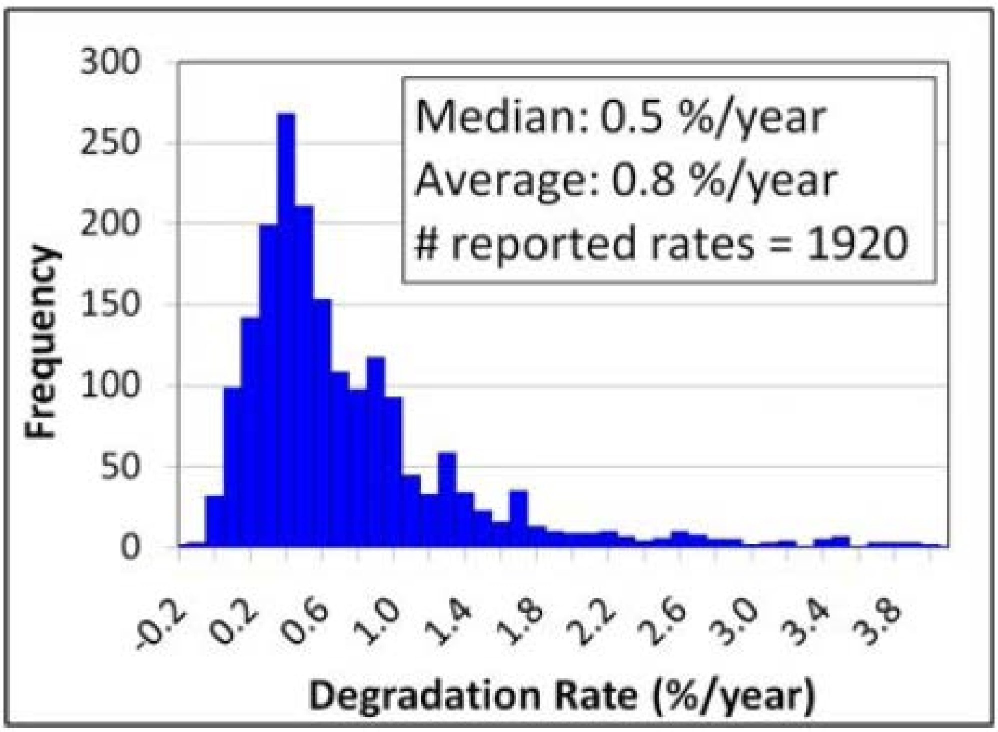


Figure 15 Histogram of reported degradation rates from literatures (Jordan and Kurtz, 2010)

The result showed that the average degradation rate, regardless of scientific categorization of PV type is estimated to be around 0.8% per year with the standard deviation of 0.15% per year (Jordan and Kurtz, 2010).

The degradation rate in the model was estimated to be the average rate plus normalized deviation. The deviation reflects the stochastic behavior of degradation process over time. Integrating this data to the linear regression model, the simulated value is shown in Figure 16.

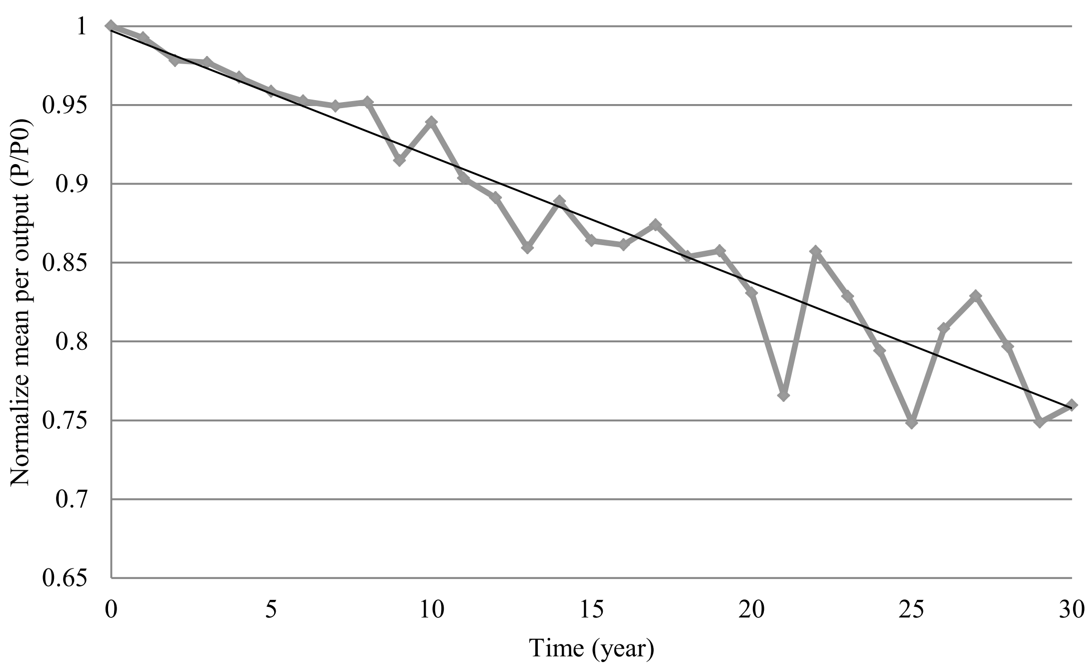


Figure 16 Degradation simulation of PV output

6.4 Financial calculation

In this section, all the variables and assumptions are used to calculate NPV of the project. NPV and BCR calculation use input from project assumptions and uncertainties. The structure of this section is shown in Figure 17.

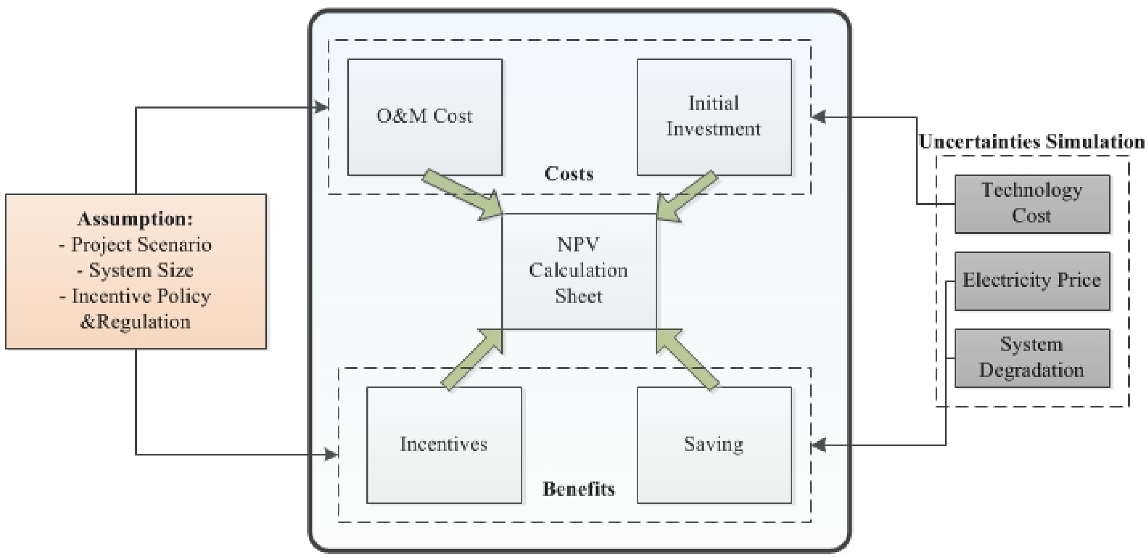


Figure 17 Model structure and inputs of financial calculation section

Input costs in this model are all annual cost. The initial investment for sustainable feature is the unit cost of technology multiplies the system size which is based on the project assumptions. In the illustrated case, the PV system size is roughly calculated according to a desired number of kWh of solar electricity, project location and system inefficiency. Detailed calculation from outside of this model can be substituted. Operation and maintenance (O&M) cost can be varied based on location and conditions.

In this work, fixed O&M cost needs to be assumed on acceptable range with growth adjustment.

There are two positive cash flows considered in the model. First, annual saving is amount of money that is saved yearly by using solar electricity instead of on-grid electricity. Another benefit is an incentive from support of local or federal government. The incentive can be varied by project location. In some states such as California, incentive can also be considered as uncertainty. California has the policy to phase out PV incentives whenever the statewide PV capacity has reached its goal. Therefore the incentive varies by the amount of PV system installed (DSIRE, 2012). However, this work illustrates the case in the state where an incentive is fixed to avoid model complexity.

6.5 Real options analysis

This section is used to reflect the real option in the project. It was developed to analyze the input and the set condition (change in uncertainties) to see the impact of flexibility strategy, and utilize as an assessment tool to decide whether or not to exercise the option to grow, defer or abandon.

With flexible strategy, owners can make a decision based on perceived situation. Monte Carlo simulation is applied in this section to generate random paths of uncertainties. When the set of conditions matches the decision policy, the option will be exercised, if not, the decision will be deferred until the requirements are met. The model then calculates NPV for each path.

The flow chart showing the process this section is presented in Figure 18.

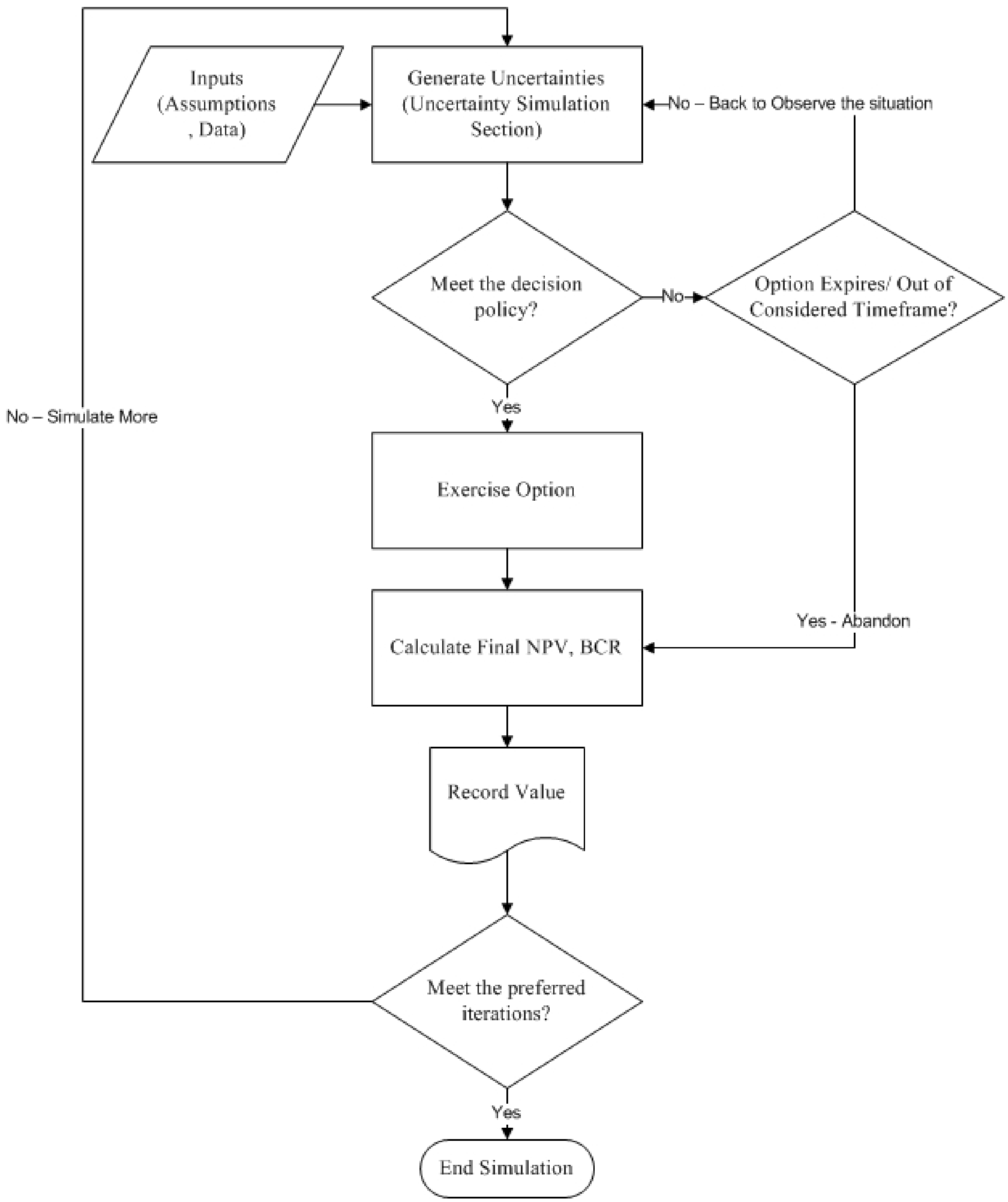


Figure 18 Real options analysis model structure

The decision trigger is modeled as the "If-Then-Else" statement. The equation will show the result "1" if all the criteria are met, which means that the owner decides to exercise the option. On the other hand, it will show the value "0" if any criteria is not satisfied which means that the decision will be deferred until further information is available. For example the equation statement for electricity price and PV price criteria can be presented as follow:

= IF(OR("Option has been exercised" ,IF(AND ("Current electricity price criteria is met", "Current PV price criteria is met",1,0)=1), 1, 0)

6.6 Validation

According to Office of the Comptroller of the Currency (2011), "all model components, including input, processing, and reporting, should be subject to validation." Model testing is a necessary step to answer the questions whether the model reliable and whether the model can be used as a basis for decision making. The two main assessments are structure validation and behavior validation.

6.6.1 Structure validation

The structure assessment tests mainly focus on the level of aggregation, structure consistency and the conformance of the model to basic physical realities. An approach for validating the model is to simulate the original known behaviors. First, the main model equations were inspected. Second, variables were tested for variability to ensure they conform to the realistic behaviors. The variables that were checked for negative or zero value are listed as follow:

- Benefit to Cost Ratio (BCR)
- Payback period
- PV cost
- Electricity price
- PV output
- Exercise triggers
- Incentive

Programming statement is used to control variables that contain random generator function not to generate negative or zero value. Given "newRand" as a command function in VBA programming to regenerate the random value, the variable is controlled by the function statement:

If Sheet1.Cells ("A1") <= 0 Then GoTo newRand

This function statement will force to regenerate the value in cell A1 in an Excel sheet 1 again if the previous generation is not greater than zero. By using this, it will be certain that variables cannot be unrealistic values.

Third, the known behaviors are tested if their behavior reality or support literatures. The cumulative costs over the life cycle were simulated on 3 study cases: conventional building, building with PV system added at the beginning, and building with an option to add PV system in favorable condition. These cases are graphically shown in Figure 19. For the first case, no cost was added as there was no investment.

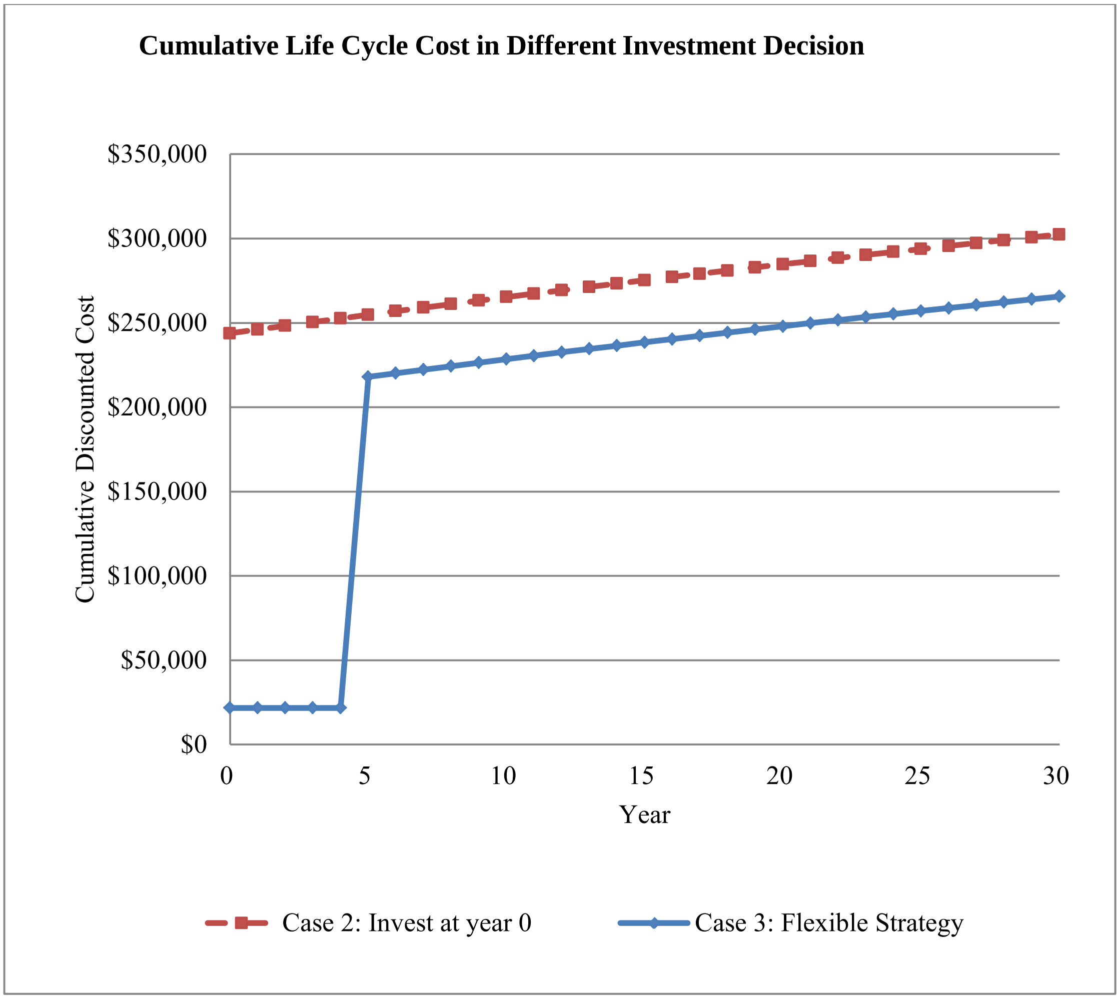


Figure 19 Cumulative cost graphs in 3 study cases based on ideal condition

The simulate condition was the ideal condition where the PV output, stayed constant. The first case generated the zero cost as expected because the building has none of the initial investment on PV system and O&M cost for PV. For case 2, the cost should start on the high side because of initial investment at year 0 but the slope will not be as steep because it will have only operation and maintenance cost. The graph confirms this behavior. Lastly, the graph of the building that was built with an option to install PV also presents a realistic behavior. The overall cost at year 0 equaled to an exercise price to have an option. After the option was exercised, an investment cost was added and the overall cost increased sharply. Finally, the cumulative cost stayed at the small slope as it already saved the electricity cost.

6.6.2 Behavior validation

With the model structure validated, uncertainty simulations were tested with reference mode from literature and the simulation results are close to the real situations because they were modeled based on real historical data. The behavior of the model was also validated by taking an extreme condition tests. The test consists on changing the values of key parameters to extreme low or high numbers and compares the behavior of the model to the behavior expected. Table 6 shows the variables include in the extreme condition test, along with the expected behaviors and results.

Table 6 Extreme condition test parameters

Variable	Extreme Case		Output Variable	Expected Behavior	Result (See Appendix B)
	Condition	Value			
Decision policy: based on change in PV cost	Low	Decide if PV cost is decreased by 1%	Decision	Exercise in early years	Figure B.1
Decision policy: based on change in PV cost	High	Decide if PV cost is decreased by 95%	Decision	Turn on late or not at all	Figure B.1
Decision policy: based on electricity price	Low	Decide if electricity price is increased by 1%	Decision	Exercise in early years	Figure B.2
Decision policy: based on electricity price	High	Decide if electricity price is increased by 200% (3 times)	Decision	Turn on late or not at all	Figure B.2
Decision policy: invest by year	Low-High	Year0, Year29	Decision	Exercise at year 0 and 29	Figure B.3
PV degradation rate	Low	0%	Cumulative discounted cost	Slowly increase, exponential	Figure B.4
PV degradation rate	Low	0%	NPV	Rapidly increase	Figure B.5
PV degradation rate	High	5.0%	Cumulative discounted cost	Rapidly increase, exponential	Figure B.4
PV degradation rate	High	5.0%	NPV	Slowly increase	Figure B.5
O&M Cost	Low	$1/kwh/year	Cumulative discounted cost	Slowly increase	Figure B.6
O&M Cost	Low	$1/kwh/year	NPV	Rapidly increase and turn positive early	Figure B.7
O&M Cost	High	$200/kwh/year	Cumulative discounted cost	Rapidly increase	Figure B.6
O&M Cost	High	$200/kwh/year	NPV	Slowly increase and turn positive late or not at all	Figure B.7

6.7 Model use

This research is expected to contribute to an improvement in professional practices and studies. The model use section provides the detail of spreadsheet model, guideline and steps of use.

The spreadsheet approach was applied to the case of installing a PV system in a building project. The project is subjected to two observable uncertainties which are PV cost and electricity price. The flexibility in this case is when owners design, construct and plan the use of space in the project to be ready for installing PV panels in order to have options to delay the decision, abandon this sustainability improvement or install PV when the conditions become favorable.

The model can provide understanding about the impacts and significance of flexible strategy to the sustainable improvement projects for investors, professionals and future researchers. The approach and the model can provide the application of real options analysis that can be utilized as an assessment tool for decision makers. Also, they could be a starting point for future researches on the real options approach to improve sustainability.

It is important to understand the component of the spreadsheet model in order to use or further apply. Spreadsheets are organized into 3 main functions: input and content, data and calculation sheets, and simulation. The descriptions and names are presented in Table 7.

Table 7 Spreadsheets model description

Function	Category	Sheet name	Short description	Excel Sheet no.
Input & Content	-	Instruction &Content	A start point to direct where in the spreadsheet user wants to go	Sheet30
		Input	Manual input based on each project	Sheet11
Data & Calculation Sheets	Uncertainties	Trendline	Historical Electricity Price Trend	Sheet1
		Exponential	Electricity Price Forecast Model - Exponential	Sheet2
		Linear	Electricity Price Forecast Model - Linear	Sheet3
		Solar Exponential	Solar Energy Price Forecast Model	Sheet4
	Financial Calculation	Option-EXP	Flexible Option Calculation by Criteria - Exponential model	Sheet7
		Option-LIN	Flexible Option Calculation by Criteria - Linear model	Sheet8
		Option-EXP (year)	Flexible Option Calculation by Year-Exponential model	Sheet21
		Option-LIN (year)	Flexible Option Calculation by Year - Linear model	Sheet26
		NPV-EXP	Investment at startup Calculation - Exponential model	Sheet5
		NPV-LIN	Investment at startup Calculation - Linear model	Sheet6
Simulation	Simulation by Energy Price criteria	01 NPV EXP Sim(E)	NPV Simulation Exponential Electricity Price Model	Sheet17
		02 Year EXP Sim (E)	Execution year Simulation Exponential Electricity Price Model	Sheet22
		03 NPV LIN Sim(E)	NPV Simulation Linear Electricity Price Model	Sheet20
		04 Year LIN Sim (E)	Execution year Simulation Linear Electricity Price Model	Sheet23
	Simulation by Year of Action	05 NPV EXP Sim by year	NPV Simulation Exponential Electricity Price Model	Sheet24
		06 NPV LIN Sim by year	NPV Simulation Linear Electricity Price Model	Sheet25
	Simulation by Technology Price criteria	07 NPV EXP Sim(S)	Simulation by Technology Price criteria in Exponential Electricity Price Model	Sheet27
		08 NPV LIN Sim(S)	Simulation by Technology Price criteria in Linear Electricity Price Model	Sheet28
		09 Solar Sim by Year	Execution year Simulation Exponential Electricity Price Model	Sheet29
	Both Criteria	MC Sim	Simulation by Both Energy Price and Investment Cost criteria	Sheet10

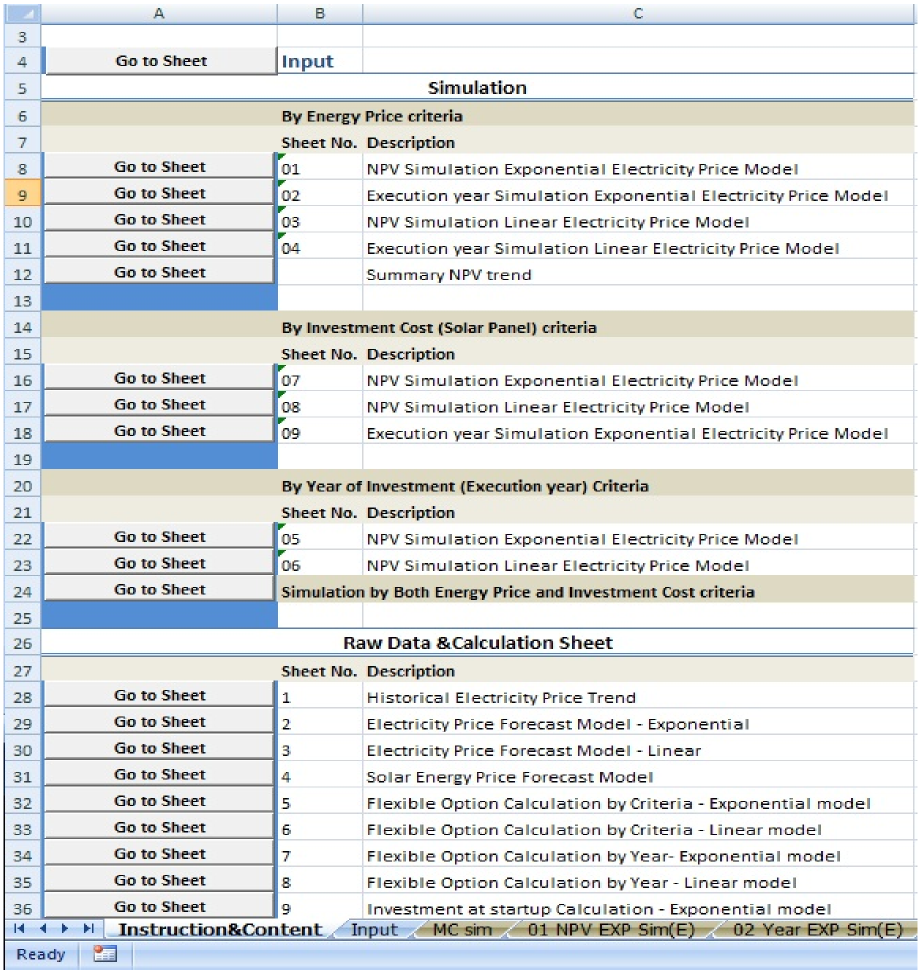
6.7.1 The steps for using with the PV installation case study

The main functionality of this model is to make an assessment of the situation to see whether the owners should decide to apply the flexible strategy to the project, and if they should, what are favorable periods and criteria to invest in sustainability improvement. Four main steps of an assessment based on research objectives and case study are navigating through the spreadsheets, determining required inputs, generating simulations and result analysis.

The approach to use the spreadsheet model for this case study is presented as follows:

Step 1: Run the program and understand the spreadsheets

The spreadsheets were created to use in MS Excel. The very first step is to make sure that macro security setting in Excel is set as “Enable”. The first sheet is the content sheet that will guide users through each function in the model. Users can navigate through the spreadsheets by clicking “Go to sheet” button in front of each sheet’s name and description. The screenshot of content sheet is presented in Figure 20.



	A	B	C
3			
4	Go to Sheet	Input	
5		Simulation	
6		By Energy Price criteria	
7		Sheet No.	Description
8	Go to Sheet	01	NPV Simulation Exponential Electricity Price Model
9	Go to Sheet	02	Execution year Simulation Exponential Electricity Price Model
10	Go to Sheet	03	NPV Simulation Linear Electricity Price Model
11	Go to Sheet	04	Execution year Simulation Linear Electricity Price Model
12	Go to Sheet		Summary NPV trend
13			
14		By Investment Cost (Solar Panel) criteria	
15		Sheet No.	Description
16	Go to Sheet	07	NPV Simulation Exponential Electricity Price Model
17	Go to Sheet	08	NPV Simulation Linear Electricity Price Model
18	Go to Sheet	09	Execution year Simulation Exponential Electricity Price Model
19			
20		By Year of Investment (Execution year) Criteria	
21		Sheet No.	Description
22	Go to Sheet	05	NPV Simulation Exponential Electricity Price Model
23	Go to Sheet	06	NPV Simulation Linear Electricity Price Model
24	Go to Sheet	Simulation by Both Energy Price and Investment Cost criteria	
25			
26		Raw Data &Calculation Sheet	
27		Sheet No.	Description
28	Go to Sheet	1	Historical Electricity Price Trend
29	Go to Sheet	2	Electricity Price Forecast Model - Exponential
30	Go to Sheet	3	Electricity Price Forecast Model - Linear
31	Go to Sheet	4	Solar Energy Price Forecast Model
32	Go to Sheet	5	Flexible Option Calculation by Criteria - Exponential model
33	Go to Sheet	6	Flexible Option Calculation by Criteria - Linear model
34	Go to Sheet	7	Flexible Option Calculation by Year- Exponential model
35	Go to Sheet	8	Flexible Option Calculation by Year - Linear model
36	Go to Sheet	9	Investment at startup Calculation - Exponential model

Figure 20 Content sheet

Step 2: Determine the required input data and make assumptions

This step is to enter basic project information, current data, assumptions and analysis options in the "Input" sheet. Figure 21 shows the screenshot of the analysis option.

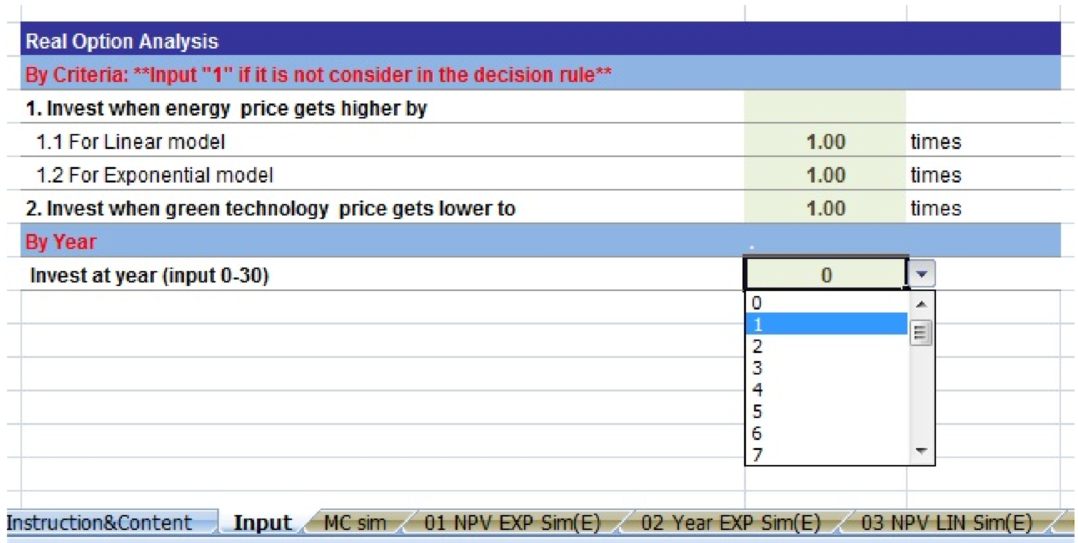


Figure 21 Screenshot of analysis option menu

There are two main analysis options, by the criteria and by investment year. The criteria are to invest if the energy price (electricity price) increases or if technology cost (cost of PV system) decreases. Users can choose to analyze either when the electricity price increases linearly or exponentially. Reasonable number should be from 1.0 - 3.0 (times) for an increment of price. The reasonable number should be between 0.0 - 1.0 for an analysis when investment decision is based on technology cost. The model will simulate based on the criterion selected. If more than two criterion values are numbers other than one, the model will show the result based on both value. If users want to analyze only one criteria option at a time, the other two inputs have to be 1. For an investment by year analysis option, there is a drop-down selection for users to choose the year that the sustainability improvement would be invested.

After all information is entered and analysis options are selected, users can click on the button "Go back to Content to select simulation sheet" to go back to contents sheet.

Step 3: Monte Carlo simulation

Simulation process can take from 5 to 30 minutes, depends on computer processing speed and the type of simulation. The general user interface is similar. In every simulation sheet, the button "Simulate &Record" or "Simulate" was encoded with a set of commands (in Appendix A) to generate 500 random paths and record the results in that spreadsheet. The generated data will be in random order and need to be sorted in order to plot the cumulative distribution graph. The second button is "Sort &Graph" which will sort the data in order and plot them in the graphs. Users can always go back to change inputs with "Go to Input" button or go back to content home with "Go back to Content" button. If a simulation needs to be stopped while processing for any reason, hit "Esc" on the keyboard twice and select "End" in the pop-up window. Figure 22 shows the screenshots of the user interface in one of the simulation sheets.

Figure 22 Screenshot of simulation sheet after results were generated and sorted for graphical representation

From Figure 22, the “Simulate &Record” button (above in the circle) includes the programming code to simulate. “Sort &Graph” button below in the circle needs to be used after simulation to sort results for graphical presentation. If data was not in order, graphical representations: frequency distribution and cumulative distribution charts will be incorrect. Note that BIN interval and BIN value can be changed according to frequency in that simulation.

Each simulation spreadsheet has different simulation purposes. Table 8 presents the objective and detail about each simulation sheet.

Table 8 Simulation sheets detail

Function	Sheet name	Detail	Invest decision Simulation	Trend of electricity price	Input	Output
Simulation by Energy Price criteria	01 NPV EXP Sim(E)	Assessment of a project's value (NPV) when the decision is based solely on the electricity price. Option will be exercised if criteria are met. The price is modeled to increase exponentially and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities. No analysis option selection need.	What-If statement: ***If*** (electricity price/baseline price) ≥ X ***then*** exercise option ***else*** delay. X is criteria value (electricity price/baseline price) range from 1.1 to 2.5	Exponential	Information and assumptions , PV sizing	NPV for each electricity price criteria along with statistical results, DCF of NPV
	02 Year EXP Sim (E)	Assessment of the time to exercise when the decision is based solely on the electricity price. Option will be exercised if criteria are met. The price is modeled to increase exponentially and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities. No analysis option selection need.	What-If statement: ***If*** (electricity price/baseline price) ≥ X ***then*** exercise option ***else*** delay. X is criteria value (electricity price/baseline price) range from 1.1 to 2.5	Exponential	Information and assumptions , PV sizing	Exercise timing (year) for each electricity price criteria along with statistical results, DCF of results

Table 8 (Continued)

Function	Sheet name	Detail	Invest decision Simulation	Trend of electricity price	Input	Output
Simulation by Energy Price criteria (Continue)	03 NPV LIN Sim(E)	Assessment of a project's value (NPV) when the decision is based solely on the electricity price. Option will be exercised if criteria are met. The price is modeled to increase linearly and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	What-If statement: ***If*** (electricity price/baseline price) ≥ X ***Then*** exercise option ***Else*** delay. X is criteria value (electricity price/baseline price) range from 1.1 to 2.0	Linear	Information and assumptions, PV sizing	NPV for each electricity price criteria along with statistical results, DCF of NPV
	04 Year LIN Sim (E)	Assessment of the time to exercise when the decision is based solely on the electricity price. Option will be exercised if criteria are met. The price is modeled to increase linearly and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	What-If statement: ***If*** (electricity price/baseline price) ≥ X ***Then*** exercise option ***Else*** delay. X is criteria value (electricity price/baseline price) range from 1.1 to 2.0	Linear	Information and assumptions, PV sizing	Exercise timing (year) for each electricity price criteria along with statistical results, DCF of results

Table 8 (Continued)

Function	Sheet name	Detail	Invest decision Simulation	Trend of electricity price	Input	Output
Simulation by Year of Action	05 NPV EXP Sim by year	Assessment of a project's value (NPV) when the decision is based solely on the exercise timing (year) Option will be exercised if the simulation runs until the assigned invest year. The price is modeled to increase exponentially and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	The model will automatically simulate from year 0-30. What-If statement: ***If*** time = assigned invest year ***Then*** exercise option	Exponential	Information and assumptions, PV sizing	NPV by the year that the option is exercised along with statistical results, DCF of NPV
	06 NPV LIN Sim by year	Assessment of a project's value (NPV) when the decision is based solely on the exercise timing (year) Option will be exercised if the simulation runs until the assigned invest year. The price is modeled to increase linearly and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	The model will automatically simulate from year 0-30. What-If statement: ***If*** time = assigned invest year ***Then*** exercise option	Linear	Information and assumptions, PV sizing	NPV by the year that the option is exercised along with statistical results, DCF of NPV

Table 8 (Continued)

Function	Sheet name	Detail	Invest decision Simulation	Trend of electricity price	Input	Output
Simulation by Technology Price criteria (Continue)	07 NPV EXP Sim(S)	Assessment of a project's value (NPV) when the decision is based solely on the PV price. The PV price is modeled to decrease exponentially and the electricity price is modeled to increase exponentially. The spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	What-If statement: ***If*** (current PV price/baseline price) ≤X ***Then*** exercise option ***Else*** delay. X is criteria value (current PV price/baseline price) range from 0.95 to 0.25	Exponential	Information and assumptions, PV sizing	NPV for each PV price criteria along with statistical results, DCF of NPV
	08 NPV LIN Sim(S)	Assessment of a project's value (NPV) when the decision is based solely on the PV price. The PV price is modeled to decrease exponentially and the electricity price is modeled to increase linearly. The spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	What-If statement: ***If*** (current PV price/baseline price) ≤X ***Then*** exercise option ***Else*** delay. X is criteria value (current PV price/baseline price) range from 0.95 to 0.25	Linear	Information and assumptions, PV sizing	NPV for each PV price criteria along with statistical results, DCF of NPV

Table 8 (Continued)

Function	Sheet name	Detail	Invest decision Simulation	Trend of electricity price	Input	Output
Simulation by Technology Price criteria (Continue)	09 Solar Sim by Year	Assessment of the time to exercise when the decision is based solely on the PV price. The PV price is modeled to decrease exponentially and the spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities.	What-If statement: ***If*** (current PV price/baseline price) ≤X ***Then*** exercise option ***Else*** delay. X is criteria value (current PV price/baseline price) range from 0.95 to 0.25	Not applicable	Information and assumptions, PV sizing	Invest time (year) for each PV price criteria along with statistical results, DCF
Electricity and PV price	MC Sim	Assessment of a project's value (NPV, BCR) and exercise timing when the decision is based on the selected analysis option in the input page. Option will be exercised if all criteria are met. The spreadsheet will automatically conduct a Monte Carlo Simulation of 500 iterations to generate 500 possibilities and compare to the parameters of the decision to invest at the beginning.	Analysis option selection need. Simulation is based on either PV or electricity criteria that are selected in "Input" sheet.	Simulate both linear and exponential models (Depends on selection)	Analysis option selection, Information and assumptions, PV sizing	NPV, BCR,payback period and invest time (year) for selected analysis criteria along with statistical results

<u>Step 4: Explore alternatives to mitigate risk and take advantage of the flexible strategy</u>

Simulation and data collection are the step to assess the impact of flexible strategy. Owners can take advantage of this model to determine alternatives to maximize the project value. For example, owners can reduce the size of the PV system or apply the strategy can could lower the building energy usage to reduce the initial investment cost.

6.7.2 Modifications for other projects

Although the model was developed to use for the case study, it can be modified for future use of similar project decision. For an investment in sustainable energy in the building, the model can be modified by the inputs. This model is already developed to be the framework to use for investment in sustainable energy under uncertainties in technology price, energy price and system performance.

Take an investment in another type of energy for example; users will have to change the price trend in "Solar Exponential" worksheet. It is important to be careful that the calculation sheets are linked to the data in certain rows and columns (in this case, column H, row 24-54). Therefore, users need to make sure that the forecast of price trend that will be used as a part of the calculation is in those cells. The steps to modify are as follows:

1. Understand the model structure.
2. The first step is to modify the historical data. Rows can be added if required.
3. Plot a scatter chart with line to see the historical trend. Add the most fitted trend line (most R squared) then on "Format trendline" function, select "Display equation on chart" show trend line equation.

4. In the “Trend” column, put the trend line equation to calculate the value along the line.
5. Determine the deviation of historical data from trend line to estimate the noise for future forecast using standard deviation.
6. Calculate the forecast value along the trend line the future in “Forecast trend” column.
7. Generate “noise” to simulate future uncertainty. Users should use “*NORMINV*” function in excel for the normal distribution. The function in “Noise” column should be equal to “*NORMINV(RAND(),Mean,SD)*”. In the equation, mean should equal to zero in order to simulate these noises to equally fluctuate along the trend line. SD is the standard deviation that derived from the detrend step (step 4).
8. Forecast values will be automatically calculated in “Forecast Random” column which contains the equation: forecast trend + noise. The value in this column will be used for simulation.

For more complex project, some programming code (Excel VBA code) might have to be modified. The model VBA codes are provided in Appendix A to advance users.

7. RESULT

To obtain the result that reflects the real system, the following data and assumptions were put in the simulation.

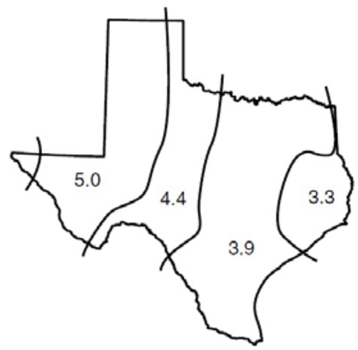


Figure 23 Solar Isolation Map for Texas (Infinitepower.org)

The solar energy system was assumed to be installed to cover all the current need of electrical energy from the grid. Figure 23 shows the amount of useful sunshine available in Texas in the worst period of year. From all of the assumptions, the estimation result of PV system size is shown in Table 9.

Table 9 PV system sizing assumptions and calculation

Parameters	Value	Source
Percentage of Solar per total consumption	100.0%	Assumption
Required electricity per day (kWh)	258.9	Calculation
The amount of useful sunshine available (hours/day)	5.0	Infinitepower.org
Inefficiency	20.0%	Assumption
Solar energy system size (kWh)	51.8	Calculation
Solar energy system size need (kWh)	64.7	Calculation

Parameter inputs for the illustrated case are shown in Table 10.

Table 10 Model parameters and inputs

Parameters	Value	Source
Interest Rate (Real Risk free rate)	3.0%	U.S. Department of Treasury (2011)
Inflation	2.0%	U.S. Department of Treasury (2011)
Type of Facility	Office Low Rise	Assumption
Facility Size (Square feet)	5,000.0	Assumption
Energy Consumption Rate (kwh/sq.ft.) per year	18.9	U.S. DOE (2011)
One time Incentive/ Rebate after installation (Bryan)	$20,250.00	DSIRE (2012)
Current Energy Price per kWh	$0.1026	U.S. EIA (2010)
O&M cost ($/kWh/year)	$35.00	Assumption
Solar energy system Operating life (years)	30.0	NREL (2010)
Solar energy system cost - Modules ($/kWh)	2,840.0	U.S. EIA (2010)
Inverter cost ($/kWh)	714.0	Solarbuzz.com (2011)
Battery backup cost ($/kWh)	213.0	Solarbuzz.com (2011)
Total Solar energy system cost per kWh	3,767.0	Calculation
Energy Consumption per year (kwh)	94,500.0	Calculation
Energy demand per day (kwh)	258.9	Calculation
Solar energy system Size (kWh)	64.7	Calculation
O&M cost ($/year)	2,265.4	Calculation
Energy Cost per year	9,695.7	Calculation
Initial Investment	243,822.9	Calculation

7.1 Simulation by assigned investment year

After simulating the case study by assigning an investment year as stated in methodology, the following results were obtained. The first case was not to make any sustainability improvement to the building, therefore, the project NPV and discounted BCR are zero. In the second case, PV system was installed at the beginning. The result shows that the average NPV is lower than the case where flexible strategy was used if the option was exercised in a favorable timing regardless the trend of electricity price. The comparison is shown in Table 11.

Table 11 Comparison of results from simulation

Scenario	Exponential electricity trend		Linear electricity trend	
	Average NPV	Average discounted BCR	Average NPV	Average discounted BCR
Case 1: No option and no investment was made	0	0	0	0
Case 2: Invest "now" with no flexibility (Invest at year 0)	$64,202	1.21	($66,346)	0.71
Case 3: With option to defer decision (Example result of the value when invest at year 8)	$72,059	1.29	($42,173)	0.74

From the table, the model was set to simulate 500 paths of uncertainties for each case. In case 3, the model was set to simulate for another 30 trials to obtain the project value when owners delay the decision and exercise the option in year 1 -30. The result shows that owners can maximize the project value if they decided to delay their decision and invest around the period that electricity price will start to increase sharply and the investment cost is lower. An investment at year 8 was selected as an example to show that flexible strategy could add value to the project. The option value was $7,857 or 12% higher in exponential forecast of electricity trend. In linear forecast of electricity trend, it was $24,173 or a little over 36% higher. From this simulation, it can be seen that flexible strategy can add value to the project.

From the previous simulation, the chart was plotted to observe the behavior over time of investment. Figure 24 shows the project value that varies by the year that option was exercised when electricity price was modeled to increase exponentially.

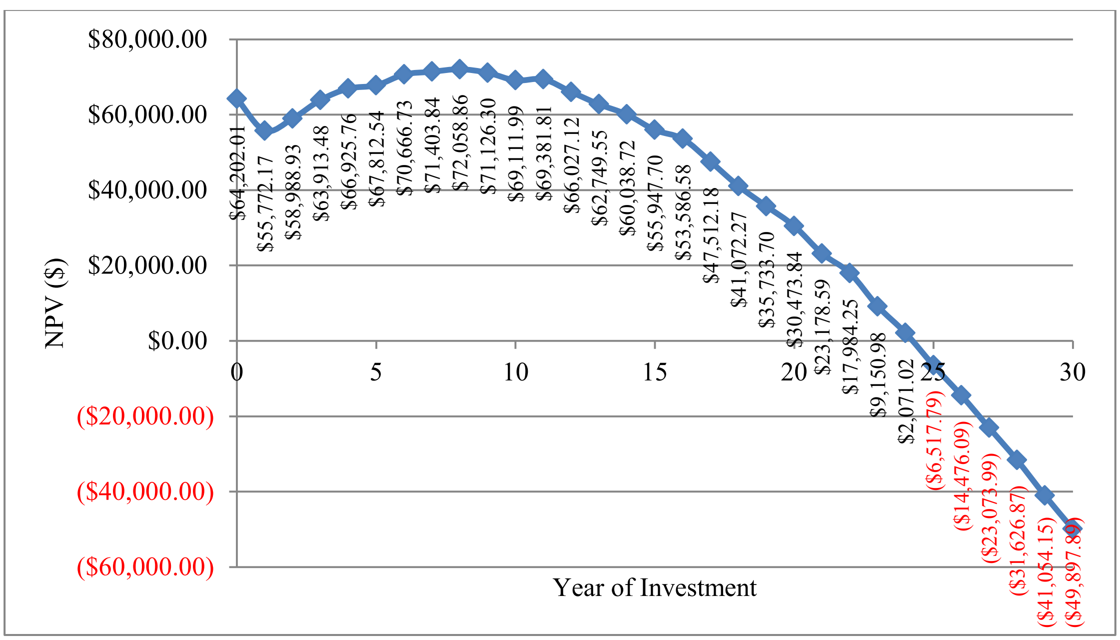


Figure 24 Average project value by the time of exercising the option (year) if electricity price trend is exponential

From the chart, there was a dip at year 1 and then the pattern was in parabolic shape. The project NPV increased in the period between year 2 and year 4 but still lower than the NPV of the base case. The project value was increased and higher than to "invests now" when the decision was delayed and the option was exercised between the year 5 and year 13. However, after it reached the maximum NPV at year 8, it continued to go down. The reason behind these behaviors will be further elaborated.

First, to explain the occurrence of the dip, the simulations were made in same uncertainty path. One simulation was for "investing now" and another for investing at year 1. It was seen that the dip occurred because:

- In year 1, although the investment cost decreased, the overall cost in first 2 years was still higher because the total investment if invested in year 1 also included an exercise cost to have flexibility. If the owner decided to delay a decision further, the investment cost may have gone down further.
- Loss the benefit of investing immediately at year 0. This resulted to the difference between discounted benefits from incentive and electricity cost saving over $10,000.

Table 12 elaborates the differences of costs and benefits between 2 decisions from a sample simulation.

Table 12 Comparison of NPV in first 2 years between the decisions to invest in year 0 and year 1

Year	Investment/ Exercise cost	O&M Cost	Annual Elec. Savings	Annual Savings +Rebates	Annual Cash Flow	Discounted annual cost	Discounted annual benefit	Annual Discounted Cash Flow	NPV over time
Invest at year 0									
0	$243,823	$0	$9,696	$29,946	-$213,877	-$243,823	$29,946	-$213,877	-$213,877
1	$0	$2,311	$10,796	$10,796	$8,485	-$2,243	$10,482	$8,238	-$205,639
					Total	**-$246,066**	**$40,427**		
Invest at year 1									
0	$19,506	$0	$0	$0	-$19,506	-$19,506	$0	-$19,506	-$19,506
1	$235,683	$0	$10,796	$31,046	-$204,637	-$228,819	$30,142	-$198,677	-$218,183
					Total	**-$248,325**	**$30,142**		

Second, the project NPV increased after the dip but still lower than the value in base case. The reason of this behavior can be explained with similar reason to the dip in year 1, the investment cost was not low enough and owners also lost the benefits they could have had during the delay. After that, the investment cost was lower and able to cover the amount of benefits loss during the delay. The value also increased because of the different in degradation. For example, the PV system that installed in year 8 will perform better than the ones installed 8 years earlier as those PV systems performance were already degraded, hence, the benefits from electricity cost were decreased over time.

Lastly, the project NPV started to decrease if the option was exercised after one point of time. This can be explained that the delay was too long; therefore, the cumulative benefits at the end, year 30, were lower than the earlier decisions to exercise.

Figure 25 shows the simulation result of the project value, varied by the year that option was exercised when electricity price was modeled to increase linearly.

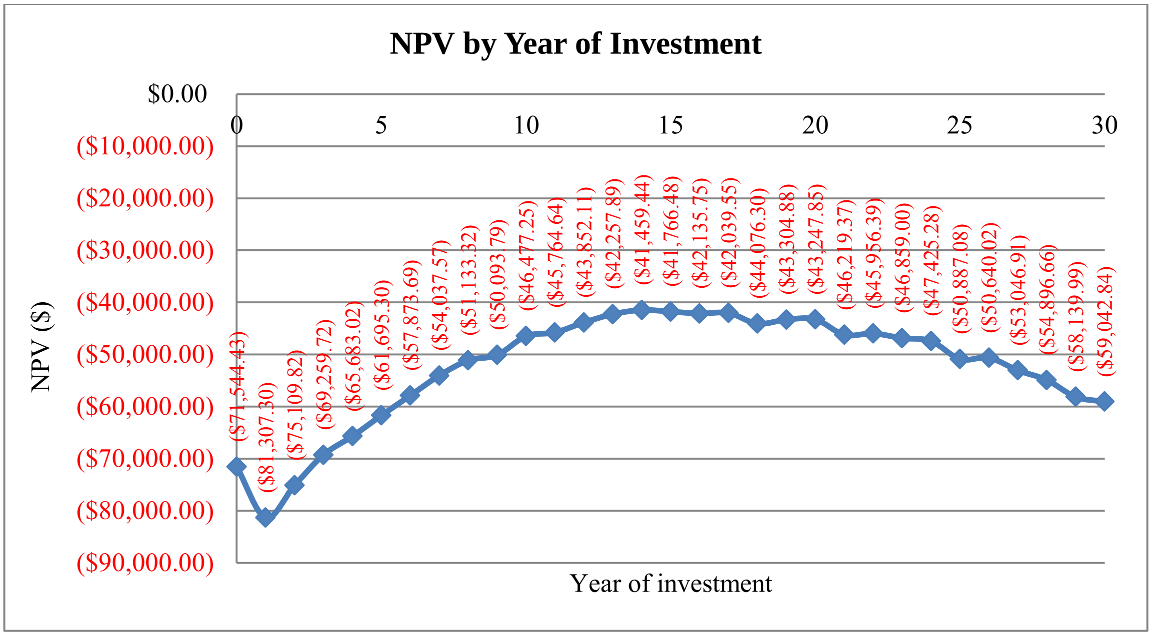


Figure 25 Average project value by the time of exercising the option (year) if electricity price trend is linear

In the case where electricity price increases linearly, although the project value was negative, NPV still increased to be higher than base case when the option was exercised after the 3rd year. The behaviors are the same with exponential forecast; there was a dip then increased until one point and then decreased. The NPV in linear forecast is much lower than the exponential forecast because the electricity price increased at a slower rate. Therefore, the benefits from electricity cost saving were not as great as the exponential case.

Figure 26 compares the cumulative distribution charts of project NPV of case 2 and case 3 which exercised an option at year 8. This was a simulation with exponential electricity price trend. The project with a flexible strategy results the higher variation of project NPV.

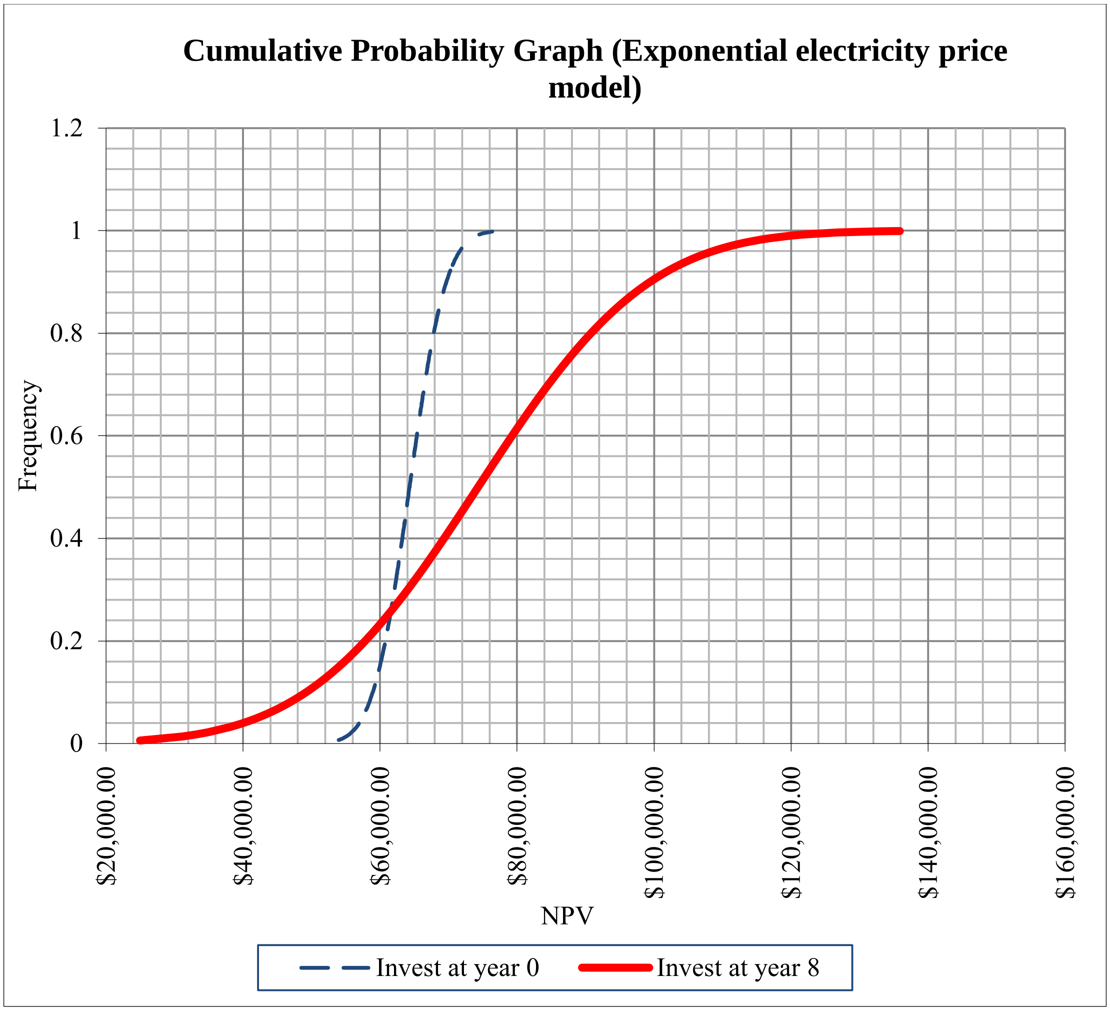


Figure 26 Cumulative distribution chart of project NPV for exponential electricity trend case

The possible range of NPV of project with flexible strategy is wider than the base case. Although the average was around $72,000, the possible NPV from the simulation can range from minimum at $21,000 to maximum at around $138,000. Delaying the decision can cause the project to lose the opportunity to earn benefits of having electricity production from PV system. On the other hand, it can be very beneficial when every condition was very favorable. From the chart, it also indicates that there are 25%

chance to have lower NPV than base case if decided to invest at year 8, which is the year that most likely provide the highest average NPV.

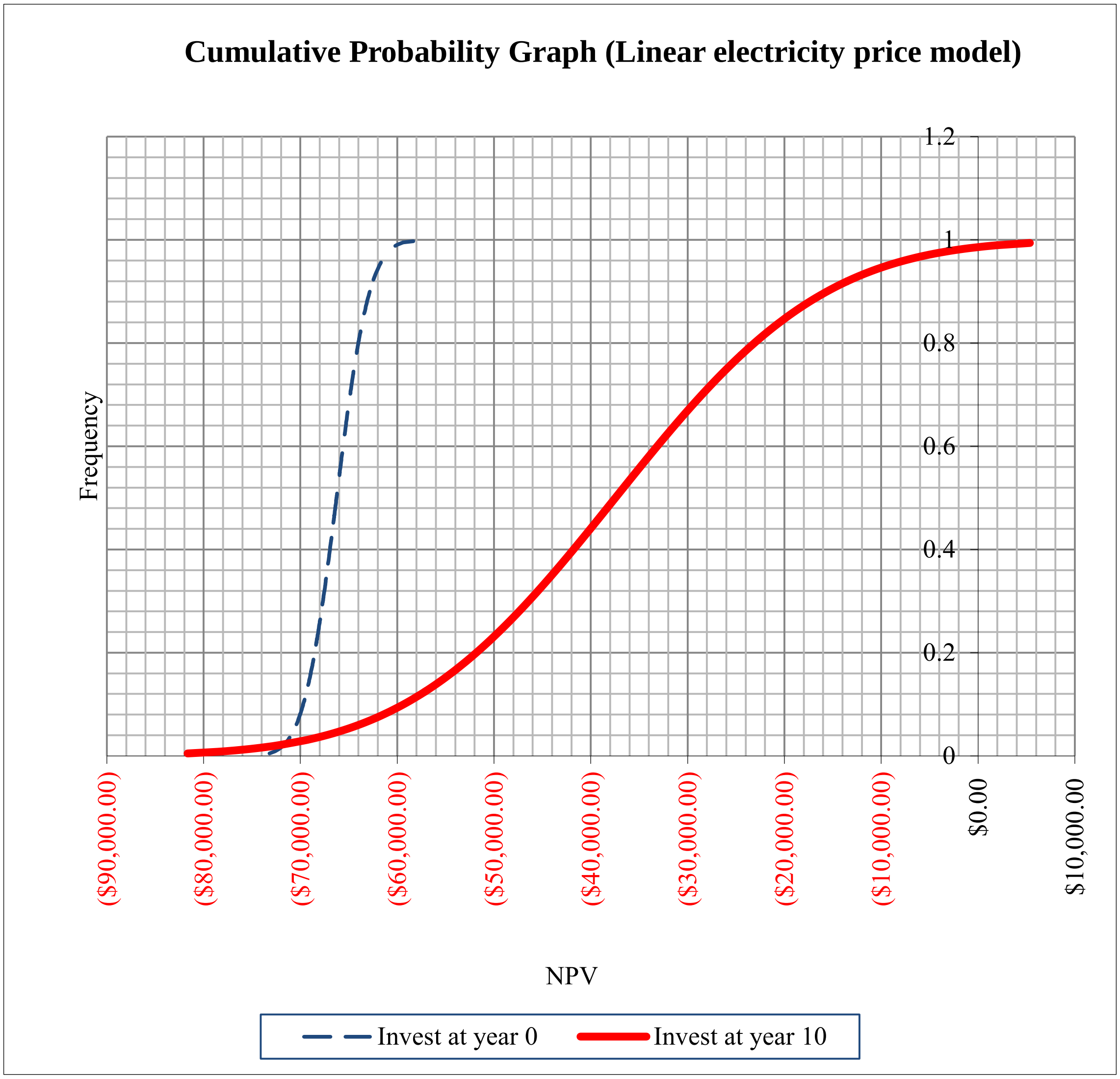


Figure 27 Cumulative distribution chart of project NPV for linear electricity trend case

From Figure 27 shows the cumulative distribution function of project NPV when option was exercised at year 10. In linear case, the pattern is similar. The reasons for wider range of possible project value can be explained by the impact of uncertainties. However, it can be seen that by delaying decision, project NPV is likely to be higher. The chance of having lower NPV than the base case is significantly less than the exponential case. This can be explained that the loss of opportunity from delaying decision is not as great because the electricity price increase constantly at slower rate. The saving of electricity cost will not be very high in this case.

However, the charts in Figure 26 and 27 are the simulations when criteria were assigned without reevaluating uncertainties to present the possibility of the project value. In practice, these two charts are not necessary because decision makers will need to reevaluate the situation based on updated data and the forecast of possible NPV to maximize the project value.

7.2 Simulation by assigned criteria

Figure 28 and 29 shows the results of project NPV in case an option was exercised when assigned criteria on uncertainties are met.

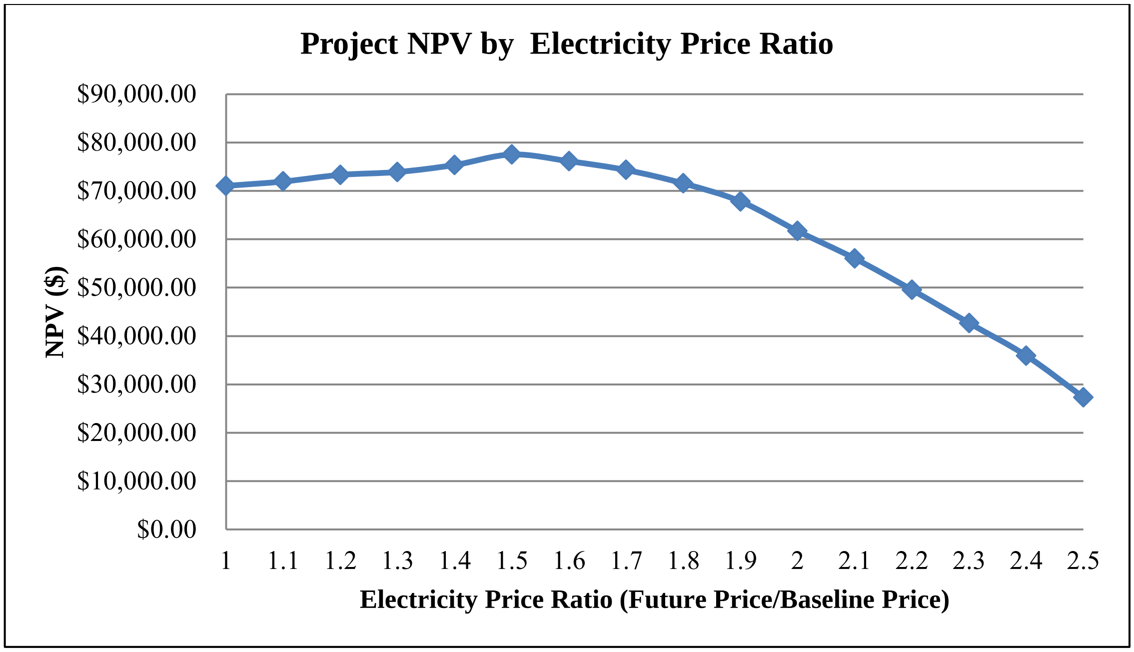


Figure 28 A chart shows project NPV when an option was exercised at different assigned electricity price ratio decision policy

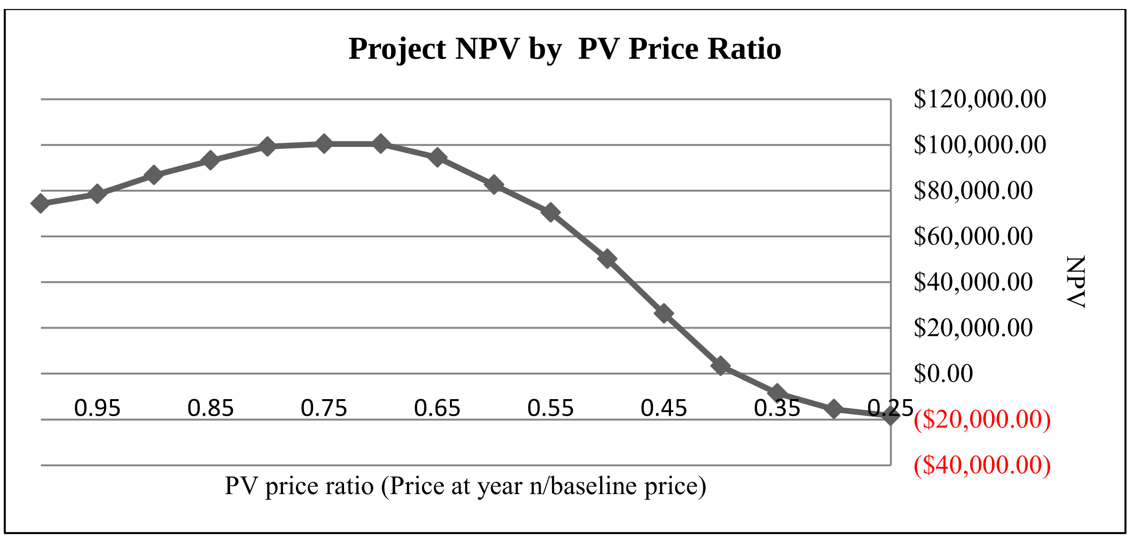


Figure 29 A chart shows project NPV when an option was exercised at different assigned PV price ratio decision policy

The charts show similar result that the flexible strategy will add value to the project when an option was exercised at a favorable condition. If owners delay their decision furthermore, the project value will decrease because it took a long time until the higher criteria can be met. This causes the cumulative benefits at the end, year 30, to be lower than the earlier decisions to exercise. Figure 29 shows that NPV decreased at lower rate when the decision policy was to wait until PV price ratio was lower (0.25-0.4). This can be explained that in some uncertainty paths, the investment was never made. Therefore, the NPV of those paths equaled to initial exercise cost that paid to have flexibility and brought up the overall average.

7.3 Model analysis

In this part, sensitivity analysis was conducted to observe the influence of exogenous variables. The result is shown in Figure 30.

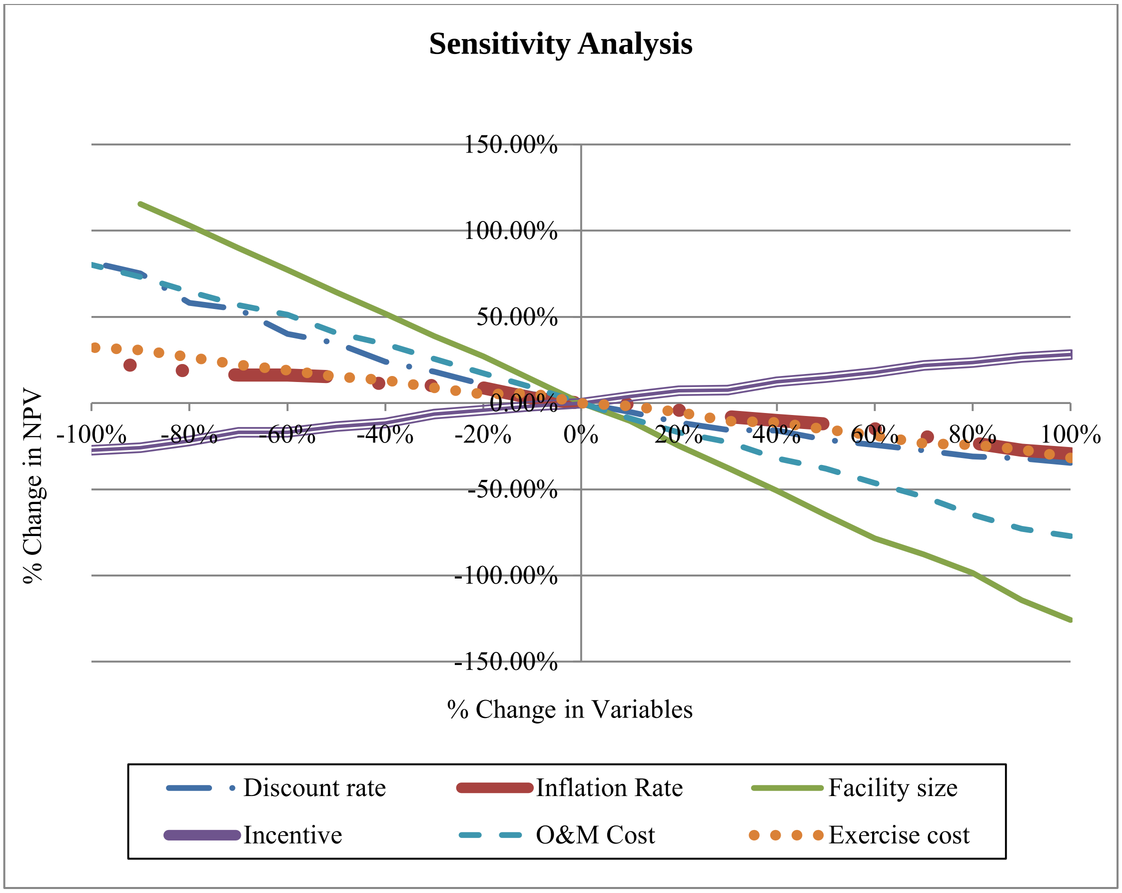


Figure 30 Sensitivity analysis of exogenous variables

As shown from the analysis, the most sensitive variable is the facility size which directly influences the amount of initial investment. The bigger the facility size, the higher amount of electric load, therefore, the larger PV system is needed. The initial investment will increase with the size of PV system owners plan to install.

The impact of each exogenous variable is summarized in Table 13.

Table 13 Impact of exogenous variables

Variables	Impact	
	Reference	**From simulation**
Investment Cost	Negative	Negative
Exercise cost	Negative	Negative
Discount rate	Positive	Negative
Volatility	Positive	Positive
Inflation rate	N/A	Negative
Incentives	N/A	Positive
O&M Cost	N/A	Negative

Table 13 compares the impact of variables with the reference (Lee, 2011). The project costs, including investment cost, exercise cost and O&M cost, all have negative impact to project value as expected. Incentive has a positive impact as it could add the value to the project. However, the discount rate has a negative impact which oppose to the reference from Lee (2011). Discount rate can have a positive impact because decision makers can advantage in deference to the investment cost. From the simulation, it also decreased the benefits over time, and because benefit from electricity cost saving can have greater effect to project value, the overall impact was negative.

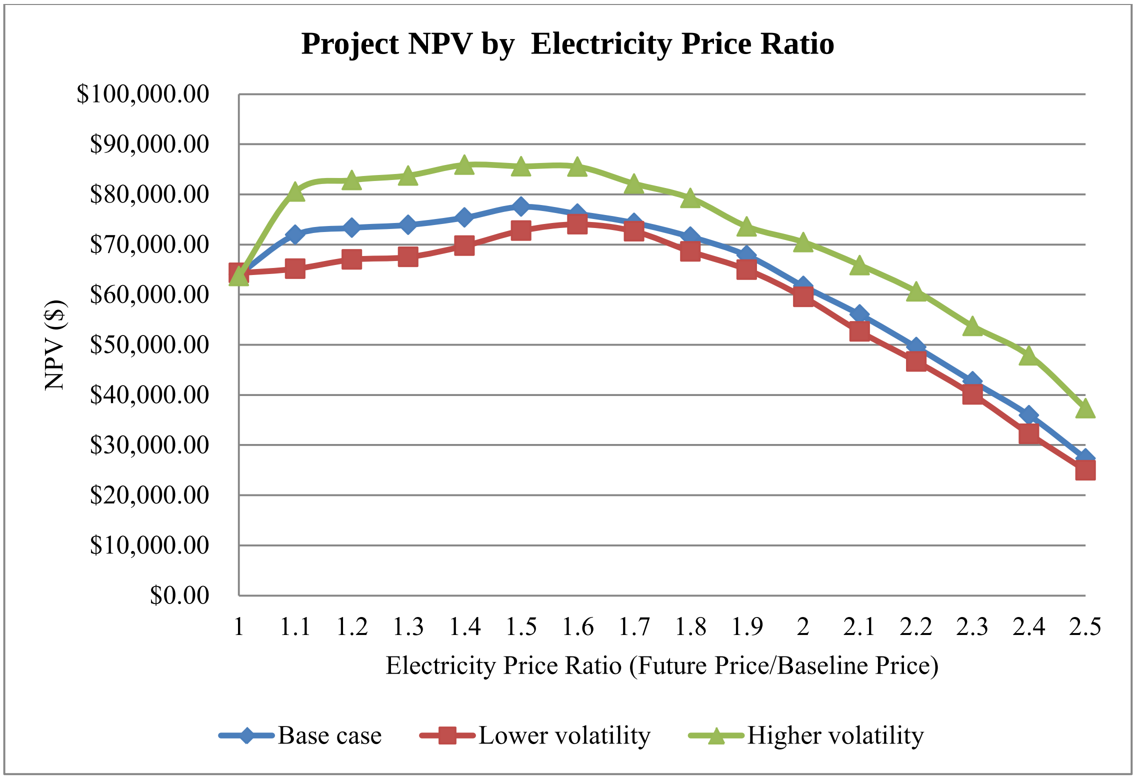


Figure 31 Impact of volatility to project value

Figure 31 shows the impact of volatility of uncertainties. The analysis was conducted by simulate 3 cases of volatility:

- High volatility: increase uncertainties standard deviation by 50% to generate more fluctuate price condition.
- Base case: uncertainties standard deviation equals to previous simulations
- Low volatility: decrease uncertainties standard deviation by 50% to generate less fluctuate price condition.

The result shows that project NPVs are higher in greater volatility conditions, if flexible strategy was applied. It can be inferred that flexible strategy has a better performance when the project is exposed to greater uncertainties.

8. CONCLUSION

The research questions focus on how the flexible strategy would impact on the project finance and how this model can be used as a tool. In the case study, PV system was considered to install to the building. Owners may never install it, install now or build the facility to be ready for installation in the future. Historical data were used and reasonable assumptions were made to demonstrate the result for this case study.

8.1 Impacts and behavior of real options in sustainable improvement according to the case study

From the simulation results, it can be seen that:

- When an option was exercised at a favorable condition, project with flexibility resulted in higher NPV, higher BCR and shorter payback period compared to the case to install at the beginning.
- If flexible strategy was applied but an option was exercised too soon, project value can be lower than invest at the beginning when same investment period was considered. The benefit from delaying to obtain lower investment cost still lower than the benefit owners could have had if they installed right at the start.
- If exercise the option too late, project value can be lower than invest at the beginning when same investment period is considered. Although the investment cost was lowered, there was less time for the benefit to payoff.
- In Monte Carlo simulation, although the project with flexibility can have a higher average NPV, it can also have a wider range of possible NPV. Delaying the

decision can cause the project to lose the opportunity to earn benefits of having sustainable energy production. In this case, the project may result in a lower NPV. On the other hand, the decision can be made at the optimum time when PV price was low and the electricity price just started to increase at sharper rate.

- Real options can perform better in greater uncertainty condition.

All in all, although this work is considered as a preliminary research and the result was conducted on one case study, it still demonstrates that the flexible strategy can have a positive impact on a sustainability improvement project when an option was exercised in the favorable period.

8.2 Impacts of real options in sustainable improvement in practice

The model can be a useful tool to provide an initial assessment of sustainability improvement project by simulating financial behavior patterns. It can also assist the analysis and development of policies by observing impacts of variables and uncertainties.

The impacts to professional practice can be concluded that, with a better understanding of real option impact can expand the use of real option in sustainable construction and project development. Because an investment in sustainability improvement project will subject to many uncertainties and exogenous variables, the good understanding of real option application is crucial.

In practice, if the owners chose to design and construct a building with flexibility, they will need to keep reevaluating the conditions by monitoring current situations, forecasting the future uncertainties and calculating possible project value. An extension of the model based on business nature can serve as an assessment tool of implementing flexible strategy in sustainability improvement project. With more accurate data and a better understanding of the boundaries provided by the industry, practitioners should be able to apply the flexible strategy to improve sustainable project investment value.

8.3 Future works

This project is useful as a starting point to evaluate a sustainable development utilizing a real option approach. In the real practice, there will be numerous sources of uncertainty. In order to improve future investigations in this field; this research presents the following recommendations:

- Other uncertainties may be considered for the future research. Possible uncertainties that can affect the sustainable development project are, but not limited to, climate change and benefit of earning sustainable building certifications such as LEED.
- Uncertainty simulations in this model are developed solely on statistical data. Future research can develop more accurate forecast models that consider various exogenous factors.
- Future research can utilize system dynamic to further investigate the impact of real option in sustainable development. The decision process can be modeled with delay in perceiving information, available budget and dynamic forecast of future value when uncertainties become clearer.

REFERENCES

Amram, M., and Kulatilaka, N. (1999). *Real Options: Managing Strategic Investment in an Uncertain World*, Harvard Business School Press, Cambridge, MA.

Ashuri, B., Augenbroe, G., Chiara, N., and Paredis, C. (2009). "How Can US AEC Firms Get the Lead in Sustainable Building Design? Motivations and Facts of Flexible Design That a Potential Leader Should Know." *2009 Specialty Conference Leadership and Management in Construction*, South Lake Tahoe, CA, <http://academiceventplanner.com/LEAD2009/papers/Ashuri_Augenbroe_Chiara_Paredis.pdf> (July, 2011).

Ashuri, B., Kashani, H., and Lu, J. (2011). "An Investment Analysis Framework for Energy Retrofit in Existing Buildings." *47th ASC Annual International Conference Proceedings*, Omaha, NE <http://ascpro0.ascweb.org/archives/cd/2011/paper/CPRT364002011.pdf> (December, 2011).

Battisti, R., and Corrado, A. (2005). "Evaluation of Technical Improvements of Photovoltaic Systems through Life Cycle Assessment Methodology." *Energy,* 30, 952–967.

Berk, J., DeMazo, P., and Harford, J. (2009). *Fundamentals of Corporate Finance*, Pearson, New York.

Black, F., and Scholes, M. (1973). "The Pricing of Options and Corporate Liabilities." *The Journal of Political Economy*, 81(3), 637-654.

Borenstein, S. (2008). "The Market Value and Cost of Solar Photovoltaic Electricity Production." *Center for the Study of Energy Markets Working Paper #182*, University of California Energy Institute, <http://faculty.haas.berkeley.edu/borenste> (December, 2011).

Brach, M. A. (2003). *Real Options in Practice*, John Wiley and Sons, Hoboken, NJ.

Brooks, W., and Dunlop, J. (2011). *NABCEP PV Installer Resource Guide,* The North American Board of Certified Energy Practitioners, New York.

Busch, T., and Hoffmann, V. (2009). "Ecology-Driven Real Options: An Investment Framework for Incorporating Uncertainties in the Context of the Natural Environment." *Journal of Business Ethics*, 90(2), 295-310.

Chappell, T. W., and Corps, C. (2009). “High Performance Green Building: What's It Worth?” *Cascadia Region Green Building Council*, <http://cascadiagbc.org/news/GBValueStudy.pdf> (December, 2011).

Cortazar, G., Schwartz, E. S., and Salinas, M. (1998). “Evaluating Environmental Investments: A Real Options Approach.” *Management Science*, 44(8), 1059-1070.

Dixit, R., Avinash, K., and Pindyck, S. (1995). “The Options Approach to Capital Investment.” *Harvard Business Review*, 77(3), 105-115.

DSIRE. (2012). “Incentives/Policies for Renewables & Efficiency.” *Database of State Incentives for Renewable and Efficienct*, <http://www.dsireusa.org> (February, 2012).

Dunlop, E. D., and Halton, D. (2005). “The Performance of Crystalline Silicon Photovoltaic Solar Modules after 22 Years of Continuous Outdoor Exposure.” *Progress in Photovoltaics: Research and Applications*, 14, 53-64.

Durmus-Pedini, A., and Ashuri, B. (2010). “An Overview of the Benefits and Risk Factors of Going Green in Existing Buildings.” *International Journal of Facility Management*, 1(1), 1-15.

Ford, D., and Barghav, S. (2006). “Project Management Quality and the Value of Flexible Strategies.” *Engineering, Construction and Architectural Management*, 13(3), 275-289.

Ford, D., and Garvin, M. (2010). “Barriers to Real Options Adoption and Use in Architecture, Engineering, and Construction Project Management Practice.” in *Real Options in Engineering Design*, *Operations and Management*, ed. H. B. Nembhard and M. Aktan, CRC Press, Boca Raton, FL, 54-61.

Ford, D., Lander, D., and Voyer, J. (2002). “A Real Options Approach to Valuing Strategic Flexibility in Uncertain Construction Projects.” *Construction Management and Economics*, 20(4), 344-345.

Fuller, S. K.., Petersen, S. R. (1995). *Life-Cycle Costing Manual for Federal Energy Management Program*, National Institute of Standards and Technology, Gaithersburg, MD.

Haselbach, L. (2008). *The Engineering Guide to LEED-New Construction: Sustainable Construction for Engineers*, McGraw-Hill, Washington, D.C.

Infinitepower.org. (n.d.). “Estimating PV System Size and Cost.” *Renewable Energy: the Infinite Power of Texas,* <www.infinitepower.org> (January, 2012).

International Energy Agency. (2011). “Key World Energy Statistics 2011.” *International Energy Agency*, <http://iea.org/textbase/nppdf/free/2011/key_world_energy_stats.pdf> (September, 2011).

Jordan, D. C., and Kurtz, S. R. (2011). “Thin-Film Reliability Trends toward Improved Stability.” *Proceedings of the 37th PV Specialists Conference*, Seattle, WA, <www.nrel.gov/docs/fy11osti/50726.pdf> (April, 2012).

Jordan, D., and Kurtz, S. (2010). “Analytical Improvements in PV Degradation Rate Determination.” *35th IEEE Photovoltaic Specialists Conference*, Honolulu, HI, 2688-2693.

Kibert, C. J. (2007). *Sustainable Construction : Green Building Design and Delivery*, 2nd Ed.,Wiley, Hoboken, NJ.

Kubba, S. (2010). *Green Construction Project Management and Cost Oversight*, Butterworth-Heinemann, Oxford.

Lee, S. C. (2011). “Using Real Option Analysis for Highly Uncertain Technology Investments: The Case of Wind Energy Technology.” *Renewable and Sustainable Energy Reviews*, 16(8), 4443-4450.

Marion, B., and Adelstein, J. (2003). “Long-Term Performance of the SERF PV Systems.” *NREL/CP-520-33531*, Denver, CO, 1-6.

McGraw-Hill Construction. (2009). “2009 Greening of Corporate America: The Pathway to Sustainability - From Strategy to Action.” *McGraw-Hill Coompanies*, < http://www.mcgraw-hill-sales.com/2009_GreeningCorpAmerica.pdf > (December, 2011).

Menassa, C., and Rexrode, A. (2010). “Life Cycle Cost Analysis and Real Option Theory for Imporved Sunstainability in Existing Buildings.” *Proceeding of 2010 Construction Research Congress*, America Society of Civil Engineers, Banff, Alberta, Canada, 1477-1486.

Mun, J. (2010). “Real Options in Practice.” in *Real Options in Engineering Design, Operations and Management*, ed. H. B. Nembhard and M. Aktan, CRC Press, Boca Raton, FL, 8-10.

Nemet, G. (2006). “Beyond the Learning Curve: Factors Influencing Cost Reductions in Photovoltaics.” *Energy Policy*, 34(7), 3218–3232.

NREL. (2010). “2008 Solar Technologies Market Report: January 2010.” *National Renewable Energy Laboratory*, <www.nrel.gov/analysis/pubs_solar.html> (September, 2011)

Office of the Comptroller of the Currency. (2011). “Supervisory Guidance on Model Risk Management.” *OCC: Office of the Comptroller of the Currency*, <http://www.occ.gov> (August, 2011).

Raghuraman, B., Lakshman, V., Kuitche, J., Shisler, W., TamizhMani, G., and Kapoor, H. (2006). “An Overview of Smud’s Outdoor Photovoltaic Test Program at Arizona State University.” *In proceeding of: Photovoltaic Energy Conversion, Conference Record of the 2006 IEEE 4th World Conference*, 2, 2214-2216.

Reis, A., Coleman, N., Marshall, M., Lehman, P., and Chamberlin, C. (2002). “Comparison of PV Module Performance Before and After 11-Years Exposure.” *Proceedings of the 29th IEEE Photovoltaics Specialists Conference*, New Orleans, LA, <http://hdl.handle.net/2148/44> (April, 2012).

RSMeans. (2010). *RSMeans Green Building Cost Data*, 1st Ed., RS Means Company Norcross, GA.

Secretariat of the Commission for Environmental Cooperation. (2008). *Green Building in North America: Opportunities and Challenges*, Communications Department of the CEC Secretariat, Montreal, Quebec, Canada.

Sick, F., and Erge, T. (1996). *Photovoltaics in Buildings: A Design Handbook for Architects and Engineers*, James & James (Science Publisher), London.

Solarbuzz. (2011), “Module Pricing.” *Solar Market Research and Analysis*, <www.solarbuzz.com> (October, 2011).

Sterman, J. (2000). *Business Dynamics: Systems Thinking and Modeling for a Complex World,* Irwin McGraw-Hill , New York.

Triantis, A. (2003). “Real Options.” in *Handbook of Modern Finance*, ed. D. Logue and J. Seward, Research Institute of America, New York, D1-D32.

U.S. Department of the Treasury. (2011). “Interest Rate Statistics.” *U.S. Department of the Treasury*, <www.treasury.gov> (October, 2011)

U.S. DOE. (2008). “Energy Efficiency Trends in Residential and Commercial Buildings.” *U.S. DOE Energy Efficiency and Renewable Energy*, <http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/bt_stateindustry.pdf> (September, 2011).

U.S. DOE. (2011). “Buildings Sector Energy Consumption.” *Building Energy Data Book*, <http://buildingsdatabook.eren.doe.gov/ChapterIntro1.aspx> (October, 2011).

U.S. EIA. (2010). *Annual Energy Review 2010*, United States Govt Printing Office, Cincinnati, OH.

USGBC. (2011). “Green Building Incentive Strategies.” *USGBC: U.S. Green Building Council*, <http://www.usgbc.org> (September, 2011).

Va´zquez, M., and Rey-Stolle, I. (2008). “Photovoltaic Module Reliability Model Based on Field Degradation Studies.” *Progress in Photovoltaics: Research and Applications*, 16, 419-433.

Weber, K., and Savitz, A. W. (2006). *The Triple Bottom Line: How Today's Best-Run Companies Are Achieving Economic, Social and Environmental Success and How You Can Too*, Jossey-Bass, San Francisco.

World Commission on Environment and Development. (1987). *Our Common Future*, Oxford University Press, New York.

Yang, M., and Blyth, W. (2007). “Modeling Investment Risks and Uncertainties with Real Options Approach.” *International Energy Agency Working Papers Series*, <http://www.iea.org/papers/2007/roa_model.pdf> (September, 2011).

APPENDIX A: MODEL CODE

The simulation was developed by simple VBA command to bring out the results from calculation sheets in designate repetition (500 times). An example of VBA program code on the simulation in "MC Sim" sheet is shown below:

```
'Clear content before simulation'
    Sheet10.Range("D11:N5010").ClearContents
    For i = 1 To Sheet10.Cells(1, 2)
    'NPV and BCR'
        'Count'
        Sheet10.Cells(10 + i, 3) = i
        'Invest at y 0 EXP NPV'
        Sheet10.Cells(10 + i, 4) = Sheet5.Cells(35, 14)
        'Invest at y 0 EXP BCR'
        Sheet10.Cells(10 + i, 5) = Sheet5.Cells(35, 18)
        'Invest at y 0 LIN NPV'
        Sheet10.Cells(10 + i, 6) = Sheet6.Cells(35, 14)
        'Invest at y 0 LIN BCR'
        Sheet10.Cells(10 + i, 7) = Sheet6.Cells(35, 18)
        'Flexible EXP NPV'
        Sheet10.Cells(10 + i, 8) = Sheet7.Cells(35, 16)
        'Flexible EXP BCR'
        Sheet10.Cells(10 + i, 9) = Sheet7.Cells(35, 20)
        'Flexible LIN NPV'
```

```
        Sheet10.Cells(10 + i, 10) = Sheet8.Cells(35, 16)
        'Flexible LIN BCR'
        Sheet10.Cells(10 + i, 11) = Sheet8.Cells(35, 20)

    'Execute time'
        '1. For Exponential'
        Sheet10.Cells(10 + i, 13) = Sheet7.Cells(36, 7)
        '2. For Linear'
        Sheet10.Cells(10 + i, 14) = Sheet8.Cells(36, 7)

    'Payback period'
        'EXP y0'
        Sheet10.Cells(10 + i, 18) = Sheet5.Cells(36, 18)
        'LIN y0'
        Sheet10.Cells(10 + i, 19) = Sheet6.Cells(36, 18)
        'LIN flex'
        Sheet10.Cells(10 + i, 21) = Sheet8.Cells(36, 20)
        'EXP flex'
        Sheet10.Cells(10 + i, 20) = Sheet7.Cells(36, 20)
    Next

End Sub
```

APPENDIX B: VALIDATION RESULT

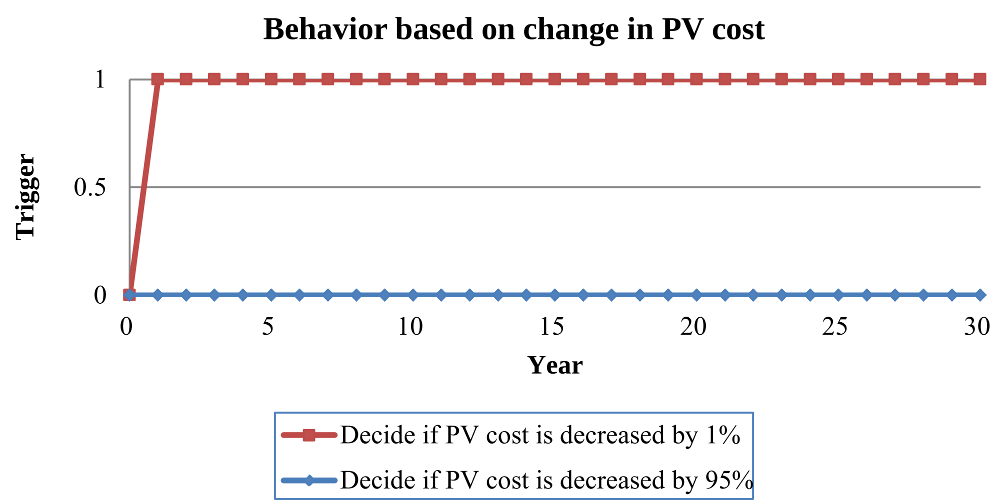


Figure B.1 Decision output based on the change in PV cost. Where 1 = Exercise (trigger pulled) and 0 = Not exercise (no action)

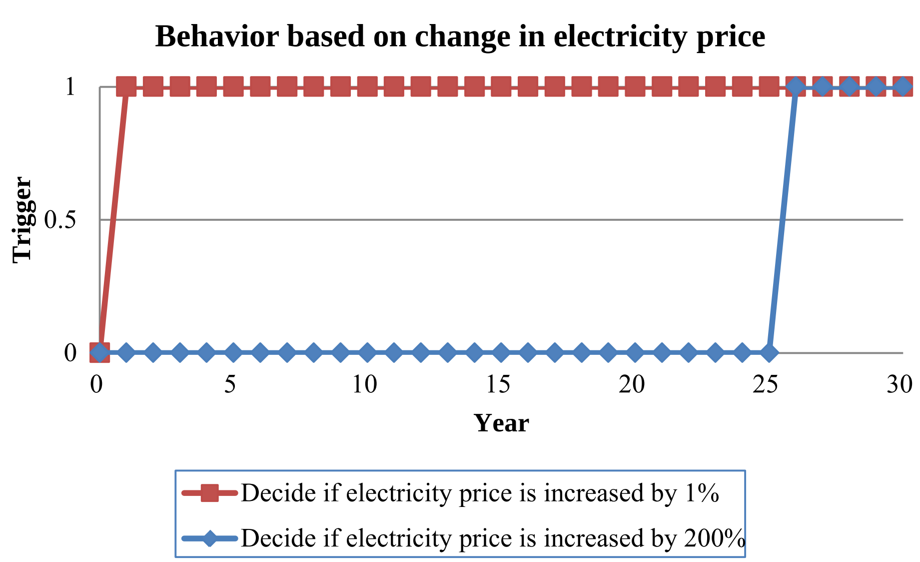


Figure B.2 Decision output based on the change in electricity price. Where 1 = Exercise (trigger pulled) and 0 = Not exercise (no action)

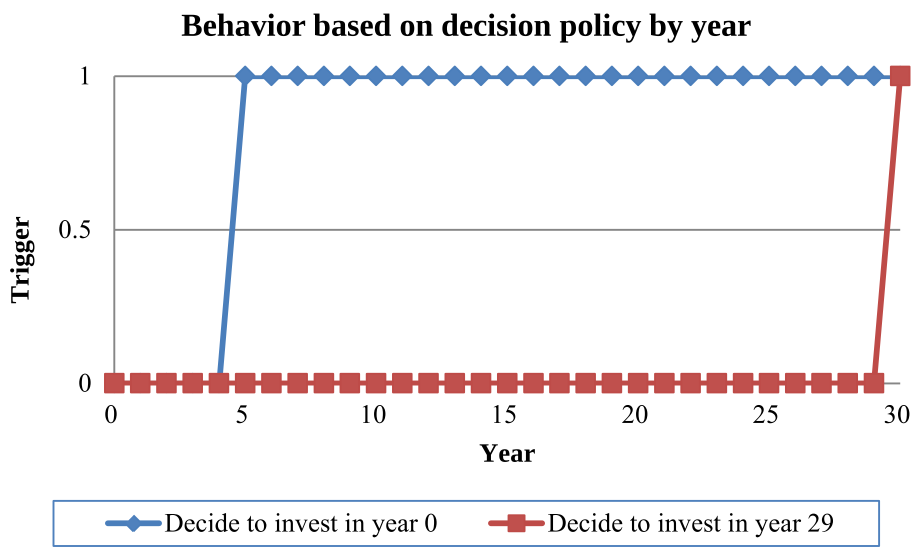


Figure B.3 Decision output based on the decision policy by year. Where 1 = Exercise (trigger pulled) and 0 = Not exercise (no action)

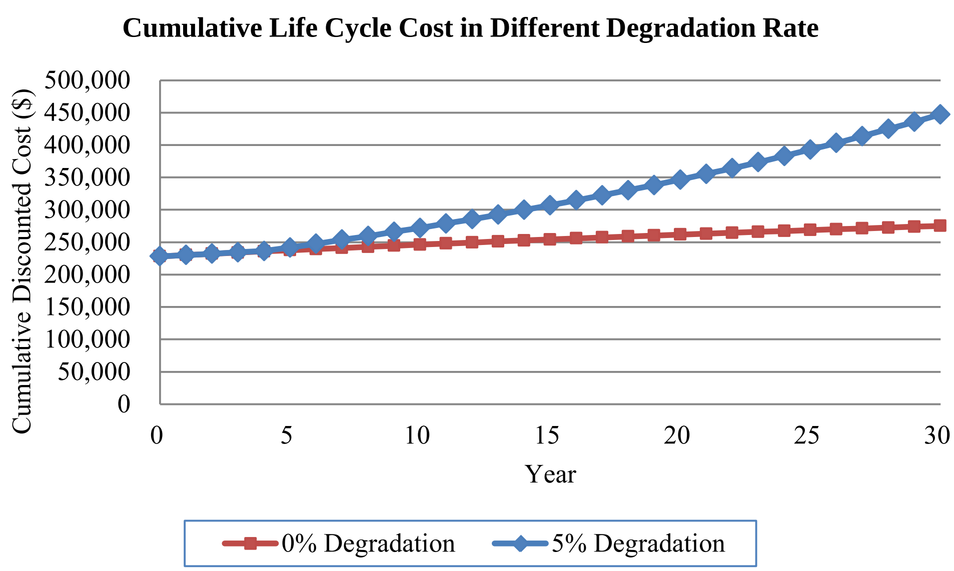


Figure B.4 Cumulation life cycle cost (discounted) based on extreme case in degradation rate of PV output. (Example of case 2 : Exercise at year 0)

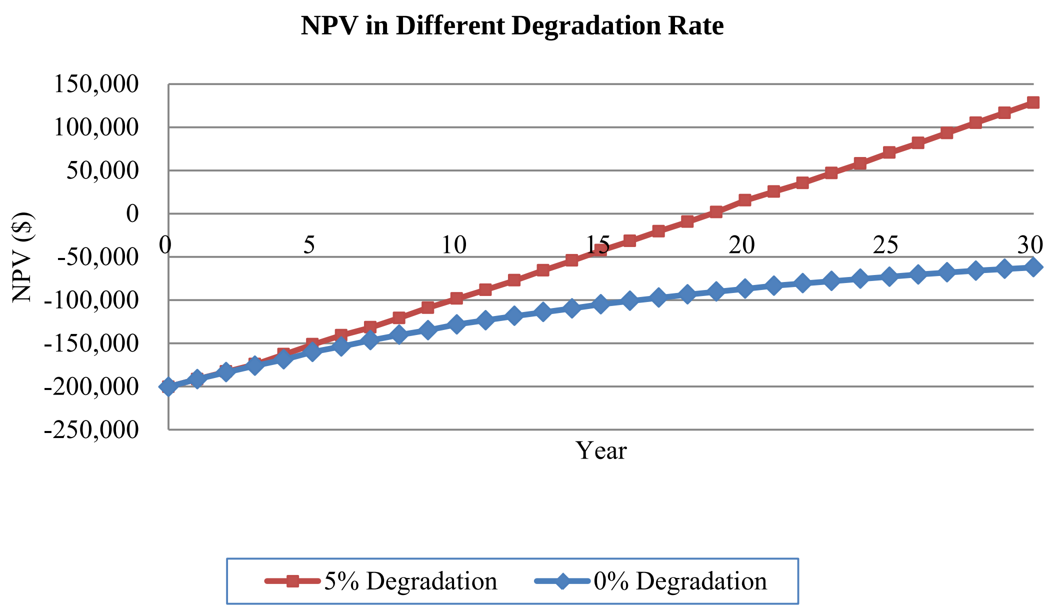


Figure B.5 NPV based on extreme case in degradation rate of PV output. (Example of case 2 : Exercise at year 0)

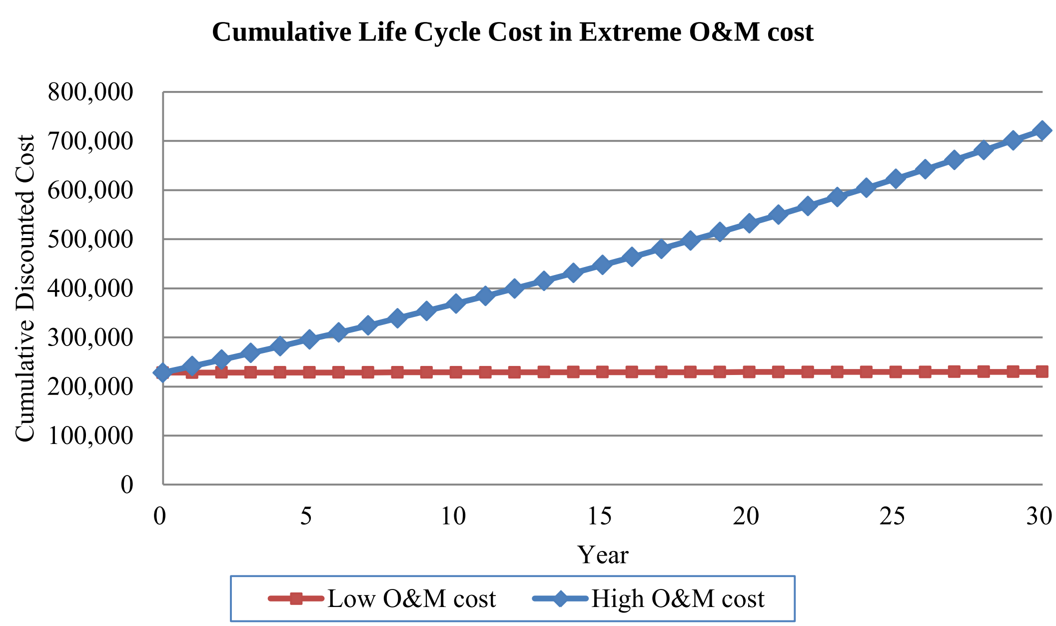


Figure B.6 Cumulation life cycle cost (discounted) based on extreme case in O&M cost. (Example of case 2 : Exercise at year 0)

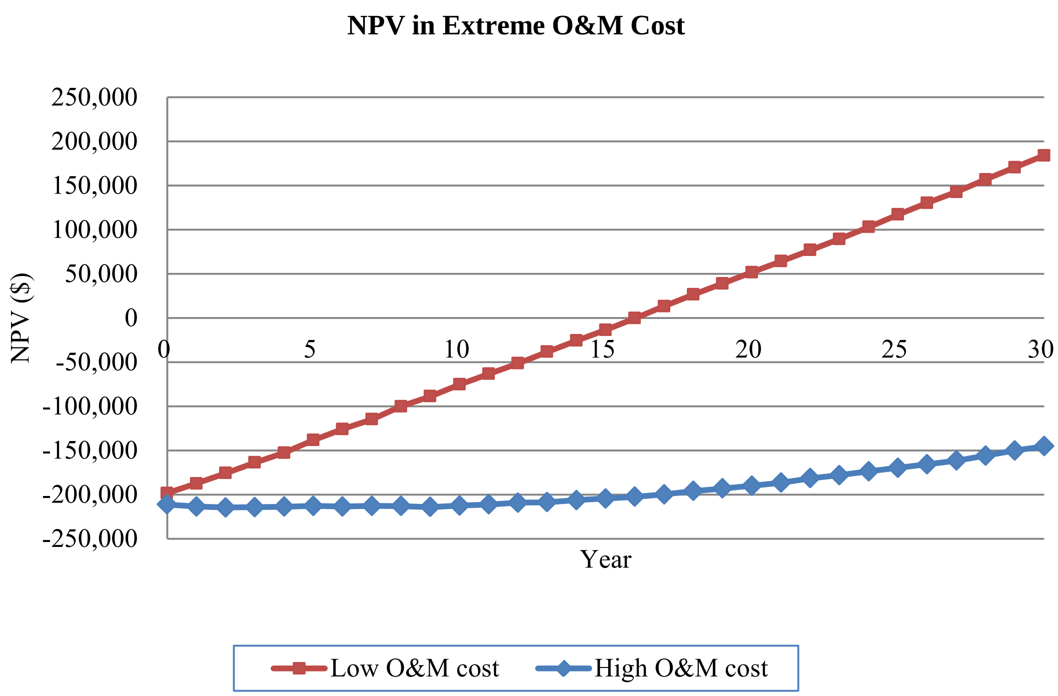


Figure B.7 NPV based on extreme case in O&M cost. (Example of case 2 : Exercise at year 0)

APPENDIX C: PRICE HISTORICAL DATA

Table C.1 Electricity Price data (U.S. EIA, 2011)

Year	Commercial Electricity price - Nominal (Cent/kWh)
1960	2.4
1961	2.4
1962	2.4
1963	2.3
1964	2.2
1965	2.2
1966	2.1
1967	2.1
1968	2.1
1969	2.1
1970	2.1
1971	2.2
1972	2.3
1973	2.4
1974	3
1975	3.5
1976	3.7
1977	4.1
1978	4.4
1979	4.7
1980	5.5
1981	6.3
1982	6.9
1983	7
1984	7.13
1985	7.27
1986	7.2
1987	7.08
1988	7.04
1989	7.2

Table C.1 (Continued)

Year	Commercial Electricity price - Nominal (Cent/kWh)
1990	7.34
1991	7.53
1992	7.66
1993	7.74
1994	7.73
1995	7.69
1996	7.64
1997	7.59
1998	7.41
1999	7.26
2000	7.43
2001	7.92
2002	7.89
2003	8.03
2004	8.17
2005	8.67
2006	9.46
2007	9.65
2008	10.36
2009	10.17
2010[P]	10.26

Table C.2 Photovoltaic module price data (U.S. EIA, 2011)

Year	PV price - Nominal ($/Watt peak)
1989	5.14
1990	5.69
1991	6.12
1992	6.11
1993	5.24
1994	4.46
1995	4.56
1996	4.09
1997	4.16
1998	3.94
1999	3.62
2000	3.46
2001	3.42
2002	3.74
2003	3.17
2004	2.99
2005	3.19
2006	3.5
2007	3.37
2008	3.49
2009	2.79
2010	2.84