ABSTRACT

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Due to the growing concerns with climate change and energy supply, Energy Performance Contracting (EPC), which uses the guaranteed future utility savings to repay the initial renovation investments, becomes increasingly popular. However, most Energy Service Companies (ESCOs) set the savings guarantee roughly based on their previous experience, which leads to inaccurate estimates in practice. This paper has built the stochastic models for the savings risks both from the energy price volatility and the facility performance instability, which follow the Geometric Brownian Motions (GBM) and Ito's lemma. Then, a flexible guarantee designing method for ESCOs is developed to minimize the financial risks and a case study has been conducted to show the application. Finally, suggestions have been made for how ESCOs set the guarantee and the extra profit sharing proportion in contracts based on the existing information. This method will help them appropriately allocate risks with successful contract negotiation.

GUARANTEE DESIGN ON ENERGY PERFORMANCE CONTRACTS UNDER UNCERTAINTY

By

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Chapter 1: Introduction

1.1 Background

Climate change and energy supply concerns, volatile and increasing energy prices, and a desire for greater energy independence have led many state and national leaders to support an increasingly prominent role for energy efficiency in energy policy. Currently, it has become one of the quickest and cheapest ways to increase the amount of energy available for use. There are numerous advantages of energy efficiency improvements, such as the psychological benefits of using natural lighting sources, which not only makes the home or office more comfortable, but also increases worker productivity or enables a retail store to be more appealing to clients, healthier, better-ventilated buildings, food that stays fresher in more efficient refrigerators and motors that run quieter, etc. Energy efficiency also offers a significant opportunity to mitigate the potential climate change by using less energy, which reduces emission of carbon dioxide, air-borne mercury, and other harmful pollutants from power plants that burn fewer fossil fuels to meet the lower energy demand (Granade et al., 2009). McKinsey & Company asserts that energy efficiency offers a vast, low-cost energy resource for the U.S. economy with profitable potential savings by 2020 totaling 23% of U.S. energy projected demand, worth over $1.2 trillion but costing less than a half.

As the most important sector compared with industry and transportation, making buildings more energy efficient has been identified as a largely untapped solution to address climate change, energy security and fossil fuel depletion. However, most clients are risk-avoided who lack the building energy-efficient renovation and operation experience. It also takes time and efforts to arrange the up-front capital cost or to get special congressional appropriations. Therefore, projects are quite possibly delayed or under consideration, though facility managers are often faced with building equipment crises such as the imminent demise of a boiler plant or an air conditioner. Energy efficiency needs a more cost-effective route to overcome those barriers and to allocate the potential high risks.

The energy performance contacting (EPC) market has several major drivers, such as savings mandates, facility modernization, green buildings and climate change. (ICF & NAESCO, 2007). Not only being amiable to the environment, EPC is a kind of win-win service for both the clients and the ESCOs. EPC allows facility owners and managers to upgrade ageing and inefficient assets while recovering capital required for the upgrade directly from the energy savings guaranteed by the ESCO. It helps to meet the energy reduction and environmental goals, at the same time, improves utility facilities to be more comfortable and reliable. At the end of the specific contract period the full benefits of the cost savings revert to the facility owner. From the clients' perspectives, EPC saves money and avoids the cost of delay and inaction as well as deferred maintenance. On the other hand, it creates incentives for the ESCO to provide high quality products and services that will perform long after installation and commission well. They get the motivation to find all energy conservation measures (ECMs) and commit to do all punch list items timely.

1.2 Problem Statement

The U.S. ESCO market has shifted away from the "shared savings" to the "guaranteed savings" type contracts over the last 15 years and 86% of the performance-based projects have specified guarantee in their contracts (Goldman et al., 2005). Under a shared savings contract, savings are split in accordance with a pre-arranged percentage: there is no 'standard' split that it depends on the cost of the project, the length of the contract and the risks taken by the ESCOs and the client. This mode limits long-term market growth and competition between the ESCOs and between financing institutions. For instance, small or new ESCOs with no previous experience in borrowing and few own resources are unlikely to get financing if such agreements dominate.

A scheme where an ESCO promises a certain level of energy savings and in this way shields the client from any performance risk is known as guaranteed savings. The guarantee for the savings that is produced by the project will be sufficient to cover the cost of financing for the life of the project. On Honeywell's website, savings guarantee has been explained as "if the new energy systems fail to reduce costs as required, Honeywell makes up the difference. Any savings above the guarantee are the client's to keep." Danfoss has also said "if we promise to save you 1 million EUR in an energy performance project and only manage to save you 800,000 EUR, we pay you the 200,000 EUR difference. If we find more, we split the over-performance, usually 50-50."

Both the ESCOs and the clients consider the savings revenue risk an important factor when they assess an energy performance project's feasibility due to the volatile energy prices and high technical instability. In most EPC cases, the ESCOs promise a minimum amount of energy-saving revenue and take on the entire risks related to the provision of energy services, including equipment-performance risks, energy-price risks and credit risks. The form of the guarantees varies between projects because the guarantees are designed to fit the requirements of particular clients, as well as federal and state legislation and regulations. Clients can also choose to be directly financed by banks or by a financing agency and then repay the loan themselves, most of those public sectors such as federal and MUSH market that can get better interest rates than the ESCOs. In that case, certain credit risks have been transferred to the ESCOs through the performance guarantee.

However, many deficiencies have still existed in the current guarantees setting. Most ESCOs guarantee the certain amount of energy savings that the project will deliver based on their historical experience without systematic estimation method. Due to the potential low-performance and loss risks, the ESCOs virtually never guarantee 100% of predicted savings and there is always a difference between the predicted and guaranteed savings amounts. Due to Oak Ridge National Laboratory research of 2007, there are only 12% of the projects that the reported annual cost savings that were equal to the guaranteed cost savings, suggesting that all of the savings in these projects were stipulated. On average, the ESCOs guarantee about 91% of the estimated cost savings and projects reports achieve about 99% of the predicted cost savings. In other words, the projects report 108% of their guaranteed cost savings in general and the average amount of the additional cost saving was 12% of the guaranteed cost savings (Shonder and Hughes, 2007).

Most of the time, clients award these "umbrella" contracts to the ESCOs based on their ability to meet the terms and conditions. From the clients' perspectives, an energy savings guarantee should be expected the higher the better. So, making conservative guarantees surely decreases the potential loss risks but at the same time also reduces the chances for the ESCOs to win the competitive bid. The objectively existed trade-off point for the ESCOs is hard to estimate and adjust, but it is critical and of great importance to pay further attention. Also, the contract clauses specifying how to share the exceeding verified profit between the ESCOs and the clients above the fixed-price guarantee are often blurred or ignored by both the ESCOs and clients in practice. Its potential risk adjusted function has not been taken consideration yet. Having a better understanding on the potential benefit sharing could not only give the clients a great reference on the optimal EPC bidder selection, future schedule and budget arrangements, but also helps the ESCOs reasonably allocate the estimated financial risks with successful contract negotiation.

1.3 Research Objectives

To supplement those deficiencies mentioned above, this thesis aims to explore methods that design more flexible and affordable revenue risk mitigation guarantees in EPC contracts. Goals of the thesis research contribute to:

1. Identifying the uncertainties of the framework and stochastic processes for the energy savings guarantee setting.

Framing the process within the context of a real-options paradigm based on the overall identification is the first step in conducting the guarantee design research. Here, we consider the predicted energy savings as the underlying asset in an option contract, taking into account that, when a nonfinancial asset is used, some adjustments have to be made to the options approach. The inner energy saving relations are among predicted, verified and guaranteed, which are all based on the corresponding ECMs that have been selected for adoption into the EPC contract before project implementation. Most of the time, there is a difference between the predicted and verified energy savings since the technologies performance and the energy price never stay constant, which keeps changing from time to time. The Geometric Brownian Motion is assumed as the stochastic process to represent the annual energy savings evolution in this thesis and the resulting stochastic energy saving model will have a probability distribution of values.

2. Explaining the causations for general energy consumption volatility and giving corresponding estimation.

Volatility is one of the most difficult input parameters to estimate in real options analysis. Real options analysis asks the volatility estimate to be yearly based. Also, considering the seasonal energy consumption differences and measurement convenience, annualized volatility is the ideal parameter we are looking for. Volatility causations for EPC energy savings mainly come from both the energy price change and the facility performance instability. There are a number of ways to model volatility changes. To simplify the model, we assume a constant volatility in our model design. Based on the Ito's Lemma, we decompose the general energy consumption volatility into recognized utility price and quantity volatility. Typically, the portfolio energy price volatility can be obtained through historical data. The Monte Carlo simulation is also conducted to generate the related performance data for guarantee design with certain subjective distribution and boundaries.

3. Exploring the inner relations between the guarantee and the exceeding profit sharing with sensitivity analysis.

Based on the stochastic process framed and the energy savings volatility identified, the amount of energy savings guarantee specified in the contract has very tight relations with the proportion of excess profit sharing that tradeoffs the guarantee with flexibility. The annual energy savings guaranteed by the ESCO as part of a performance contract may cover the energy savings risks partially or totally, which provides both the ESCOs and the clients the opportunity to participate in revenue risk coverage. In this setting, we assume the amount of potential excess energy savings traded off equals the fair price of the potential savings shortage risk coverage. By tracing back to the existing guarantee price, we can change it by a preset amount and see the effect on the resulting exceeding profit sharing proportion and finally draw the indifference curve to find out their inner correlations.

4. Assisting the ESCOs and the clients to develop effective risk mitigation methods and optimal guarantee strategies.

In this thesis, we develop a methodology to value these guarantee clauses of energy performance contracting and, for that purpose, broadens the value generation parameters by adding the exceeding profit sharing into consideration, which increases the flexibility at the same time that it decreases the uncertainty. This methodology is applied to those EPC cases that have already finished the feasibility analysis but without making the guarantee contract yet, which helps the ESCOs obtain more profit from the service and, at the same time, improve the satisfaction of clients so that loyalty is improved. The flexibility added in makes the contract more affordable, necessary to the good management and exploitation of the value from uncertainty and volatility.

1.4 Organization of Thesis

The study is structured according to the following sequential process that presents a novel valuation framework which supports developing optimal energy savings risk mitigation contracts with more flexibility as Figure 1 showing below.

1. Problem formation

Problem identification marks the first phase of the study which plays a critical role to recognize where improvements could be conducted for further analysis. Chapter 1, Introduction, introduces the energy efficiency background and identifies the significance for buildings' energy renovation. This kind of energy performance contracting (EPC) win-win mode helps the risk-avoided clients take charge of the large initial capital investment for the project construction and installation. However, the annual guaranteed energy savings specified in the contract, which helps cover the increasing energy price rate and the deficient energy performance risk, are usually under- or over-estimated. More flexible and applicable risk mitigation methodologies in the EPC guarantee contract are needed to motivate both the clients and the ESCOs' cooperation for projects success.

2. Literature review

Once the scope of the research is established, a thorough literature review is needed in order to understand what previous analysis has already been conducted and where further efforts are still needed. In this study, to have a thorough understanding of the popular general EPC process and to recognize the critical factors within the annual energy savings guarantee are what we would like to know through the literature review. Also we would like to learn the current development of the real option application which is the risk evaluation method we prefer to use in this study in order to help us make comparison and improvement on our model. Chapter 2, Literature Review, summarizes the existing research regarding the EPC state of practice such as its historical development, the project types, etc., with emphasis on the EPC financial risk allocation. Related option theories are also reviewed from the aspects of real option theory and its application.

3. Theoretical framework

After the literature review, we would like to identify the available tools to achieve the research objectives as the stochastic modeling with the EPC risk variables building in. Chapter 3, Energy Savings Guarantee Design, introduces the general schemes to model flexible EPC guarantee contracts using the real options theory. It also presents the new family of stochastic models of EPC risk variables characterized by both the objective historical datasets and the subjective simulation datasets. The Monte-Carlo simulation and real option pricing techniques have also been applied so that the saving revenue guarantees, which the ESCOs promised in the contract, takes the form of European options combined with the absent revenue make-up and the excess benefit sharing.

4. Case study

In order to demonstrate the applicability of the real option model we proposed, a theoretical exercise, which involves a real EPC case, is developed considering an environment of current volatility and analyzing the opportunities the real options theory may grant. In Chapter 4, Case Study Analysis, the case study of the EPC implemented between the clients (the University of Maryland, College Park) and the ESCO (Johnson Controls) is discussed with data collected from both the project record, the historical reports and the simulation. The optimal strategies of pricing energy savings guarantee and proportioning additional profit sharing for the improvement of project contract clauses signed by both UMCP and Johnson Controls are also developed.

5. Future Research Development

Finally, the summarized conclusions of this study have been reached, and the considerations and suggestions for future research have also discussed. Based on the previous quantitative analysis, we can conclude that the real options analysis may be a viable and preferable alternative if compared to traditional methodologies, when used in an uncertain environment, in association with contract design flexibility. Further, research could work on the accuracy of the energy savings estimation and the volatility modeling.

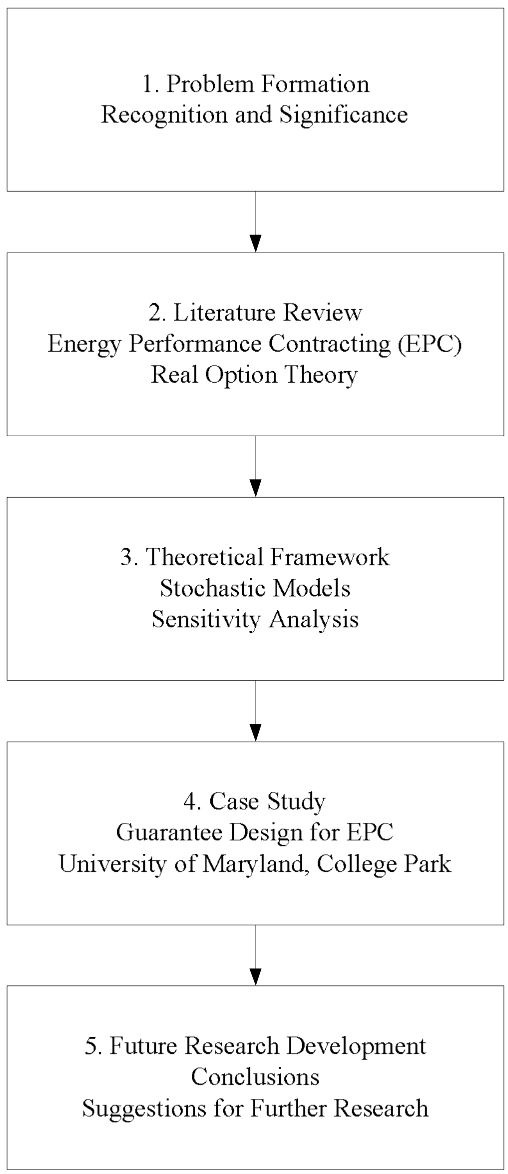

Figure 1. Logical Organization of the Thesis

Chapter 2: Literature Review

2.1 Introduction

This section will review the past and current literatures that mainly cover the following two research threads: the EPC statement of practice and the development of the option theory. For the EPC review part, there are few journal articles focused in this area and the scientific reports from the Lawrence Berkeley National Laboratory (LBNL) and the Oak Ridge National Laboratory (ORNL) are the main resources that we get the EPC background information from academic field. For the option theory review part, most articles are selected from the performance-based infrastructure area and similar guarantee clauses existing there. Reviewing what other scholars have found about EPC delivery method and option theory will help us to develop better models based on their findings.

Before making any comments about EPCs, we need to have a general understanding of what EPCs are used in practice according to the prior research. The first phase of the literature review is aimed to identify the conceptual and financial issues associated with the EPC guarantees, which centers on EPC development and financing risk allocations. Like any other new contract mode, there are several critical parameters associated with EPC such as the utility price rate, the installed facility performance, the operation and maintenance cost savings, etc., as a result of the lengthy life cycle of the project, complex contracting mechanisms, a complex pool of finances, and multiple entities with different interests in a project. The EPCs review part talks about the importance of EPCs and presents a brief overview of the development followed by different time periods. It also covers the market and industry information related to EPCs, and defines some parameters which are popularly used in this project mode. Finally, it summarizes the existing varied risk allocation methods and emphasizes the importance of specified energy savings guarantee.

In the other part, the option theory review embraces a comprehensive survey of past research on financial and real options theory with emphasis on the evaluation practice of guarantee specified in the project contract. Studying the uncertainty factors and stochastic process is essential for tracking the special characteristics, such as the long performing period associated with the EPCs. Introducing the different attempts to the application of real options theory is also very important for us in understanding the potential effect of the risks in such kind of guarantees that have been covered in the contract. Financial option analysis, real options analysis and the evaluation practice in the guarantee are the three main parts for the second phase of this section.

2.2 Energy Performance Contracting

Energy efficiency of the building sector plays a vital role in reducing energy consumption. According to the U.S. DOE (2009), building-related energy consumption accounts for about 40% of total energy consumption in the United States, which serves the most important proportion compared with the sectors of industry and transportation as Figure 2 shows below. To aid in the process of energy efficiency improvement, a large private-sector energy-efficiency service industry has developed over the last two decades and the most commonly used contracting method adopted by these companies is Energy Performance Contracting (EPC) (Osborn et al., 2002).

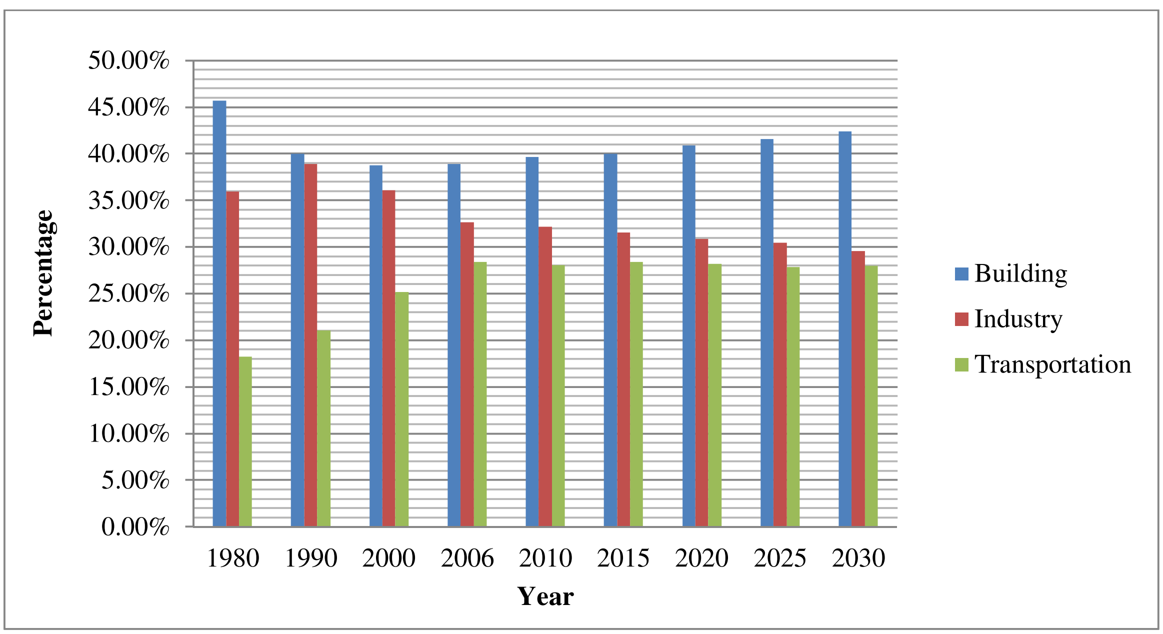

Figure 2. Sectors Proportions of U.S. Primary Energy Consumption

(Adapted from U.S. DOE 2009 Buildings Energy Data Book)

Facility owners and operators know that energy costs are significant, and that these costs could be reduced by investing in proven and cost effective energy-saving technologies, systems and procedures. Yet they face a formidable number of barriers before investing in energy conservation. Some lack technical knowledge; others lack adequate finances, or are unable to raise sufficient finances; while others have reservations about the ability of energy-saving equipment to perform as promised (AEPCA, 2000).

Energy Performance Contracting is a turnkey service that provides clients with a comprehensive set of energy efficiency, renewable energy and distributed generation measures and is often accompanied with guarantees that the savings produced by a project will be sufficient to finance the full cost of the project (ICF & NAESCO, 2007). New technologies implemented to reduce the energy consumption of a building are called energy conservation measures (ECMs), which include not only energy savings such as electricity, natural gas, fuel oil and water, but also O&M savings as well as other non-energy benefits, such as tariff changes resulting from fuel switching (Hopper et al., 2005). The Energy service companies (ESCOs) that provide the performance contracting services are seen as important vehicles around the world for promoting energy efficiency, especially in those countries experiencing increased competition and privatization in the electric utility business (Vine et al., 2003). Under a performance contract for energy saving, the ESCO examines a facility, evaluates the level of energy savings that could be achieved, and then offers to implement the project and guarantee those savings over an agreed term.

2.2.1 The EPC Process

According to the EPC guideline of the Australasian Energy Performance Contracting Association (AEPCA), the major steps towards implementing an EPC involve deciding whether or not to use energy performance contracting; determining whether there are energy saving opportunities worth pursuing and selecting a preferred supplier; developing and agreeing on the final scope of the project; and negotiating and awarding a contract as outlined in Figure 3.

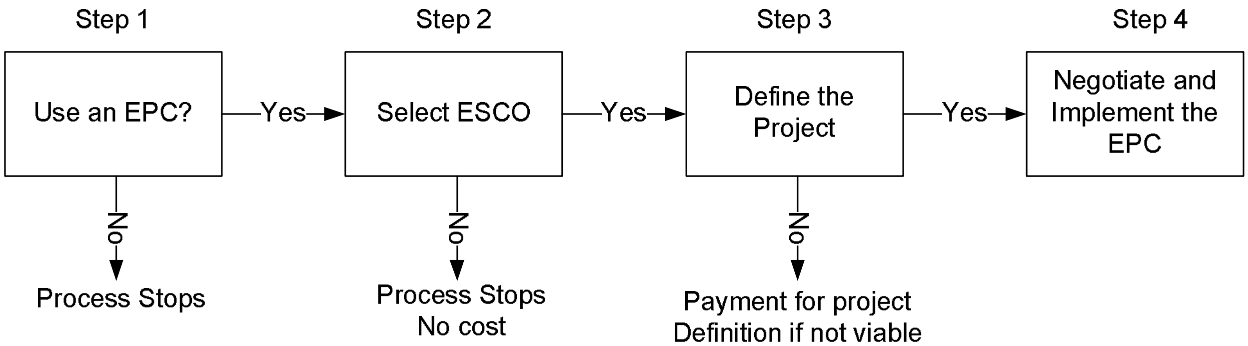

Figure 3. Flow Chart of Major Decision Steps towards an EPC

(Source: A Best Practice Guide to Energy Performance Contracts by AEPCA, 2000).

During the decision-making process, a public call for Expressions of Interest (EOI) is usually advertised in the local or national press. The EOI states the Client's interest in entering into an EPC, with general details about the project scope and a request for respondents to describe how they would approach the work. An EPC implies a long-term financial relationship between the client and the ESCO. The financial stability of the ESCO is, therefore, a major consideration in evaluating proposals. A Detailed Facility Study (DFS) has been developed by the selected ESCO for the project scope specification, as well as the financial criteria such as Internal Rate of Return (IRR), Net Present Value (NPV), and minimum energy cost savings (AEPCA, 2000). Some common issues that might be the subject of negotiation include funding, maintenance, energy savings guarantee, baseline adjustment, and measurement and verification (M&V).

2.2.2 State of the Practice

The investment level of the ESCO projects continues to expand both because of the ESCO production input cost increases and client demand for more comprehensive mixes of technologies (Satchwell et al., 2010). ICF and NAESCO (2007) pointed out that the increasing and volatile energy prices, federal and state energy savings mandates, the continued lack of capital and maintenance budgets for federal facilities, and growing awareness of the need for large-scale action to limit greenhouse gas emissions are all factors that drive the EPC growth in the last decades. Based on the LBNL survey results, the U.S. ESCO industry has grown rapidly over the last decades as summarized in Figure 3 with revenues increasing at a 24% annualized rate through 1990 to 2000 (Goldman et al., 2002), 20% per year between 2004 and 2006 (Hopper et al., 2007), 7% per year between 2006 and 2008, despite the onset of a severe economic recession and the average annual growth rate of 26% between 2009 and 2011 (Satchwell et al., 2010).

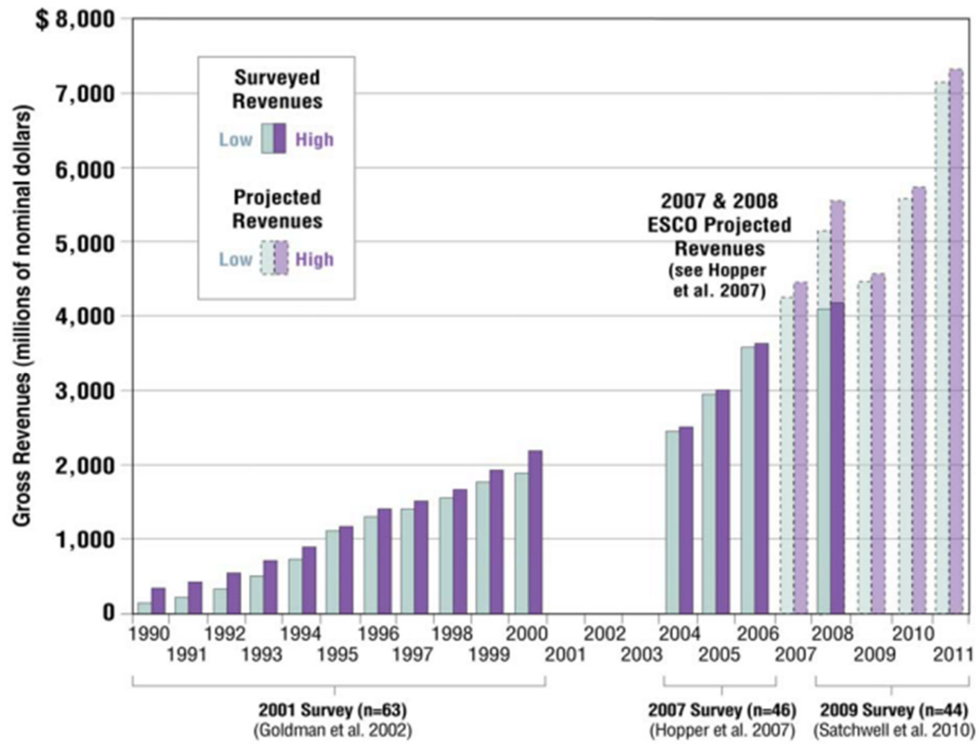

Figure 4. ESCO Industry Revenues Trends from 2007 to 2011

(Source: A Survey of the U.S. ESCO Industry: Market Growth and Development from 2008 to 2011 by Satchwell et al., 2010)

ICF and NAESCO (2007) divided the history of the performance contracting industry into four stages:

(1) The Beginning of DSM (Pre-1985). In the late 1970s and early 1980s, ESCOs were established to provide manpower and systems for enabling utilities to meet federal and state mandates and offer energy conservation services. Measurement and Verification (M&V) systems were also initially used to track the progress of first-generation utility DSM programs that tended to measure activities rather than outcomes.

(2) Emergence of EPC (1985-1993). Utility programs evolved from purchasing services (e.g., home energy audits) to acquiring large amounts of kW or kWh as part of their Integrated Resource Plans (IRPs) in the mid-1980s. ESCOs started to bid to provide the kW or kWh and delivered turnkey projects to large industrial and institutional clients and financed the projects themselves. At the same time, new types of M&V protocols were required to accurately measure the energy and demand savings produced by a project. ESCOs and clients struggled to develop replicable M&V systems for unfamiliar technologies, and often used "shared savings" contracts in which the ESCO was paid a share of project savings to mitigate perceived client risks.

(3) Success and Consolidation (1994-2002). Commercial lenders jumped into the business, and quickly drove down the cost of project financing through competition and the development of new financing vehicles, such as low-cost municipal leases with ESCO savings guarantees. The advent of the International Performance Measurement and Verification Protocol (IPMVP) as well as the body of project savings histories, enabled the performance contracting business to enter a fast-growth stage in the late 1990s and early 2000s. Successful project experience proved to clients that EPC projects involved little technological risk, and the development of the IPMVP gave institutional financiers a standard method for validating project savings.

(4) Pause and then Fast Growth (2003-Present). The collapse of Enron, the one-year sunset of the federal performance contracting program and the diminished prospects for the de-regulated retail energy business all combined to moderate ESCO growth from 2002 to 2004. The industry consolidated as many utilities folded up or sold their ESCOs. A new generation of M&V were also developed that validated new streams of EPC project value, such as operations and maintenance (O&M) savings, greenhouse gas reduction and electricity system capacity credits.

Particularly, several key parameters need to be paid attention to in the EPC. Within the certain amount of energy cost savings that ESCOs guaranteed to be delivered by their EPC services, 79.3% of the reported annual cost savings were due to reductions in utility bills and 20.7% were due to O&M or R&R savings with other economic benefits not directly tied to energy savings, such as capital cost avoidance or reductions in personnel costs. (Shonder and Hughes, 2007) The typical duration of energy performance contracts is 10 years with 20% of projects completed in shorter than 5 years and 10% of projects with contract terms of 15 years or greater. (Goldman et al., 2005) Hughes et al. (2003) have selected sixteen characteristics to define a typical Super ESPC project, a special EPC service for government agencies, as time to award delivery order and complete construction, implementation price and financed amount, interest rate and contract term, etc. Detailed information is shown in Table 1 that data have been collected from the Federal Energy Management Program (FEMP) database through 71 delivery orders by the end of 2001.

Table 1. Financial Parameters for the Average Super ESPC

1	Average time to DO award	15 months
2	Average design/construction period	12 months
3	Average implementation price	$3,263,000
4	Average financed amount	$2,990,000
5	Average per-performance-period payment	$509,000
6	Average financing procurement price	$236,000
7	Average project total annual interest rate	8.07%
8	Average delivery order term	206 months
9	Average first-year guaranteed cost savings	$354,000
10	Average escalation rate for guaranteed annual cost savings	1.87%
11	Average first-year M&V price	$13,300
12	Average escalation rate for annual M&V price	3.78%
13	Average first-year performance-period-services price, excluding M&V	$36,400
14	Average escalation rate for annual performance-period-services price, excluding M&V	3.95%
15	Average percentage of guaranteed cost savings paid to ESCO	98%
16	Average escalation rate for annual contractor payment	1.87%

(Source: Evaluation of Federal Energy Savings Performance Contracting: Methodology for Comparing Processes and Costs of ESPC and Appropriations-Funded Energy Projects by Hughes et al, 2003)

2.2.3 Market Segments and Industry Structure

Market activity continues to increase in both absolute and relative terms (Satchwell et al., 2010), though some industry observers believe the public/institutional market sectors may be approaching saturation, as first noted by Hopper et al. (2007). Considering EPC's growing success in the public sector and escalating energy consumption in the private building sector, the federal and state governments adopted EPC as the preferred method for producing energy efficiency improvements in large facilities. California and New York implemented standard performance contracting programs as the largest programs in their state energy efficiency program portfolios. (ICF & NAESCO, 2007)

A breakdown of ESCO industry revenues among various client market segments according to the LBNL/NAESCO's survey are represented in Figure 4 that compares U.S. ESCO industry revenues by various client market segments for 2006 and 2008. Since transaction costs in developing and implementing performance contracts are relatively high in the United States, the MUSH markets (municipal and state governments, universities and colleges, K-12 schools, and hospitals) have historically hosted the largest share of ESCO industry activity. (ICF and NAESCO, 2007) As a result, ESCOs continued to target the MUSH and the federal market in the United States, which accounted for 84% of ESCO revenues ($3.4 billion) in 2008 and was a slight increase from 2006 when 80% of ESCO revenues ($2.9 billion) were from projects in the public/institutional market sector. Commercial building and industrial projects were also active but have had more limited success in penetrating these markets, which comprised about 15% in 2006 and 7% in 2008, compared to the remainder of the residential and public housing projects. (ICF and NAESCO, 2007)

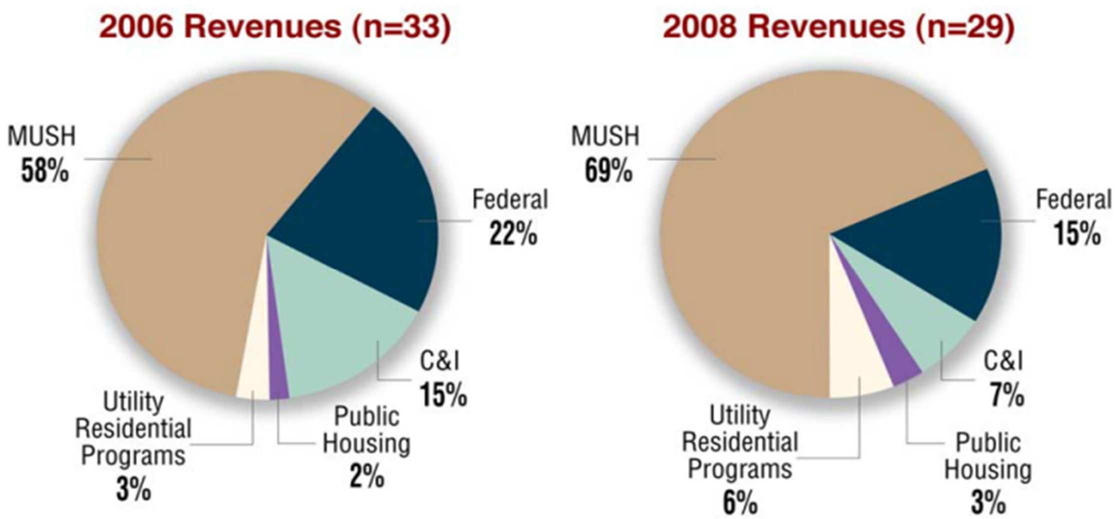

Figure 5. ESCO Industry Revenues by Market Segment in 2006 and 2008

(Source: A Survey of the U.S. ESCO Industry: Market Growth and Development from 2008 to 2011 by Satchwell et al., 2010)

State/local government projects are the most "typical" of all market segments since every performance indicator – costs, savings and economics – stays in the mid-range, compared to other public/institutional market segments. University/college campuses represent the largest facilities within the MUSH markets, and project investment per square foot is correspondingly low ($2.43/ft2 median). K-12 schools projects tend to have more challenging economics (the median payback time is 14.7 years) because they often leverage energy savings to pay for new energy and non-energy equipment. Hospital projects pay back the quickest (4.9 year median) and are cost-effective at more stringent evaluation criteria than other public/institutional market segments. (Hopper et al., 2005)

ESCO industry is also characterized by a diversity of companies and could be dissected to examine trends in the ownership. Four categories have been classified for the ESCOs composition as independent ESCOs, building equipment manufacturers, utility companies and other energy/engineering companies such as international oil/gas companies, non-regulated energy suppliers, or large engineering firms, etc. (ICF and NAESCO, 2007) Figure 5 shows the general trends in ESCO industry shares.

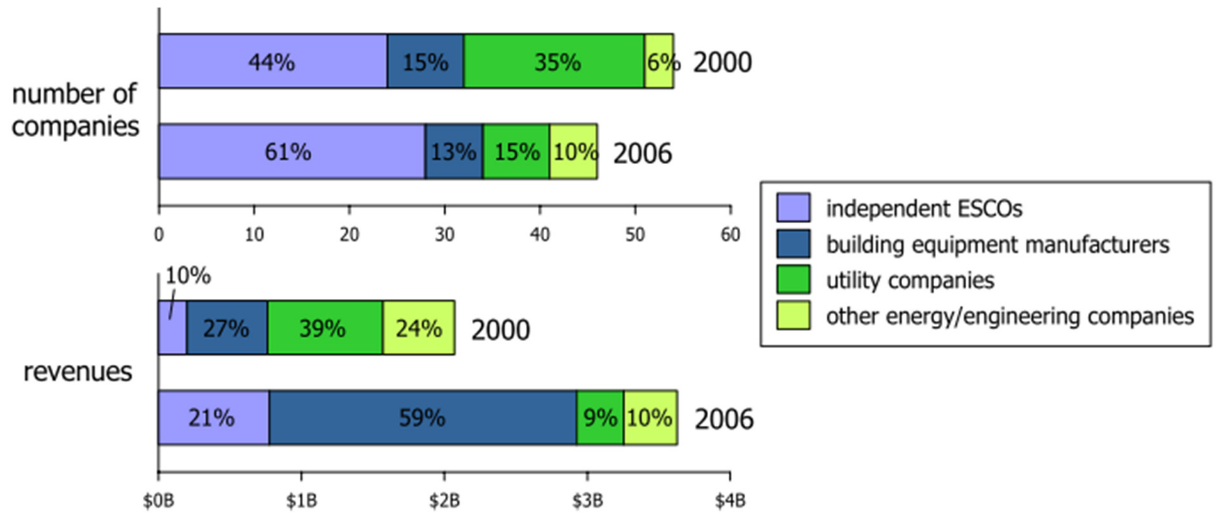

Figure 6. Trends in ESCO Industry Shares by Company Ownership

(Source: Introduction to Energy Performance Contracting by ICF & NAESCO, 2007)

Independent ESCOs are numerous but relatively small in that 61% of companies comprised only 21% of revenues in 2006. Building equipment and controls manufacturers have remained fairly constant in terms of number of companies from 15% in 2000 to 15% in 2006, but their share of industry revenues has increased substantially, from 27% in 2000 to 59% in 2006. The number of utility-owned ESCOs has declined from 35% in 2000 to only 15% in 2006 since they focus more on core regulated businesses or developing power generation, rather than retail energy services or power marketing. The share of companies owned by oil and gas companies, unregulated electric or gas suppliers, or large engineering companies has increased from 6% in 2000 to 9% in 2006. But, their revenue share has decreased substantially from 24% to 10% attributable to the Enron bankruptcy. (ICF and NAESCO, 2007)

2.2.4 Financial Risk Allocation

Energy Performance Contracting is results-driven ensuring quality of performance, which differs from traditional contracting, which is invariably price-driven. ESCOs search for efficiencies and performance reliability to deliver contractual guarantees. Shonder et al., (2006) have found that

EPCs have a lower life-cycle cost than the directly funded projects which take more than two years longer to complete and survey with a 6% greater project costs. But, EPCs are also perceived as more risky because they are often non-asset-based investments, especially for small or start-up ESCOs (Vine, 2005).

The ESCOs' competitive advantage hinges on the ability to develop complex projects and offer performance contracts, primarily "guaranteed savings" agreements, but they also engage in non-performance-based work, typically "design/build" contracts that cover the design and installation of equipment but not ongoing servicing or performance monitoring (Hopper et al., 2005). Figure 6 shows the general matrix for common types of ESCO contracts as follows.

"Shared savings" and "guaranteed savings" distinguish themselves based on the allocation of financing risks (Hopper et al., 2005). According to LBNL's study, the U.S. ESCO market has shifted away from "shared savings" to "guaranteed savings" over the last decade and 86% of the performance-based projects have specified guarantees in their contracts (Goldman et al., 2005). EPC projects are classified as ESCO-financed guaranteed savings contracts, of which 66% were classified as guaranteed savings, and 7% as shared savings or other types of performance agreement. The remaining 27% are non-performance-based, design/build contracts (Hopper et al. 2005), which decreases to 22% of reported 2008 industry revenues and 3% to ESCO consulting services (Satchwell et al., 2010).

		Financing Risk	
		ESCOs	Clients
Performance Risk	ESCOs (savings shared by ESCOs and clients)	shared savings	
	ESCOs (minimum savings guaranteed to clients)	ESCO-financed guaranteed savings	guaranteed savings
	Clients		design/build

Figure 7. Risk Allocation Matrix for Common ESCO Contracts

(Source: Public and Institutional Markets for ESCO Services: Comparing Programs, Practices and Performanceby by Hopper et al., 2005)

A typical guaranteed savings project would normally be structured as in Figure 8 below. There are separate agreements required between the client and the ESCO, and the client and the bank or financier. The relationship between the bank and the ESCO is usually indirect, and primarily for the benefit of the bank to assess the stream of the guaranteed savings. The term “bank” here is generic and intended to imply any financial institution providing capital funds for a project. (AEPCA, 2000)

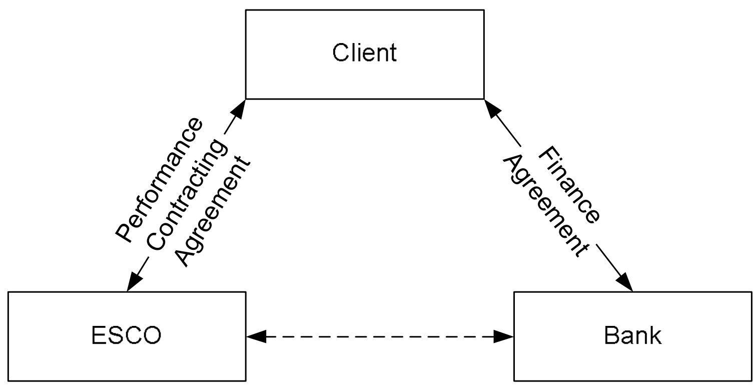

Figure 8. Relations between the Client, the ESCO and the Bank

(Source: A Best Practice Guide to Energy Performance Contracts by AEPCA, 2000)

Guaranteed savings contracts are preferred because of the greater certainty of savings, lower financing costs (most MUSH clients can obtain tax-exempt financing, whereas ESCOs cannot), and lower transaction costs (ESCOs can focus on project performance and need not assume financing risk) (Hopper et al. 2005). The risk of project under-performance is in the form of guarantee offered by the ESCO to the owner regarding the savings in energy cost for meeting or exceeding annual payment in order to cover all project costs (Vine et al. 1999). The value to clients of savings guarantees combined with long-term, reliable M&V lies in minimizing this risk by allocating responsibility for project performance to the ESCO and by identifying when savings shortfalls occur and savings guarantees should be exercised (Hopper et al. 2005).

Predicted energy savings are the ESCO's predicted estimate of annual savings prior to installation of the project, and guaranteed energy savings are the annual energy savings guaranteed by the ESCO as part of a performance contract. The verified energy savings mean actual energy savings from the project that are verified by the ESCO after installation and that are reported either on a yearly basis or as a calculated annual average of actual energy savings achieved (Goldman, 2002). Shonder and Hughes (2007) analyzed the most current M&V reports from all ongoing projects of ORNL database and concluded that aggregate verified savings is about 108% of aggregate guaranteed cost savings. Aggregate verified savings is about 99% of the predicted savings, and ESCOs are guaranteeing about 91% of the cost savings they predicted for a given period.

Hopper et al. (2005) had examined the difference between the predicted and verified energy savings. About 54% of projects had actual energy savings that exceeded predictions. Thirty-four percent experienced shortfalls relative to predicted savings (57% of these were shortfalls greater than 10%), and 12% of projects were 100% stipulated. Goldman (2002) had also conducted similar research and found in 63% of the cases that actual savings exceeded predicted savings. Thirteen percent of these projects stipulated savings for all installed measures (100% stipulated savings) and 59% of projects realized savings within 15% of ESCO predictions.

The ratio of guaranteed to predicted savings provides an indicator of how much performance risk the ESCO is willing to assume. Goldman (2002) found that the relationship between guaranteed and predicted savings is driven mainly by individual ESCO business practices rather than by retrofit strategy. Segmented by company, 7 of the 15 different ESCOs consistently guaranteed 100% of predicted savings. Six companies guaranteed between 50-100% of predicted savings and two companies actually guaranteed less than 50% of predicted savings. Among the eight ESCOs where guaranteed savings were less than predicted savings, no discernible pattern or formula (e.g., guaranteed savings are set at 80% of predicted savings) had been found, but rather the ratio of guaranteed to predicted savings tended to be project-specific.

Shonder and Hughes (2007) found the total reported cost savings was 110% of the total guaranteed cost savings from the ORNL Database. Cost savings shortfalls were reported in seven of the 88 non-stipulated projects, which ranged from 0.7% to 22% of the annual guaranteed savings, with the average amount being 6% of the annual guaranteed cost savings. The average amount of the additional cost saving was 12% of the guaranteed cost savings. Another research study was based on the projects in the NAESCO/LBNL database, 72% experienced greater savings than were guaranteed by the ESCO. Nineteen percent encountered savings shortfalls, of which 63% reported shortfalls greater than 10%. (Hopper et al. 2005)

2.3 Real Options Theory

Real options theory is a modern approach for economic valuation of projects under uncertainty. It focuses on the managerial flexibility value to optimally respond of a changing scenario characterized by uncertainty.

The long history of the theory of option pricing began in 1900 when the French mathematician Louis Bachelier deduced an option pricing formula based on the assumption that stock prices follow a Brownian motion with zero drift. Since that time, numerous researchers have contributed to the theory. Black and Scholes (1973) viewed most corporate liabilities such as common stock, corporate bonds and warrants as combinations of options and derived a theoretical valuation formula for them. In particular, the formula can be used to derive the discount that should be applied to a corporate bond because of the possibility of default. Merton (1973) examined and extended the seminal Black-Scholes theory of option pricing when dividends are paid on the underlying common stock and when the terms of the option contract can be changed explicitly by a change in exercise price or implicitly by a shift in the investment or capital structure policy of the firm. The effects of dividends and call provisions on the warrant price were also examined.

Option theory embraces two principal research fields: financial option theory and real options theory. The former refers to option theory applied to assets traded in a financial market, while the latter concerns option theory applied to non-financial assets or real assets. The similarity between real and financial decision-making has been recognized for at least two decades, when researchers such as Tourinho (1979) who pioneered to apply real options theory in studies on natural reserves, Brennan and Schwartz (1985) who discussed the option to stop operations and abandon a mine by considering commodity spot and future prices, McDonald and Siegel (1986) who motivated the use of the firm's opportunity cost of capital as the discount rate by assuming that projects are held by publicly owned corporations and Paddock et al. (1988) who used options theory to value the timing of an offshore leasing and development investment, extended the financial-option theories of Black and Scholes and Merton to encompass irreversible real investment such as investment in mining.

In finance, the option is a derivative financial instrument that establishes a contract between two parties concerning the buying or selling of an asset at a reference price. The buyer of the option gains the right without the obligation to engage in some specific transaction on the asset, while the seller incurs the obligation to fulfill the transaction if so requested by the buyer. The price of an option derives from the difference between the reference price and the value of the underlying asset, commonly a stock, a bond, a currency or a futures contract, plus a premium based on the time remaining until the expiration of the option.

As a discipline, real options extend from its application in corporate finance, to decision-making under uncertainty in general, adapting the techniques developed for financial options to real-life decisions. For example, R&D managers can use the real options method to help them determine where to best invest their money in research.

Table 2. Comparison between Real Options “on” and “in” Projects

Real options "on" projects	**Real options "in" projects**
Value opportunities	Design flexibility
Valuation important	Decision important (go or no go)
Relatively easy to define	Difficult to define
Interdependency/Path-dependency less an issue	Interdependency/Path-dependency an important issue

(Source: Real Options “in” Projects by Wang & de Neufville, 2005)

It thus forces decision-makers to be explicit about the assumptions underlying their projections, and for this reason, the real options method is increasingly employed as a tool in business strategy formulation. Real options can be categorized as those that are either “on” or “in” projects (de Neufville, 2002). Wang and de Neufville (2005) clarified the different nature of real options as Table 2 showing above. Real options “on” projects refer to the valuation of investment opportunities, while real options “in” projects are mostly concerned with design of flexibility.

2.3.1 Real Options for Valuation

Real options for valuation refer to the valuation of investment opportunities that are mostly concerned with an accurate value to assist sound investment decisions. For real options “on” projects, analysts need to get the value of options, which could be deemed as financial options taken on technical things, treating technology itself as a “black box” (Wang and de Neufville, 2005). Myers (1977) first proposed the "real options" concept and compared the similarities between the financial options and real options. It referred to the application of option pricing theory to the valuation of non-financial or real investments with learning and flexibility, such as multi-stage R&D, modular manufacturing plant expansion and the like. Ross (1978) considered the inherent potential investment opportunity of risky projects as real options, and then discussed the theory of real option valuation. In an asset market where there are no unexploited arbitrage opportunities, there will exist a linear valuation operator that can unambiguously price return streams with perfect market substitutes or bound values for streams bounded by market combinations.

Over the years, the real options theory has been significantly expanded. Borison (2003) recognized five major analytical approaches for applying real options to help corporate investment decisions as the classic approach, the subjective approach, the Market Asset Disclaimer (MAD) approach, the revised classic approach and the integrated approach. It concludes with observations about the relative strengths and weaknesses of the proposed approaches and specific recommendations on which ones to use in certain circumstances. Jaillet et al. (2004) extracted market information from forward prices and volatilities and build a pricing framework for swing options based on a one-factor mean-reverting stochastic process for energy prices that explicitly incorporates seasonal effects. A numerical scheme for the valuation of swing options calibrated for the case of natural gas has also been presented.

Since the construction cost is not fixed and the cost uncertainty may affect the investment value, Yiu and Tam (2006) proposed a real options model using the binomial lattice method and analyzed a real-life construction project tender to examine how management flexibility and uncertainty provide real options value. The under-priced portion is the options value that the bidder is willing to pay for the flexibility and the uncertainty that enables contractors to be more competitive and in construction costs estimation. de Moraes Marreco and Carpio (2006) presented a valuation study of operational flexibility in the complex Brazilian Power System. They adopted a real options approach to calculate the fair value of a financial subsidy to be paid to the thermal generators for their availability to the system. Cui et al., (2008) presented an analysis of the effectiveness of the warranty clauses in the New Mexico State Highway and Transportation Department Route 44 project, which is the first long-term highway warranty project in the United States. Using the real options approach, it finds that the warranty ceiling clause can be evaluated and the ceiling on expenditure can be valuable.

2.3.2 Real Options for Designing

Real options for designing are options created by changing the actual design of the technical system, which are mostly concerned with the design of flexibility. It is mostly concerned with "go" or "no go" decisions and an accurate value is less important. For real options "in" projects, analysts do not have to provide the exact value of the options but simply provide what real flexibility to design into the physical systems (Wang and de Neufville, 2005). Ford et al., (2002) presented a real options approach for proactively using strategic flexibility to recognize and capture project values hidden in dynamic uncertainties. They applied the proposed method of valuing managerial flexibility as well as to evaluate and select strategic planning for a toll road project proposal. Potential impacts of the use of real options are discussed and challenges in valuing real options in construction projects are identified.

Several authors have investigated the use of real options analysis in infrastructure problems, which helped to promote the feasibility estimation efficiency at the first beginning. Ho and Liu (2002) presented an option pricing based model, the BOT (Build-Operate-Transfer) option valuation model, for evaluating the financial viability of a privatized infrastructure project. The quantitative model not only considers the project characteristics explicitly and evaluates the project from the perspectives of the project promoter and of the government when the project is under bankruptcy risk, but also evaluates the impact of the government guarantee and the developer negotiation option on the project financial viability. Zhao and Tseng (2003) presented the use of an option pricing model for assessing design flexibility in infrastructure projects. The foundation of a parking garage can be enhanced to take into account a future expansion due to an increased service demand. Enhancing the foundation and columns represents an up-front cost, but it has a return in flexibility for future expansion. The proposed real options model is used to assess the expansion option relative to the construction of a public parking garage with the optimal foundation size determined. Valuation modeling such as discounted cash flow analysis with uncertainty modeling is important to capitalize on the worth of flexibility. Zhao et al., (2004) presented a multi-stage stochastic model for decision-making in highway development, operation, expansion, and rehabilitation. The proposed real options model accounts for the evolution of three uncertainties such as traffic demand, land price, and highway deterioration, as well as their interdependency, which achieves decision-making optimality that is generally not well defined in traditional policy-based approaches for highway planning.

Considering those flexibilities at the very start of the financing estimation shall help the implementation of a satisfactory infrastructure project. Garvin and Cheah (2004) applied real options valuation on a model of the Dulles Greenway, a BOT toll road in Virginia, U.S., to incorporate the option of waiting to build the highway limited to five years. The presentation illustrates that the selection of a valuation model depends critically upon the characteristics of a project's variables and that informed judgment remains an integral part of the decision-making process. Bowe and Lee (2004) analyzed the Taiwan High-Speed Rail project, the construction and operation of the rail system embodying multiple interacting flexibilities, involving the option to defer or postpone construction, the option to abandon early in the construction phase, the options to expand or to contract and the option to abandon or switch use at any time. The value of these options is shown, which greatly reduces the risk of the project. Based on data available in practice, de Neufville et al., (2006) presented a spreadsheet approach for valuing flexibility in engineering systems, which uses standard procedures and provides graphics that explain the results intuitively. The expansion option for a multistory parking garage is also employed as the practical application of the proposed approach.

2.3.3 Practice in Guarantee Valuation

Guarantees and subsidies have been valued by many authors and non-standard real options have also been considered as popular tools to measure the uncertainty behind. The topic attracted moderate interest and a number of articles were published on theory and applications. Pollio (1998) explored the preference for and the features unique to project finance, one of the favored vehicles for funding energy development. According to Pollio, an additional benefit of the proposed guarantee is to minimize an implicit abandonment option. In high leveraged projects involving project finance structures, the concessionaire could decide to pay the debt service or to abandon the project in each period. Huang & Chou (2006) valued a minimum revenue guarantee, an option to abandon during the construction phase and the interaction among them in BOT infrastructure projects using an analytical method. The Taiwan High-Speed Rail Project is chosen as a numerical case to apply the formulas and the results show both the minimum revenue guarantee and the option to abandon can create values. Cheah & Liu (2006) analyzed the minimum revenue guarantee in the case of the Malaysia-Singapore Second Crossing, which shows the value of a guarantee can indeed be significant relative to the basic net present value. Relevant elements of a contractual package are treated as a form of real options and a proposition is put forward to incorporate the value of such options into the negotiation framework.

In privately financed infrastructure projects host governments usually provide financial support by means of guarantees. Irwin (2003) mentioned that when the guarantees have been specified in the contract, though the governments indeed do not incur immediate cash cost, they must assume contingent liabilities. That report sets out a framework intended to help governments make good decisions about the provision of fiscal support for private infrastructure services and provides some tools to facilitate the analysis. Irwin (2007) explained a World Bank study on how governments value the guarantees they are thinking of granting and how they can modify aspects of public sector management to improve the likely quality of their decisions about guarantees. Making better decisions about guarantees and subsidies helps governments respond to such requests and make precise the invoked principle that risks should be allocated to those best placed to manage them.

Some empirical studies about revenue guarantee in infrastructure projects have also adopted real options analysis techniques for their valuation. Chiara et al. (2007) proposed a new approach for revenue guarantees improving risk mitigation and facilitating contractual and financial negotiations in BOT projects, considering that the exercise dates are determined during the operational phase. The multi-least-squares Monte Carlo technique is presented to determine the fair value of this variety of real options. Alonso-Conde et al., (2007) analyzed the Melbourne CityLink Project, a toll road in Australia and consider option to abandon the operation when the revenue shortfall is below a specified maximum loss threshold or when the investor's DCF rate of return becomes smaller than a certain agreed value. Two agreements can be identified as interacting options embedded in the project. One is that the government has the right to terminate the project before the end of the concession term if investor's IRR is greater than a certain agreed value. The other is the option that the investors have to defer the payment of the concession fee to the government under certain conditions. Doan & Patel (2010) modeled the BOT toll road investment with cost and revenue uncertainties in the presence of government guarantees as a portfolio of real options with cost contingency and government subsidy at the operation stage. They demonstrated that the investment value is highly sensitive to cost and revenue uncertainties and a numerical example suggested that the investment value of risky project is higher when net income guarantee is used instead of minimum revenue guarantee.

2.4 Literature Review Discussion

This section covers the past and current literature, which follows two research threads of EPC statement in practice and the development of option theory. Based on the literature review, we learned the critical role that the EPC has played in the energy efficiency progress acceleration, also their current market segments and the industry structure information. Not only improving facilities to be more comfortable and reliable, EPC is a kind of win-win service for both the clients and ESCOs to achieve the energy reduction and environmental goals. There are several critical parameters associated with EPC such as the utility price rate, the installed facility performance, the operation and maintenance cost savings, etc., as a result of the lengthy life cycle of the project, complex contracting mechanisms and a complex pool of finances. Also, we know the development of real options theory from the financial options and its current application. In finance, the option is a derivative financial instrument that establishes a contract between two parties concerning the buying or selling of an asset at a reference price. As a discipline, real options extend from its application in corporate finance, to decision-making under uncertainty in general, adapting the techniques developed for financial options to real-life decisions. Real options for valuation refer to the valuation of investment opportunities, while real options for designing are mostly concerned with the design of flexibility. In this study, most articles in the option theory review part are selected from the infrastructure area. The guarantee clauses and subsidies specified in the project contract are valuable and can be evaluated, which helps to decide the amount of risk contingency for reserving.

After reviewing all the market and industry information on the EPC model, we can conclude that there is enough necessity and significance to develop such a stochastic model and conduct sensitivity analysis on the specified energy savings guarantee. Since it could not only give the clients a great reference on the optimal EPC bidder selection and future budget arrangements, but also helps ESCOs reasonably allocate the estimated financial risks with successful contract negotiation. Reviewing the literature of the real options theory helps us make sure the feasibility of identifying the uncertainties of the framework and stochastic processes for the energy savings guarantee setting. Explaining the causations for general energy consumption volatility and giving corresponding estimation is another goal in this study, which explores the inner relations between the guarantee and the exceeding profit sharing with sensitivity analysis.

Chapter 3: Valuation of the Energy Savings Guarantee

3.1 Introduction

The scheme where an ESCO promises a certain level of annual energy savings that shields the client from the performance risks is known as guaranteed energy savings. Most ESCOs guarantee the certain amount of energy savings that the project will deliver based on their historical experience. When requesting proposals the client also request information that demonstrates the financial condition of the ESCO and its ability to support the performance guarantees.

Due to the potential low-performance and loss risks, ESCOs virtually never guarantee a hundred percent of predicted savings and there is always a difference between the predicted and guaranteed savings amounts. Based on the ORNL research of 2007, there are only 12% of the projects where the reported annual cost savings were equal to the guaranteed cost savings, suggesting that all of the savings in these projects were stipulated. On average, ESCOs guarantee about 91% of the estimated cost savings and projects report they achieve about 99% of the predicted cost savings. In other words, the projects report 108% of their guaranteed cost savings in general and the average amount of the additional cost saving was 12% of the guaranteed cost savings (Shonder and Hughes, 2007).

The measurement and verification process that compares the verified energy savings with the guarantee has been conducted year by year. However, the certain amount of guarantee had already been specified in the contract at the very beginning of the project and would not be changed barring any unforeseen circumstance. Thus, both ESCOs and clients consider the savings revenue risk an important factor when they assess an energy performance project's feasibility due to the volatile energy prices and high technical instability. Inner relations among the predicted energy savings, guaranteed energy savings and the verified energy savings have been displayed in Figure 9.

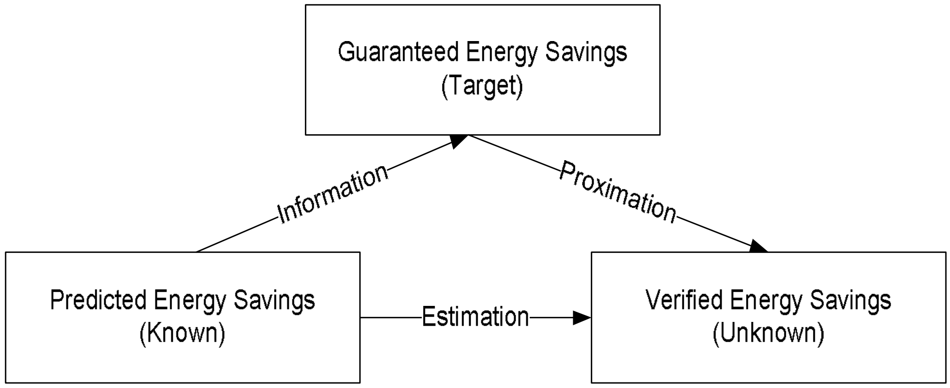

Figure 9. Relations among the Predicted, Guaranteed and Verified Energy Savings

Predicted annual energy savings could be varied for different years and multiple stochastic processes could be considered for the whole operation and maintenance period, one for each year. The valuation of the annual guarantees can be modeled as a series of independent European options with maturities between the first and the delivery years. For each year, the value to clients of ongoing M&V in a guaranteed savings contract lies in identifying when savings shortfalls occur and savings guarantees should be exercised. To design an energy cost savings guarantee, two pieces of specific information need to be delivered in the contract: the guaranteed energy savings amount and the split proportions if savings are over-achieved. Since the form of the guarantees varies between projects that are designed to fit the requirements of particular clients, as well as federal and state regulations, typically, if there is a shortfall in savings, the ESCO reimburses the client, and if savings exceed the ESCO's guarantee, the client keeps the excess or splits the over-performance part at a certain proportion with ESCOs. For instance, on Honeywell's website, savings guarantee has been explained as "if the new energy systems fail to reduce costs as required, Honeywell makes up the difference. Any savings above the guarantee are the client's to keep." Danfoss has also said "if we promise to save you 1 million EUR in an energy performance project and only manage to save you 800,000 EUR, we pay you the 200,000 EUR difference. If we find more, we split the over-performance, usually 50-50."

Clients award these energy performance contracts to ESCOs based on their ability to meet the terms and conditions. From the clients' perspectives, an energy savings guarantee should be expected to be the higher, the better. From the ESCOs' view, making conservative guarantees surely decreases the potential loss risks but at the same time reduces the chances for ESCOs to win the competitive bid. The trade-off point for ESCOs is critical and the contract specifying how to share the exceeding verified profit between ESCOs and clients above the fixed-price guarantee are of great importance for paying further attention. Having a better understanding on the potential benefit sharing could not only give the clients a great reference on the optimal EPC bidder selection, future schedule and budget arrangements, but also helps ESCOs reasonably allocate the estimated financial risks with successful contract negotiation.

3.2 Energy Savings Guarantee

In financial options, the volatility of stock price is a function of the uncertainty for the stock price movements, because the flexibility is built into the financial instrument. When applying the financial options theory for the purposes of project valuation, an estimation of volatility is required. In the EPC case, the volatility of expected energy savings revenue is a combination function of the energy price fluctuation and the facility performance instability. Year is a good unit for volatility analysis since it minimizes the shifting seasonal inference. It is also more convenient to get the estimated and verified performance records. In the EPC model, multiple stochastic processes need to be considered because the whole O&M period usually lasts more than ten years. There is a time series of annual predicted energy savings from the project financial estimation that needs to be compared with the verified energy savings each year through M&V process. Upon the analogic features between the levers of real option and the financial option value, we build the energy savings guarantee option model for a specific year as the mapping between the project characteristics and financial option value drivers depicted in the following Table 3.

For a specific year, the energy savings guarantee could be deemed as the exercise price (X), since it has been fixed at the beginning of the project lifecycle, which gives a cut-off point whether the energy savings guarantee need to be executed. Similarly, the actual energy cost savings is analogous to the stock price (S), which is affected by many potential risk factors and has both the possibility to go up or down during a specific time period compared with the predicted energy savings at the first beginning. The time to measurement and verification could be compared with the time of maturity in a financial option (t). It is the period of time, expressed in years, from the beginning of the project to the specific year when measurement and verification has been conducted and the verified energy savings have been recorded. The risk-free rate (r_f) and the volatility of expected cost savings (σ) also have the similar features as in the financial market when applied to a real options situation.

Table 3 Mapping between the Financial Option Drivers and Savings Guarantee

Financial option value levers	**Variable**	**Real option value levers**
Exercise price	X	Energy savings guarantee
Stock price	S	Verified energy cost savings
Time to expiry	t	Time to M&V
Risk-free interest rate	r_f	Risk-free interest rate
Uncertainty of stock price movements	σ	Volatility of expected cost savings

In most EPC cases, ESCOs secure a minimum amount of energy-saving revenue and the guarantee for the savings that is produced by the project will be sufficient to cover the cost of financing for the whole lifecycle of the project. Figure 10 below illustrates the estimated cost composition of the energy savings guarantee during the whole project life cycle. The verified annual cost savings have not been reached yet in the graph, and the guaranteed energy savings part have not taken the potential volatile energy price rates or the ECMs' technical performance instability into consideration.

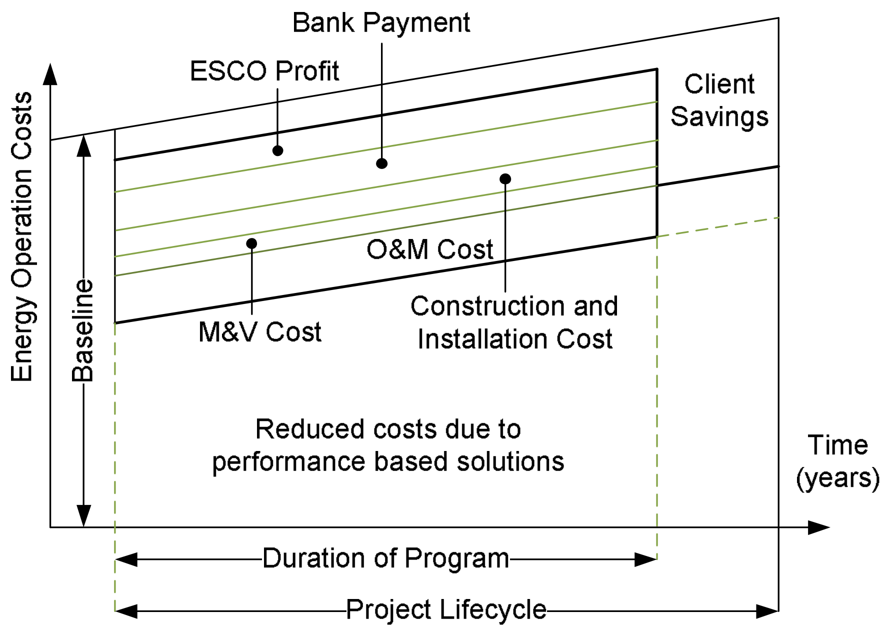

Figure 10. Composition of the Energy Savings Guarantee

Typically, there are two common kinds of guarantees in EPC according to the different situations: one is to guarantee the yearly energy savings quantity (G_{Qt}) that has been broken down by the categorized ECMs (G_{Qtj}) where the footnote t stands for a specific year and j represents a utility category; the other is to guarantee a monetary based amount of annual energy savings (G_t) for the entire project. Associated with the destination that the energy savings guarantee goes to each year, the following formula could be reached as Equation (1) and Equation (2) showing below. Here, all the savings and costs are financial-based in order to illustrate the inner relations with a consistent unit and make comparison. For the t^{th} year, the categorized energy unit price rate (P_{Etj}) and the guaranteed O&M cost savings (G_{CMt}) are also considered. Both the energy quantity savings guarantee ($\sum_{j=1}^{n}(P_{Etj} * G_{Qtj}) + G_{CMt}$) or the guaranteed energy savings (G_t) could be decomposed by the client savings profit within the guarantee ($Profit_{Ct}$), the bank loan payment (C_{Ft}), the operation & maintenance cost for the new facility installed (C'_{Mt}), the measurement & verification cost (C_{Vt}), and the ESCOs' profit within guarantee ($Profit_{Et}$). Within our EPC context, the measurement & verification cost (C_{Vt}) is a controllable small amount of expenditure and takes very similar charges each year for the M&V procedure without huge uncertainties existed here. Therefore it is usually deemed as constant.

$$\sum_{j=1}^{n}(P_{Etj} * G_{Qtj}) + G_{CMt} = Profit_{Ct} + C_{Ft} + C'_{Mt} + C_{Vt} + Profit_{Et} \tag{1}$$

$$G_t = Profit_{Ct} + C_{Ft} + C'_{Mt} + C_{Vt} + Profit_{Et} \tag{2}$$

Here we sum the bank loan payment (C_{Ft}), the operation & maintenance cost for the new facility installed (C'_{Mt}) and the measurement & verification cost (C_{Vt}) as a constant cost (C_t) for the following discussion.

$$C_t = C_{Ft} + C'_{Mt} + C_{Vt} \tag{3}$$

$$\sum_{j=1}^{n}(P_{Etj} * G_{Qtj}) + G_{CMt} = Profit_{Ct} + C_t + Profit_{Et} \tag{4}$$

$$G_t = Profit_{Ct} + C_t + Profit_{Et} \tag{5}$$

3.2.1 Energy Quantity Savings Guarantee

One of the EPC guarantees that have been widely adopted on a yearly basis is the annual energy quantity savings guarantee, which is usually broken down by ECMs categories. This contract option model has just taken the facility technical instability risk factor into consideration and paid more attention to the verified energy savings quantity than the measurement and verification cost mentioned before. This tool is useful for the ESCOs to focus more on the reliable quality work they are going to deliver, and at the same time, eliminate the potential energy price volatility risks that they have no power to control. For the operation and maintenance cost savings, usually they are also deemed as one kind of ECM savings quantity into the contract and therefore could be valued appropriately. Taking the risk factors of the energy savings guarantee into consideration, the verified energy savings volume (Q_t) are used to compare with the guaranteed energy quantity savings (G_{Qt}) in order to calculate the clients total savings profit ($Profit'_{Ct}$) and the ESCOs total profit ($Profit'_{Et}$) under uncertainty. P_{Et} represents the portfolio energy unit price at the t^{th} year.

From the Clients' perspective, in the simplified yearly energy quantity savings guarantee, the payoff of the energy savings guarantee on a specific year will be represented as follows: the guaranteed energy savings quantity (G_{Qt}) is non-monetary based and different from the guaranteed energy savings (G_t) mentioned before. The portfolio energy unit price at the t^{th} year (P_{Et}) is the spot price of time t.

$$\text{If } Q_t < G_{Qt}, \quad Extra\ Profit_{Ct} = 0 \tag{6}$$

$$\text{If } Q_t \geq G_{Qt}, \quad Extra\ Profit_{Ct} = (Q_t - G_{Qt}) * P_{Et} * \alpha_1 \tag{7}$$

Combining them together, formula for the client's extra profit ($Extra\ Profit_{Ct}$) with guaranteed quantity savings could be presented as Equation (8) showing below.

$$Extra\ Profit_{Ct} = \max[0, (Q_t - G_{Qt}) * P_{Et} * \alpha_1] \tag{8}$$

Considering the percentage of clients' savings revenue sharing within the guaranteed energy savings (α_0), the client savings profit within the guarantee ($Profit_{Ct}$) could be reached as Equation (9) showing below.

$$Profit_{Ct} = P_{Et} * G_{Qt} * \alpha_0 \tag{9}$$

There are both possibilities that the guarantee may or may not be executed. If the verified energy savings (Q_t) do not reach the guaranteed amount (G_{Qt}), clients could get the specified proportion of benefit from the guarantee. Even so, if the verified energy savings (Q_t) exceed the guarantee (G_{Qt}), clients could get the profit from both the proportion of guarantee and the exceeding sharing. To be more specific, the profit for the t^{th} year should be presented as Equation (10) and

(11). Another important parameter, the percentage of clients' extra profit sharing beyond the guarantee (α_1), has also been considered.

$$\text{If } Q_t < G_{Qt}, \quad Profit'_{Ct} = Profit_{Ct} = P_{Et} * G_{Qt} * \alpha_0 \tag{10}$$

$$\begin{aligned} \text{If } Q_t \geq G_{Qt}, \quad Profit'_{Ct} &= Profit_{Ct} + (Q_t - G_{Qt}) * P_{Et} * \alpha_1 \\ &= P_{Et} * G_{Qt} * \alpha_0 + (Q_t - G_{Qt}) * P_{Et} * \alpha_1 \end{aligned} \tag{11}$$

Combining them together, formula for the client's extra profit (*Extra Profit*$_{Ct}$) with guaranteed quantity savings could be presented as Equation (12) showing below.

$$Profit'_{Ct} = \max[P_{Et} * G_{Qt} * \alpha_0,\ P_{Et} * G_{Qt} * \alpha_0 + (Q_t - G_{Qt}) * P_{Et} * \alpha_1] \tag{12}$$

Based on Equations (10) and (11), the client's extra profit ($Profit'_{Ct}$) graph could be drawn as follows, which looks like a European call option with the underlying assets of the verified energy savings on the t^{th} year (Q_t).

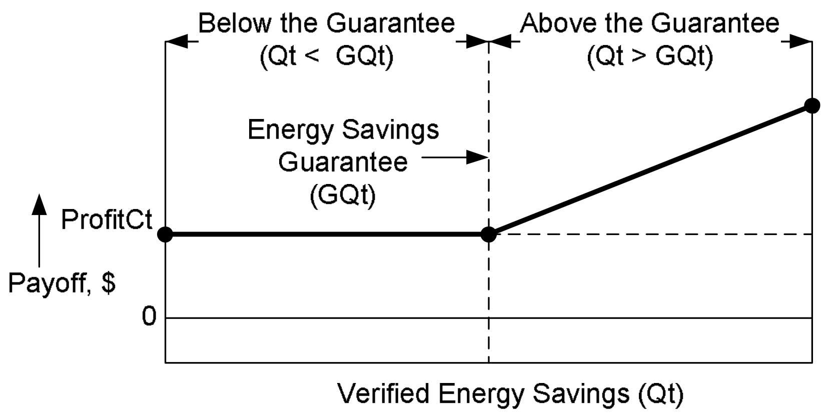

Figure 11. The Clients' Profit on the Energy Quantity Savings Guarantee

Similarly, the extra profit of the guarantee from the ESCO's perspective for the t^{th} year should be presented as Equations (13) and (14) below.

If $Q_t < G_{Qt}$, $\quad Extra\ Profit_{Et} = (Q_t - G_{Qt}) * P_{Et}$ (13)

If $Q_t \geq G_{Qt}$, $\quad Extra\ Profit_{Et} = (Q_t - G_{Qt}) * P_{Et} * (1-\alpha_1)$ (14)

Combining them together, formula for the client's extra profit ($Extra\ Profit_{Ct}$) with guaranteed quantity savings could be presented as Equation (15) showing below.

$$Extra\ Profit_{Et} = \min[(Q_t - G_{Qt}) * P_{Et}, (Q_t - G_{Qt}) * P_{Et} * (1-\alpha_1)] \quad (15)$$

If the verified energy savings (Q_t) do not reach the guaranteed amount (G_{Qt}), ESCOs need to make up the deficiency. Meanwhile, if the verified energy savings amount (Q_t) exceeds the guarantee (G_{Qt}), ESCOs could not only get the specified profit from the guarantee, but also the proportion of the exceeding sharing.

If $Q_t < G_{Qt}$, $\quad Profit'_{Et} = Profit_{Et} + (Q_t - G_{Qt}) * P_{Et}$ (16)

If $Q_t \geq G_{Qt}$, $\quad Profit'_{Et} = Profit_{Et} + (Q_t - G_{Qt}) * P_{Et} * (1-\alpha_1)$ (17)

Combining Equations (16) and (17) together, formula for the client's extra profit ($Extra\ Profit_{Ct}$) with guaranteed quantity savings could be presented as Equation (18) showing below.

$$Profit'_{Et} = \min[Profit_{Et} + (Q_t - G_{Qt}) * P_{Et}, Profit_{Et} + (Q_t - G_{Qt}) * P_{Et} * (1-\alpha_1)] \quad (18)$$

According to Equation (16) and Equation (17), the option graph could be described as the following Figure 12, which has a different graph shape from Figure 11 above.

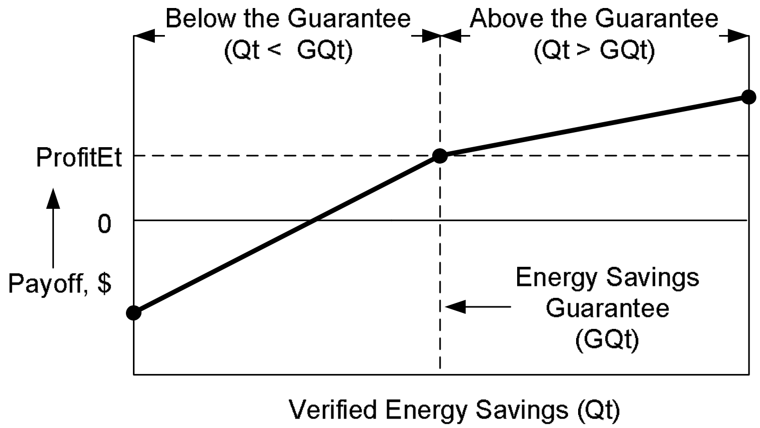

Figure 12. The ESCOs' Profit on the Energy Quantity Savings Guarantee

No matter what final verified energy quantity savings (Q_t) has been reached, the sum of the total profit for both the clients and the ESCOs stays the same, which equals to ($P_{Et}*G_{Qt}*(\alpha_0-1) + Profit_{Et} + P_{Et}*Q_t$). It means that this kind of guarantee in the contract has changed the future savings profit risk allocation according to the actual energy quantity savings performance.

3.2.2 Energy Cost Savings Guarantee

The other contract model that has also been popularly adopted in EPC is to guarantee fixed monetary amount of annual energy savings in the entire EPC operation period. This is much easier for the clients to understand and control what further energy savings revenue could be reached, and at the same time, be more convenient for the ESCO's financing and ECMs conducted flexibility adjustment. This contract model has taken both the energy prices volatility and facility technical instability risk factors into consideration. The risk analysis model goes a little bit more complex comparing with the energy quantity savings guarantee contract mode discussed before.

For the energy cost savings guarantee, the option value of the guarantee in a specific year could be represented as following Equation (19) and (20) from the options perspective, which is different from Equation (6) and (7).

If $I'_t < G_t$, $Extra\ Profit_{Ct} = 0$ (19)

If $I'_t \geq G_t$, $Extra\ Profit_{Ct} = (I'_t - G_t) * \alpha_1$ (20)

Combining them together, formula for the client's extra profit ($Extra\ Profit_{Ct}$) with guaranteed quantity savings could be presented as Equation (21) showing below.

$$Extra\ Profit_{Ct} = \max[0, (I'_t - G_t) * \alpha_1] \tag{21}$$

Taken the risk factors of the energy savings guarantee back into consideration, predicted energy cost savings (I_t) and verified energy cost savings (I'_t) are used to compare with the guaranteed energy savings (G_t) in order to calculate the ESCOs total profit ($Profit'_{Et}$) and the clients total savings profit ($Profit'_{Ct}$) under uncertainty. Two important parameters, the percentage of clients sharing within the guaranteed energy savings (α_0) and the clients' percentage in the exceeding profit sharing (α_1), are also paid attention to. We could reach Equation (22) as follows.

$$Profit_{Ct} = G_t * \alpha_0 \tag{22}$$

From the Clients' perspective, there are both the possibilities that the guarantee may or may not be executed. If the verified energy savings do not reach the guaranteed amount, then clients could get the specified proportion of benefit from the guarantee. If the verified energy cost savings (I'_t) exceed the guarantee (G_t), clients could get the profit from both the proportion of guarantee and the exceeding sharing. Concretely, the profit for the t^{th} year should be presented as Equation (23) and (24).

If $I'_t < G_t$, $Profit'_{Ct} = Profit_{Ct} = G_t * \alpha_0$ (23)

If $I'_t \geq G_t$, $Profit'_{Ct} = Profit_{Ct} + (I'_t - G_t) * \alpha_1 = G_t * \alpha_0 + (I'_t - G_t) * \alpha_1$ (24)

Combining them together, formula for the client's extra profit (*Extra Profit*$_{Ct}$) with guaranteed quantity savings could be presented as Equation (25) showing below.

$$Profit'_{Ct} = \max[G_t{*}\alpha_0,\ G_t{*}\alpha_0 + (\,I'_t - G_t)\ {*}\alpha_1] \qquad (25)$$

Based on Equations (23) and (24), the *Profit'*$_{Ct}$ graph could be drawn as follows with the underlying assets of the verified energy savings on the t^{th} year.

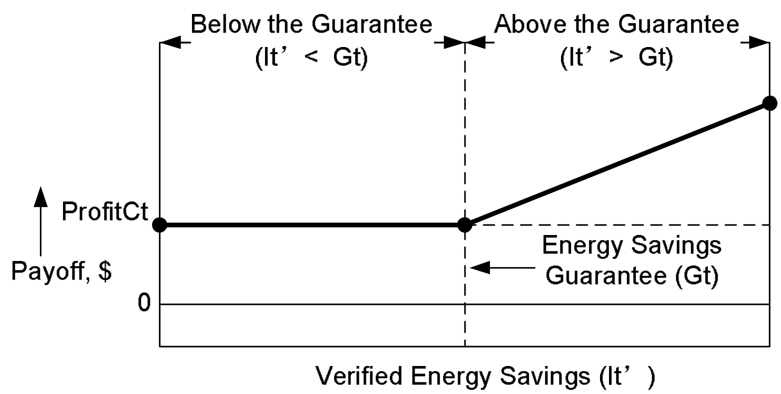

Figure 13. The Clients' Profit on the Energy Cost Savings Guarantee

From the ESCO's perspective, the profit for the t^{th} year should be presented as Equations (26) and (27) showing below.

$$\text{If } I'_t < G_t,\quad Extra\ Profit_{Et} = (I'_t - G_t) \qquad (26)$$

$$\text{If } I'_t \geq G_t,\quad Extra\ Profit_{Et} = (I'_t - G_t)\ {*}(1-\alpha_1) \qquad (27)$$

Combining them together, formula for the client's extra profit (*Extra Profit*$_{Ct}$) with guaranteed quantity savings could be presented as Equation (28) showing below.

$$Extra\ Profit_{Et} = \min[(I'_t - G_t),\ (\,I'_t - G_t\,)\ {*}(1-\alpha_1)] \qquad (28)$$

If the verified energy savings do not reach the guaranteed amount, ESCOs need to make up the deficiency. Further, if the verified energy savings exceed the guarantee, ESCOs could not only get the specified profit from the guarantee, but also the proportion of the exceeding sharing.

$$\text{If } I'_t < G_t,\quad Profit'_{Et} = Profit_{Et} + (I'_t - G_t) \tag{29}$$

$$\text{If } I'_t \geq G_t,\quad Profit'_{Et} = Profit_{Et} + (I'_t - G_t) * (1-\alpha_1) \tag{30}$$

Combining them together, formula for the client's extra profit (*Extra* $Profit_{Ct}$) with guaranteed quantity savings could be presented as Equation (31) showing below.

$$\begin{aligned} Profit'_{Et} &= \min[Profit_{Et} + (I'_t - G_t), Profit_{Et} + (I'_t - G_t)*(1-\alpha_1)] \\ &= \min[I'_t - C - G_t*\alpha_0 + (I'_t - G_t), I'_t - C - G_t*\alpha_0 + (I'_t - G_t)*(1-\alpha_1)] \end{aligned} \tag{31}$$

Then, the ESCO's profit graph on the energy cost savings guarantee could be described as the following Figure 14, which has a different graph shape from Figure 13 above.

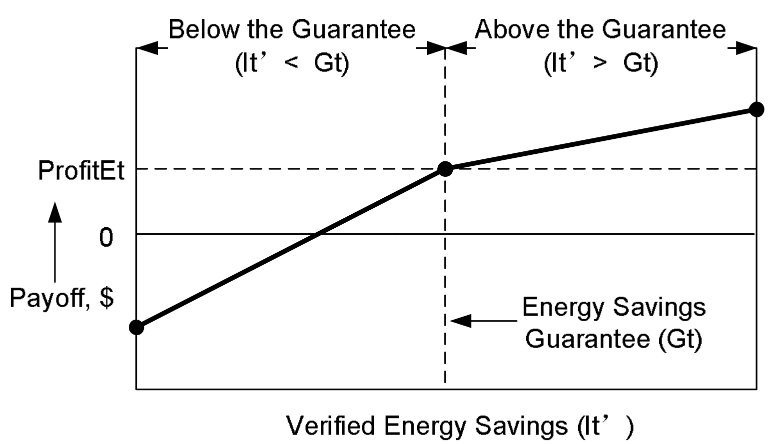

Figure 14. The ESCO's Profit on the Energy Cost Savings Guarantee

Regardless of what final verified energy cost savings (I'_t) has been achieved, the sum of the total profit for both the clients and the ESCOs stays the same, which equals to ($G_t*\alpha_0 + Profit_{Et} + I'_t$-

G_t). It means that this kind of guarantee in the contract has convert the future savings profit risk allocation to another standard according to the actual energy cost savings performance.

3.4 Verified Energy Savings Pricing Model

Based on the energy savings guarantee analysis above, the clients' extra savings profit (*Extra* $Profit_{Ct}$) stays either zero or above regardless of the energy savings guarantee type which would never fall to be negative. It means that even if the clients did not earn money from the guarantee, they would not have any potential expenditure if certain guarantee clause has been specified in the contract. However, ESCOs need to carefully consider the guarantee design which may cause huge loss if the guarantee was set inappropriately. ESCOs shall afford the potential loss risk if the guarantee has been specified in the contract and the risk analysis is focused from the ESCO's perspective. They also have more power on the EPC controlling.

The clients' total savings profit ($Profit'_{Ct}$) could be discounted as Equation (32) displayed, which has been expected the higher the better from the clients' perspective.

$$\sum_{t=1}^{n} \frac{Profit'_{Ct}}{(1+r)^t} = \sum_{t=1}^{n} \frac{\max[G_t\alpha_0, G_t\alpha_0 + (I'_t - G_t)\alpha_1]}{(1+r)^t} \tag{32}$$

The ESCOs' total profit ($Profit'_{Et}$) is different from Equation (32) showing above which also been expected the higher the better from the ESCOs' perspective.

$$\sum_{t=1}^{n} \frac{Profit'_{Et}}{(1+r)^t} = \sum_{t=1}^{n} \frac{\min[I'_t - C_t - G_t\alpha_0, I'_t - C_t - G_t\alpha_0 - (I'_t - G_t)\alpha_1]}{(1+r)^t} \tag{33}$$

During the whole O&M period ($T=$ *n years*), the predicted annual energy savings (I_t) could be varied from year to year, while the guaranteed savings stay constant. Therefore, the trade-off point for the ESCOs' guarantee amount (G_t) is critical and expected to be equal to the verified energy savings (I'_t). Here the discount rate (r) has taken both the risk-free rate (r_f) and the risk premium into consideration.

$$\sum_{t=1}^{n}\frac{I_t^{'}}{(1+r)^t}=\sum_{t=1}^{n}\frac{G_t}{(1+r)^t}+\sum_{t=1}^{n}\frac{\max[0,(I_t^{'}-G_t)\alpha_1]}{(1+r)^t}+\sum_{t=1}^{n}\frac{\min[(I_t^{'}-G_t),(I_t^{'}-G_t)(1-\alpha_1)]}{(1+r)^t} \qquad (34)$$

Under this situation, the ESCOs' expected total extra savings profit shall be equal to zero. Equation (35) has shown detailed formulas below.

$$\sum_{t=1}^{n}\frac{Profit'_{Et}-Profit_{Et}}{(1+r)^t}=\sum_{t=1}^{n}\frac{\min[(I_t^{'}-G_t),(I_t^{'}-G_t)(1-\alpha_1)]}{(1+r)^t}=0 \qquad (35)$$

From the ESCOs' view, making more conservative energy savings guarantees surely decreases the potential loss risks but at the same time reduces the chances for ESCOs to win the competitive bid. Because most clients are risk-avoided who prefer the more secured energy savings promise and in practice the higher the better. Therefore, the accurate total energy cost savings guarantee which converges towards the verified energy savings is the ESCOs' expectation.

3.3 Risk Analysis Model

The actual energy savings are verified by the ESCOs after installation and are reported either on a yearly basis or as a calculated annual average of actual energy savings achieved (Goldman, 2002). There are three main factors that may affect the potential deficient or exceeding performance of the verified annual energy savings at the t^{th} year (I'_t), as the different energy unit price rate (P_{Etj}), the varied energy savings quantity (Q_{tj}) and the operation & maintenance cost savings (C_{Mt}). Here, j implies the certain kind of utility savings. The verified energy cost savings (I'_t) could be represented by the sum of savings that comes from both the utility consumption savings and the operation & maintenance cost savings.

$$I_t^{'} = \sum_{j=1}^{n} (P_{Etj} * Q_{tj}) + C_{Mt} \tag{36}$$

Here, we use the portfolio energy unit price at the t^{th} year (P_{Et}) and the total verified energy quantity savings at the same year (Q_t) to simplify the calculation process in Equation (36) above, which combines all different kinds of energy savings from varied ECMs, including the operation & maintenance cost savings (C_{Mt}), as Equation (37) shows below.

$$I_t^{'} = P_{Et} * Q_t \tag{37}$$

Given those uncertainties about the future level of the energy price rate and utility consumption amount, we consider both the portfolio energy unit price at the t^{th} year (P_{Et}) and the total consumed energy quantity at the t^{th} year (Q_t) vary in time following the stochastic process of GBM in order to model this energy cost savings guarantee contract.

Equation (38) below has been added in for the better risk issues explanation which illustrates the evolution process of the portfolio energy unit price at the t^{th} year (P_{Et}).

$$dP_{Et} = \alpha_{Et} P_{Et} dt + \sigma_{Et} P_{Et} dz_1(t) \tag{38}$$

Where dP_{Et} is the incremental change in the energy unit price rate during a short period of time dt,
α_{Et} is the energy unit price growth rate in a short period of time dt,
σ_{Et} is the volatility of the energy unit price rate,
$dz_1(t) = \mathcal{E}_1\sqrt{dt}$, where $\mathcal{E}_1$ ~ N(0,1) is the standard Wiener process.

Based on Equation (38) above, we can reach the following analogic results in Equations (39) and (40) as follows, which show the detailed information between each time period for the portfolio energy unit price.

$$d \ln P_{Et} = (\alpha_{Et} - \frac{\sigma_{Et}^2}{2}) dt + \sigma_{Et} dz_1 \tag{39}$$

$$P_{Et+\Delta t} = P_{Et} e^{(\alpha_{Et} - \frac{\sigma_{Et}^2}{2})\Delta t + \sigma_{Et}\varepsilon_1\sqrt{\Delta t}} \quad (40)$$

This process can be complete specifying only its initial value (P_{E0}), an annual growth trend (α_E) and the volatility of the process (σ_E), which we usually assume to be constant during the concession period. Simulations could be conducted through Equation (39) and (40).

Given the uncertainty about the future level of the utility consumption amount in order to model this variable, we also consider the total energy savings quantity at the t^{th} year (Q_t) vary stochastically in time, following a GBM as is usually used in mathematical finance to model stock prices. Equation (41) has been reached as follows.

$$dQ_t = \alpha_{Qt} Q_t dt + \sigma_{Qt} Q_t dz_2(t) \quad (41)$$

Where dQ_t is the incremental change in the total consumed energy quantity during a short period of time dt,

α_{Qt} is the energy consumption savings quantity growth rate in a short period of time dt,

σ_{Qt} is the volatility of the energy savings quantity,

$dz_2(t) = \mathcal{E}_2 \sqrt{dt}$, where $\mathcal{E}_2$ ~ N(0,1) is the standard Wiener process.

Similar to Equations (39) and (40), we can also reach the following analogic results in Equations (42) and (43) as follows, which show the detailed information between each time period for the total energy savings quantity at the t^{th} year (Q_t).

$$dlnQ_t = (\alpha_{Qt} - \frac{\sigma_{Qt}^2}{2})dt + \sigma_{Qt} dz_2 \quad (42)$$

$$Q_{t+\Delta t} = Q_t\, e^{\left(\alpha_{Qt} - \frac{\sigma_{Qt}^2}{2}\right)\Delta t + \sigma_{Qt}\varepsilon_2\sqrt{\Delta t}} \quad (43)$$

This process can be completely specified considering only its initial value Q_0, a yearly growth rate (α_Q) and the volatility of the process (σ_Q), which we assume to be constant during the concession period. Or, it could also be adjusted based on the predicting energy savings quantity

($\hat{Q}_t$) where i represents any one or more years that the most accurate performance estimation has been conducted based on the known information.

Combining both the stochastic processes of the portfolio energy unit price at the t^{th} year (P_{Et}) and the total energy savings quantity at the t^{th} year (Q_t) together, Equation (44) and Equation (45) could be reached below according to Ito's Lemma.

$$\mathrm{d}I_t^{'} = \frac{\partial I_t^{'}}{\partial t}dt + \frac{\partial I_t^{'}}{\partial P_{Et}}dP_{Et} + \frac{\partial I_t^{'}}{\partial Q_t}dQ_t + \frac{1}{2}\frac{(\partial I_t^{'})^2}{(\partial P_{Et})^2}(dP_{Et})^2 + \frac{1}{2}\frac{(\partial I_t^{'})^2}{(\partial Q_t)^2}(dQ_t)^2 + \frac{(\partial I_t^{'})^2}{\partial P_{Et}\partial Q_t}(dP_{Et}dQ_t)$$

$$\mathrm{d}I_t^{'} = P_{Et}dQ_t + Q_t dP_{Et} + dP_{Et}dQ_t \tag{44}$$

$$\mathrm{d}I_t^{'} = (\alpha_{Et}P_{Et}Q_t + \alpha_{Qt}P_{Et}Q_t + \rho\sigma_{Et}\sigma_{Qt}P_{Et}Q_t)\ \mathrm{d}t + (\sigma_{Et}P_{Et}Q_t dz_1 + \sigma_{Qt}P_{Et}Q_t dz_2) \tag{45}$$

Here, ρ is the correlation coefficient of dz_1 and dz_2. At the same time, ρ equals to the expectation of $\mathcal{E}_1\mathcal{E}_2$. The potential inner correlations between the portfolio energy unit price at the t^{th} year (P_{Et}) and the total energy savings quantity at the t^{th} year (Q_t) should be considered if necessary.

3.5 Model Discussion

Either the energy quantity savings guarantee or the energy cost savings guarantee gives an option to the client that they have the authority to choose how to define the verified energy savings amount as the measurement result or the fixed amount specified in the contract. It is very similar to the options in financial markets with the underlying assets of the verified energy savings on the t^{th} year. In financial options, the volatility of stock prices is a function of the uncertainty for the stock price movements, which could be analogic to the stochastic process of GBM. In the EPC case, the estimation of volatility is a little bit different between the energy quantity savings guarantee and the energy cost savings guarantee when applying financial options theory. The expected energy savings revenue is a combination function of the energy price rate and the facility savings performance volume. Here, we consider the energy cost savings guarantee of the renewal facilities as a stochastic variable which may achieve higher or lower performance than expected in the energy quantity savings guarantee contract. For the energy cost savings guarantee contract, we also consider the potential the energy price rate volatility that never stays constant as another stochastic variable that combines with the facility instable performance together to affect the future EPC savings revenue during the O&M period of the project whole lifecycle.

Both the ESCOs and the clients consider the annual energy savings revenue to be an important risk factor when they assess the feasibility of an energy performance project due to the volatile energy prices and high technical instability through the whole operation period. In real practice, the predicted annual energy savings should be varied at different years because of the nature of the facilities performance. For example, since all the ECMs have to be installed in some sequences that may delay the best performance for the renewed facilities at the very beginning of the project, the energy savings should demonstrate an increasing trend at the first few contract years. Then, as time goes by, some ECMs may suffer deterioration and might not perform as well as before, so the energy savings amount might also decrease. Those trends and specific energy savings amount could be foreseeable by the experienced implementation engineers before signing the contract, especially at the savings quantity level. Thus, here we could reasonably assume that the estimation for the predicting energy savings quantity ($\hat{Q}_t$) has stood for the best performance estimation that has already been conducted based on the existing information.

Based on the most accurate estimation, for the total verified energy quantity savings (Q_t), this process can be completely specified considering only its initial value Q_0, a yearly growth rate and the volatility of the process that we assume to be constant during the O&M period before delivery, which represents the evolution process of the project revenue. Or, it could also be adjusted according to the recognized financial feasible information that any one or more years when best performance estimation has been conducted based on the existing information. Multiple stochastic processes should be considered for the whole O&M period, one for each year, and the valuation of the annual guarantees can be modeled as a series of independent European options with maturities between the first and the delivery years.

Chapter 4: Case Study of the University of Maryland College Park

The University of Maryland main campus occupies 1,250 acres (5.1 km^2) of land in Prince George's County, Maryland, U.S.A, with 264 buildings that include classrooms and laboratories, as well as residence halls, dining facilities, libraries, offices buildings, athletic facilities, and performance centers. The inventory also includes the Maryland Fire and Rescue Institute (MFRI) and the Maryland Agricultural Experiment Station (MAES) managed by the College of Agriculture and Natural Resources, which occupies an additional 1,300 acres of land throughout the State. In 2009, the University's building space, including its satellite programs, occupied 398 buildings totaling 13.4 million square feet. Since 2005, square footage growth has been flat with an average annual growth rate of just 0.3%. In October 2009, the university was named America's Greenest Campus by Climate Culture for having the largest number of campus community members register to calculate their carbon footprint.

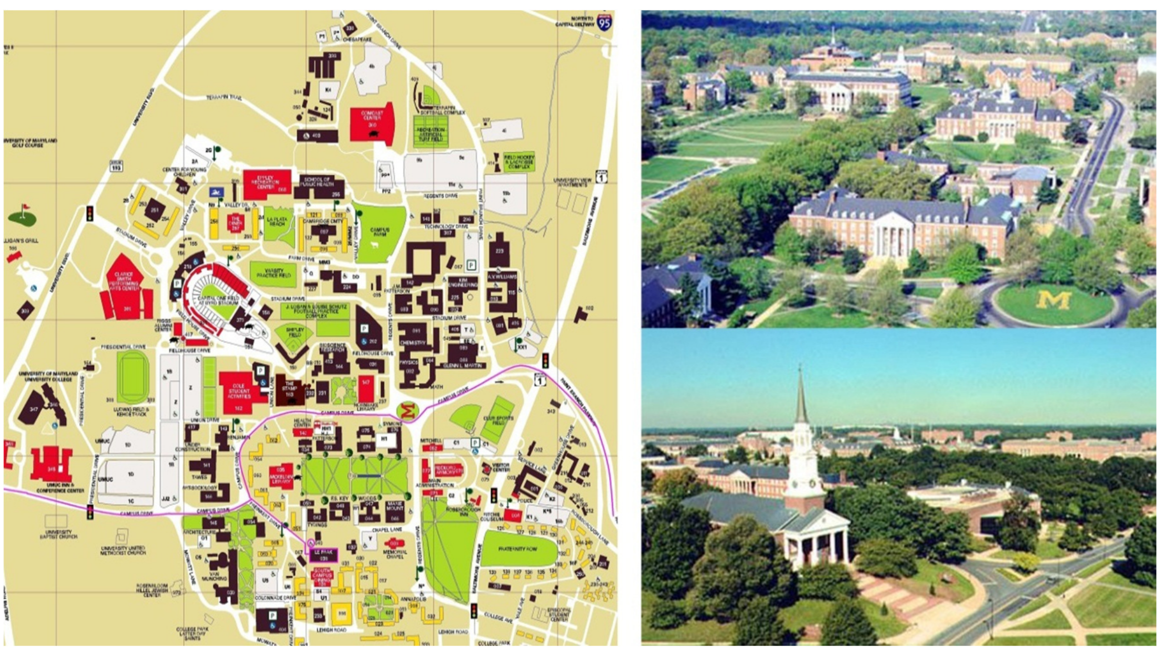

Figure 15. University of Maryland College Park Campus

Both the University and the State of Maryland are making great strides in green building construction and renovation. As a public research university founded in 1856, the University of Maryland campus consumes a lot of energy for the daily operation and maintenance activities. In our case, 75% of those 264 buildings are more than 25 years old and 32% of them have exceeded 50 years. The average age for the campus buildings is 40 years and 55% of them require renovation. As a result, the operation and maintenance cost increases $18 million each year. Since the buildings operation conditions varied, each building receives a comprehensive energy audit to determine a customized list of conservation measures that would provide the best results. With an energy bill of over $50 million per year, climbing energy rates, and growing concerns about the effects of greenhouse gas emissions on the environment, it is necessary for the university to start implementing energy efficiency and conservation upgrades for facilities renewal, which will help the campus conserve energy, reduce the use of raw materials and save money.

4.1 Introduction

In April 2009, the University of Maryland, College Park (UMCP) and Johnson Controls, Inc. signed a 13-year Comprehensive Energy Efficiency and Guaranteed Savings Program contract, which adopted the Energy Performance Contracting service to improve facility infrastructure around campus while reducing energy expenditure costs. The performance contracts allow energy conservation measures and technologies to be installed without upfront capital cost to the university, and the ESCO is repaid through utility bill savings over the term of the contract. In this case, the University of Maryland is the client and Johnson Controls is the ESCO that provides energy conservation measures in nine important buildings around the campus, which help the campus community live, work, and learn in increasingly efficient buildings while enjoying a higher standard of indoor environmental quality.

The common ECMs Johnson Controls plans to use for UMCP projects include lighting redesign, lighting occupancy controls, vending machine controls, domestic water upgrades, non-domestic water conservation, infiltration reduction, window replacement, steam trap replacement, insulation blankets, pipe insulation, energy awareness program, SEEC, etc, which could be categorized as Figure 16 shows below. The estimation of energy conservation and facility improvement projects initial investment is $20,668,991 with an annual interest rate of 3.1%.

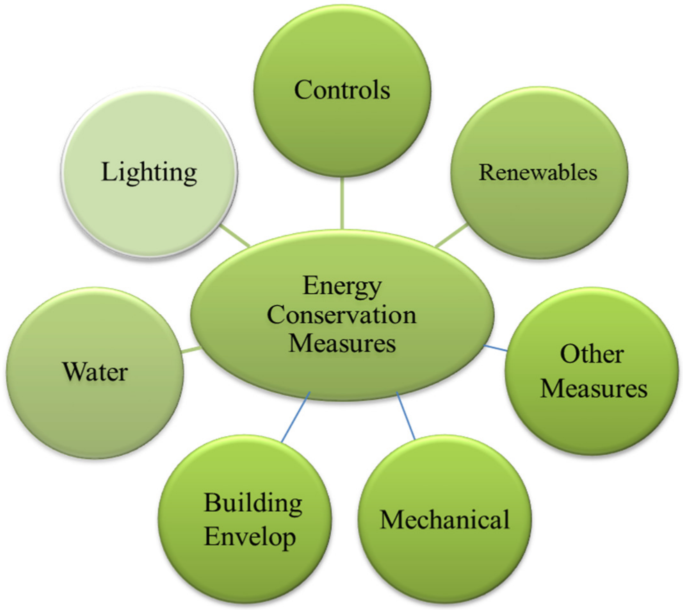

Figure 16. Energy Conservation and Facility Improvement Measures for UMCP

From the EPC win-win project model, Johnson Controls will provide UMCP with maintenance and training support, as well as ongoing performance-monitoring services, and then be compensated from a 22% energy and operating cost avoidance each year compared to the baseline. Also, UMCP can get a 20% reduction of GHG in selected buildings that is the equivalent of planting 20,700 trees per year with a carbon footprint reduction of 4,100 tons of greenhouse gas emissions annually. This program not only improves the productivity while reducing maintenance costs, but also supports achievement of the Presidents Climate Commitment and the Governor's Empower Maryland energy reduction goals. The ESCO guarantees projected savings and a measurement and verification program ensures that these savings are realized, which promised $1.7 million in energy costs avoided annually.

Through this energy-efficiency program with a portfolio of EPC projects, Johnson Controls provides UMCP with a guaranteed fixed price of $1,904,343 to cover all of the costs savings associated with the selected ECMs and operational savings annually. This financial commitment, which represents as a typical energy cost savings guarantee contract model, means that Johnson Controls is responsible for delivering the guaranteed savings result for the clearly defined and agreed-upon price. If the verified energy savings amount is less than the specified guaranteed, they will pay the shortfall between what has been guaranteed and what is actually achieved. The actual energy savings amount will be measured monthly and reconciled annually with UMCP, which takes both the energy price volatility and the facility technical instability risk factors into consideration. Year is a good unit for volatility analysis, which eliminates the seasonal utility volatile factors.

However, certain information has been blurred in the energy performance contract between Johnson Controls and UMCP; for instance, how to set the sharing proportion if the exceeding energy savings amount has been achieved beyond the guarantee to appropriately allocate the energy price and facility performance risks in order to maximally protect the benefits for both sides and lead to successful cooperation. In the current EPC market, the percentages of extra profit sharing for the exceeding part of energy cost savings beyond the given guarantees seem varied between the clients and ESCOs according to their historical experience. But, the optimal sharing proportion does exist, which not only correlatively helps the client maximize the saving guarantee amount at a certain risk level, but also motivates the ESCO to deliver the quality performance in the project. Here, we intend to work it out in the following sections and at the same time, understand the inner profit sharing relation changes according to the energy savings guarantee with actual data collected or simulated from the UMCP case.

4.2 Pricing Model for UMCP Energy Cost Savings

Theoretically, the energy cost savings guarantee could help decrease or eliminate risks that the verified energy cost savings may go down and may not achieve the predicted expectation, if there are appropriate proportions of extra profit sharing for the exceeding part of energy cost savings beyond the given guarantees. Analogous to the financial option situation, in the UMCP case, the annual guaranteed energy and operational cost savings of $1,904,343 is deemed as the Strike Price (X or K), which has already been fixed in the contract as the value through negotiations between UMCP and Johnson Controls. The estimated energy cost savings that have been specified in the financial analysis of contract are treated as the Spot Prices (S), which reflect the most accurate expectation for future possible energy and operational cost savings. Those estimations may vary year by year. The verified energy cost savings are what we could only know when they actually occur, and we need to monitor and measure them during the whole operation and maintenance period. Volatility (σ) causes the differences between the predicted and the verified energy cost savings, which come from both the future uncertainty of utility usage quantity and the constant changing energy price rate. Thus, as in the model, which has been discussed in Chapter 3, we need to take the portfolio energy unit price (P_{Et}) and the total energy consumption savings quantity (Q_t) into consideration. Both of them apply to the GBM stochastic process and vary all the time.

4.2.1 Energy Price Rate Model

For the estimation of the portfolio energy unit price of the t^{th} year (P_{Et}), we adopted the energy price data from both the residential sector and commercial sector for the past 14 years from 1995 to 2008. Figure 17 below shows the general trend of the building energy unit price from the U.S. Energy Information Administration of 2008. Detailed energy price information shall be found in Appendix I and Appendix II.

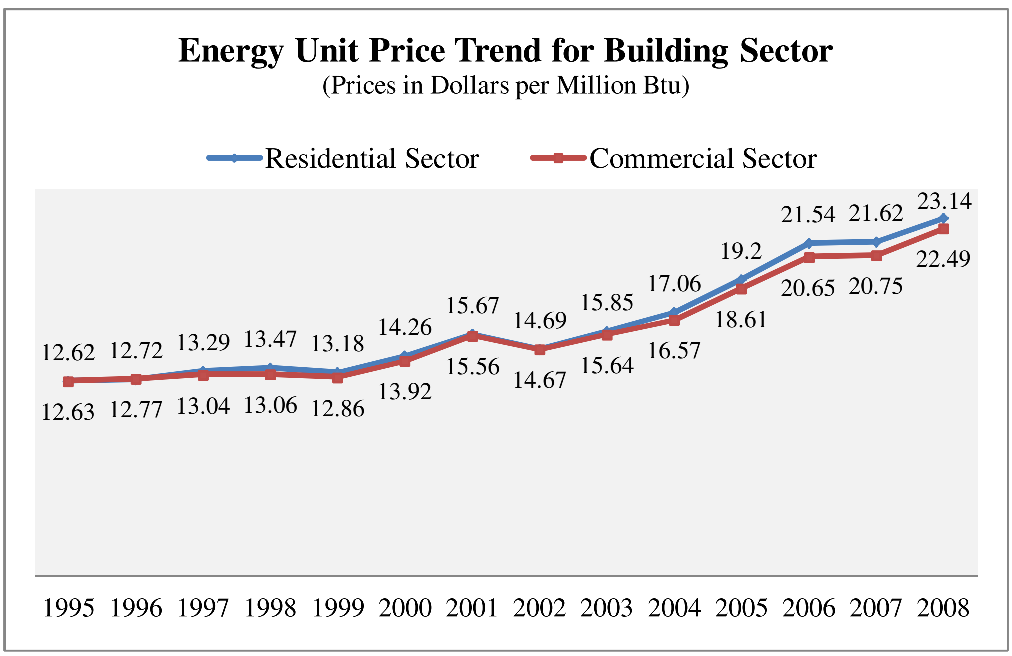

Figure 17. Energy Unit Price and Expenditure for Building Sector from 1995 to 2008

(Data adapted from U.S. Energy Information Administration, State Energy Data 2008: Prices and Expenditures)

Based on the data information, here, we assume the annual energy unit price growth rate (α_E) and the volatility of the energy unit price rate (σ_E) stay constant each year in the following analysis for estimation in order to simplify the calculation process. Here, we use the logarithmic approach to calculate the volatility using the historical energy price rate and their corresponding logarithmic returns. Starting with a series of annual energy price rate, we convert them into relative returns. Then, we take the natural logarithms of these relative returns. The standard deviation of these natural logarithm returns is the volatility of the energy unit price rate used in a real options analysis. The volatility of both the residential sector and the commercial sector energy price rate estimation (σ_E) is then calculated as Equation (46) below as the sample standard deviations, where x represents the natural logarithm and the energy price rate and the footnote i stands for the ith year.

$$\sigma_E = STDEV.S(x_i) = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{46}$$

Table 4. Residential Sector Energy Price Rate and Their Logarithmic Return

(Prices in Dollars per Million Btu)

Time Period	**Energy Price Rate**	**Relative Proportion**	**Natural Logarithm (*x*)**
1995	12.62	-	-
1996	12.72	1.007924	0.007893
1997	13.29	1.044811	0.043836
1998	13.47	1.013544	0.013453
1999	13.18	0.978471	-0.02176
2000	14.26	1.081942	0.078758
2001	15.67	1.098878	0.09429
2002	14.69	0.93746	-0.06458
2003	15.85	1.078965	0.076003
2004	17.06	1.076341	0.073567
2005	19.2	1.12544	0.118174
2006	21.54	1.121875	0.115001
2007	21.62	1.003714	0.003707
2008	23.14	1.070305	0.067944

(Source: U.S. EIA, State Energy Data 2008: Prices and Expenditures)

σ_E (Residential Sector) = 5.53%

Table 5. Commercial Sector Energy Price Rate and Their Logarithmic Return

(Prices in Dollars per Million Btu)

Time Period	Energy Price Rate	Relative Proportion	Natural Logarithm (x)
1995	12.63	-	-
1996	12.77	1.011085	0.011024
1997	13.04	1.021143	0.020923
1998	13.06	1.001534	0.001533
1999	12.86	0.984686	-0.01543
2000	13.92	1.082426	0.079205
2001	15.56	1.117816	0.111377
2002	14.67	0.942802	-0.0589
2003	15.64	1.066121	0.064027
2004	16.57	1.059463	0.057762
2005	18.61	1.123114	0.116105
2006	20.65	1.109618	0.104016
2007	20.75	1.004843	0.004831
2008	22.49	1.083855	0.080525

(Source: U.S. EIA, State Energy Data 2008: Prices and Expenditures)

σ_E (Commercial Sector) = 5.45%

Through Table 4 and Table 5 above, we reached the energy unit price volatility of the residential sector (σ_E =5.53%), and the energy unit price volatility of the commercial sector, (σ_E =5.45%). Since the results of both sectors are very close, here, we simply deem their average as the general volatility of the energy unit price rate (σ_E = 5.5%) for the building sector estimation, which has been applied to the UMCP case.

Based on the basic GBM formula of the portfolio energy unit price at the t^{th} year (P_{Et}) in Equation (26) and (27), we get the following Equation (47) and (48) for the estimation of the annual energy unit price growth rate (α_E), where Δt =1.

$$\ln\left(\frac{P_{Et+1}}{P_{Et}}\right) = \alpha_{Et} - \frac{\sigma_{Et}^2}{2} + \sigma_{Et}\varepsilon_2 \tag{47}$$

$$\alpha_{Et} = E[\ln(\frac{P_{Et+1}}{P_{Et}})] + \frac{\sigma_{Et}^2}{2} \tag{48}$$

Also, we have reached the annual energy unit price growth rates for the residential sector (α_{Et} = 0.0482) and for the commercial sector (α_{Et} = 0.0459), which we assumed to be constant. Here, we consider to adopt the general energy unit price growth rate for building sectors (α_E =0.047) as the average of the residential and commercial sectors for the UMCP case.

Based on the previous information, we use the portfolio energy unit price of the year 2008 (P_{E0} =$22.82 per million Btu) for the estimation of the specific UMCP case. It is also the average energy unit price of the residential sector and the commercial sector in 2008. According to the 10,000 times Monte-Carlo simulation, we reached the distributions of the energy unit price results for each year. Here the results for 2016 and 2021 are displayed in following Figure 18. Energy unit prices for each year are all following normal distribution.

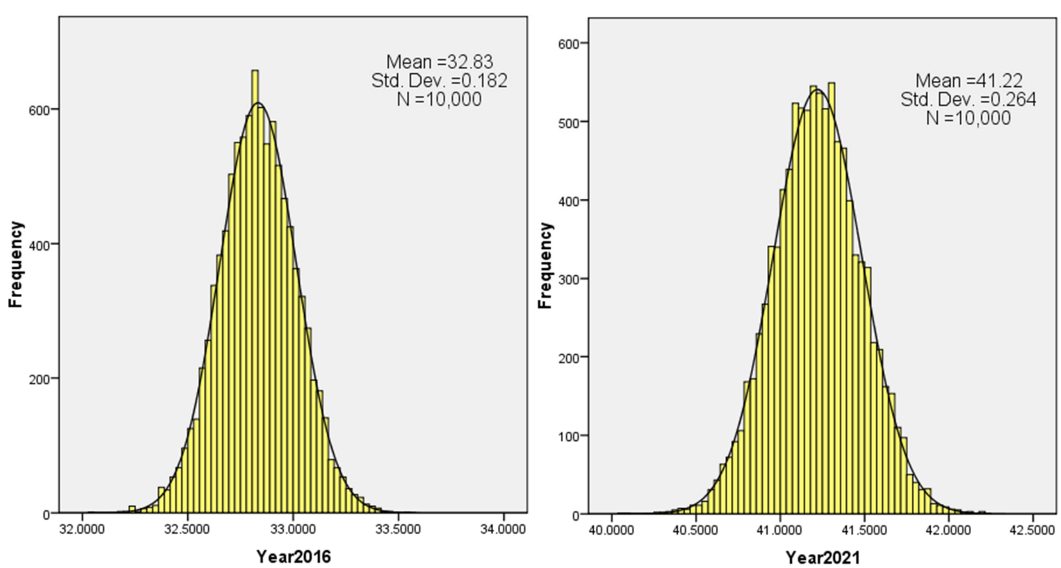

Figure 18. Distribution of the Energy Unit Price of the 2009 and 2021

4.2.2 Energy Savings Quantity Model

We also consider the energy savings quantity for each year vary stochastically following GBM as is usually used in mathematical finance to model stock prices. Uncertainties in the future utility consumption amount has been considered. Associated with the first year prediction of the annual energy and operational cost savings (I_1=$1,904,343), which has been specified in the contract, and the portfolio energy unit price of the year 2009 (P_{E1} =$23.88 per million Btu), the predicted energy savings quantity for the first year (Q_1=79.75 billion Btu) has been reached, which plays as the initial value in the energy savings quantity model.

It is usually very hard to collect historical data for the prediction of the energy savings quantity. Because different energy performance projects involves varied ECMs combination according to the buildings actual conditions and the possible length of the O&M period. However, the trends and specific energy savings amount for each year are foreseeable for the implementation engineers based on their intelligence and experience before signing the contract. Therefore, it is more reasonable and convenient to use the subjective estimation for the annual energy savings quantity at the t^{th} year ($\hat{Q}_t$) associated with the specific project situations. In reality, the predicted annual energy quantity savings shall change year by year because of the nature of facilities performance. For instance, since all the ECMs have to be installed in some sequences that may delay the best performance for the renewed facilities at the very beginning of the project, the energy savings should demonstrate an increasing trend at the first few contract years. As time goes by, some ECMs may suffer deterioration or might not perform as well as before. As a result, the energy savings amount might decrease at the end. Figure 19 shows the subjective best estimation of the expected energy savings quantity trend according to the UMCP case's situation.

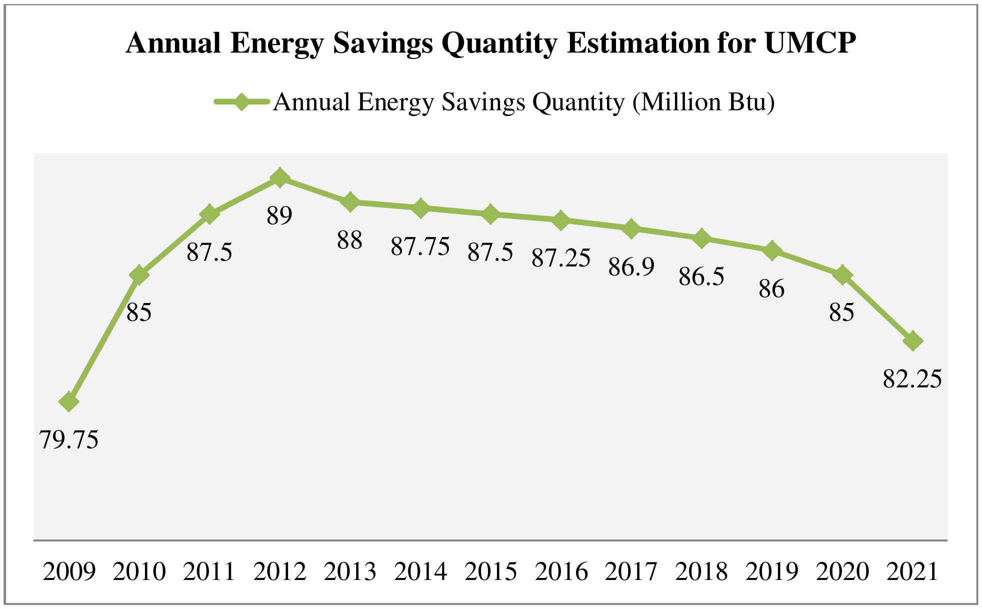

Figure 19. Annual Energy Savings Quantity Trend for UMCP Case

The evolution process of the project energy savings quantity is not exactly as same as the stock price in the financial market, which goes either up or down of memory less without barriers limitation. According to the EPC situation, the performance of the equipment and facilities installed in the building for energy savings should obey certain natural law and could be estimated in advance appropriately. Therefore, we assume the predicting energy savings quantity comes from the most accurate performance estimation associated with the recognized knowledge. The best annual energy savings quantity estimations have been considered as the inputs and are displayed in Table 6.

Table 6. Annual Energy Savings Quantity Estimation for UMCP Case (Million Btu)

2009	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**	**2021**
79.75	85	87.5	89	88	87.75	87.5	87.25	86.9	86.5	86	85	82.25

Based on the GBM process of Equation (28) discussed before, we derive the following Equation (49) and Equation (50) for the energy quantity savings (Q_t) simulation.

$$\ln\left(\frac{Q_t}{Q_0}\right) = \ln\left(\frac{\widehat{Q}_t}{Q_0}\right) + \sigma_Q \varepsilon_2 \sqrt{t} \tag{49}$$

$$Q_t = \widehat{Q}_t e^{\sigma_Q \varepsilon_2 \sqrt{t}} \tag{50}$$

Since the volatility of the energy savings quantity (σ_Q) is dependent on the installed energy conservation performance, which varied from case to case, here we consider four scenarios (σ_Q=1%, σ_Q=5%, σ_Q=10% and σ_Q=20%) respectively. We run the simulation 10,000 times for each scenario. The correlations between the annual energy savings quantity for the t^{th} year (Q_t) and the (t+1)$^{\text{th}}$ year (Q_{t+1}) have not been considered in this simulation.

The distributions of the total energy savings quantity for the year 2016 and 2021 (σ_Q =1%) are displayed in the following Figure 20, which are close to the normal distribution.

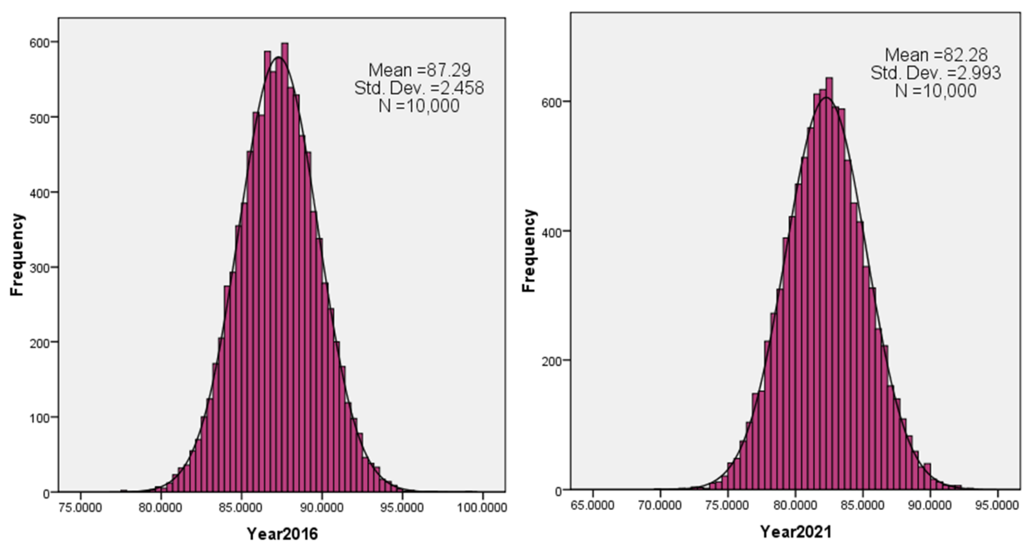

Figure 20. Distribution of the Energy Quantity Saving of 2016 and 2021 (σ_Q =1%)

As the volatility of the energy savings quantity increases (σ_Q =5%), the frequency distributions of the total energy savings quantity for year 2016 and 2021 are displayed in the following Figure 21.

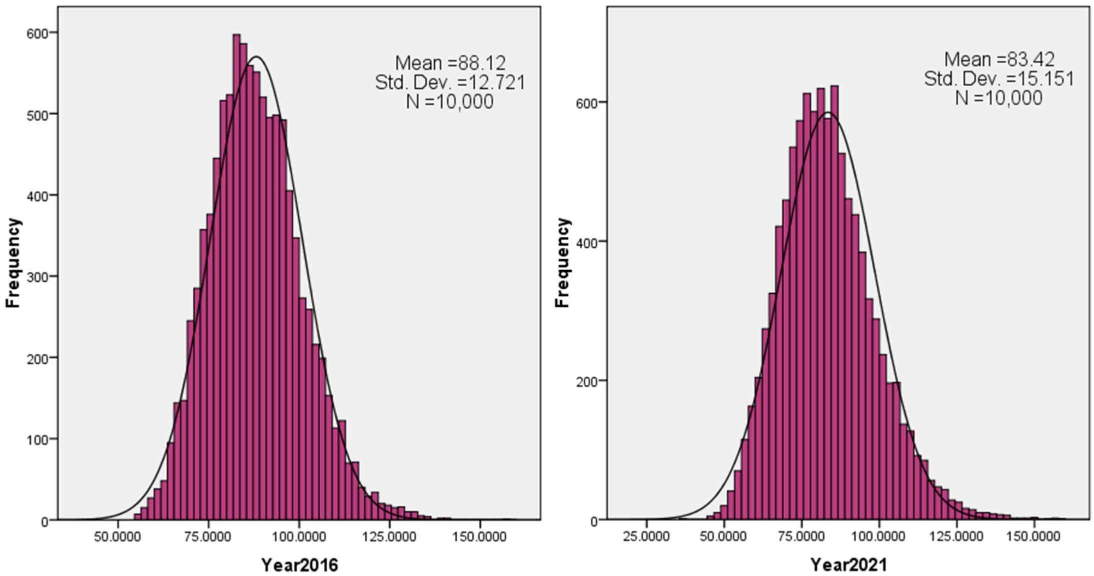

Figure 21. Distribution of the Energy Quantity Saving of 2016 and 2021

(σ_Q=5%)

The distributions of the energy savings quantity for each year (σ_Q=10%) are displayed in the following Figure 22.

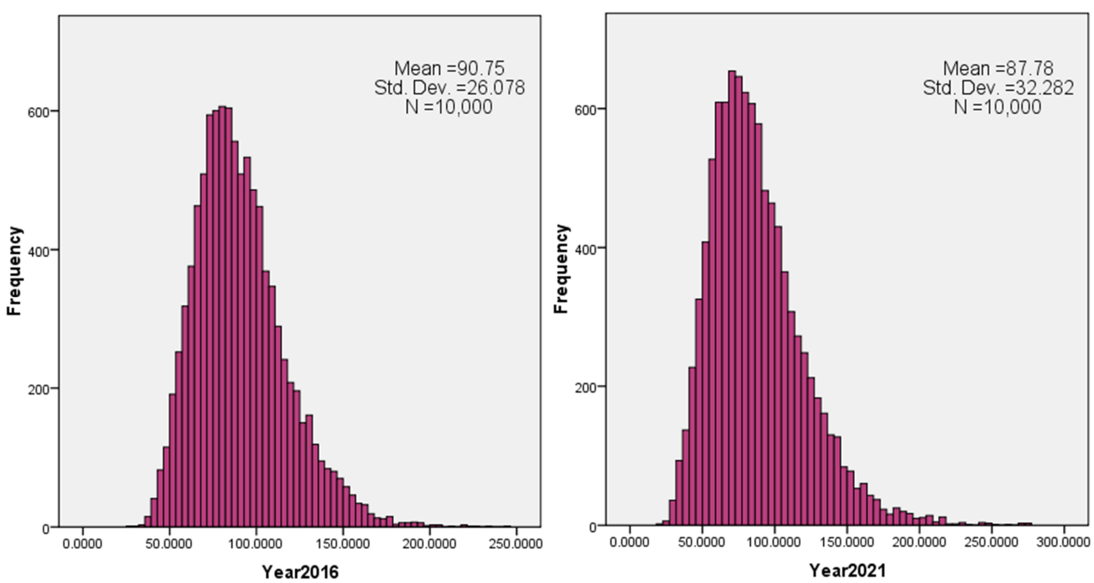

Figure 22. Distribution of the Energy Quantity Saving of 2016 and 2021

(σ_Q=10%)

The distributions of the energy savings quantity for each year (σ_Q =20%) are displayed in the following Figure 23.

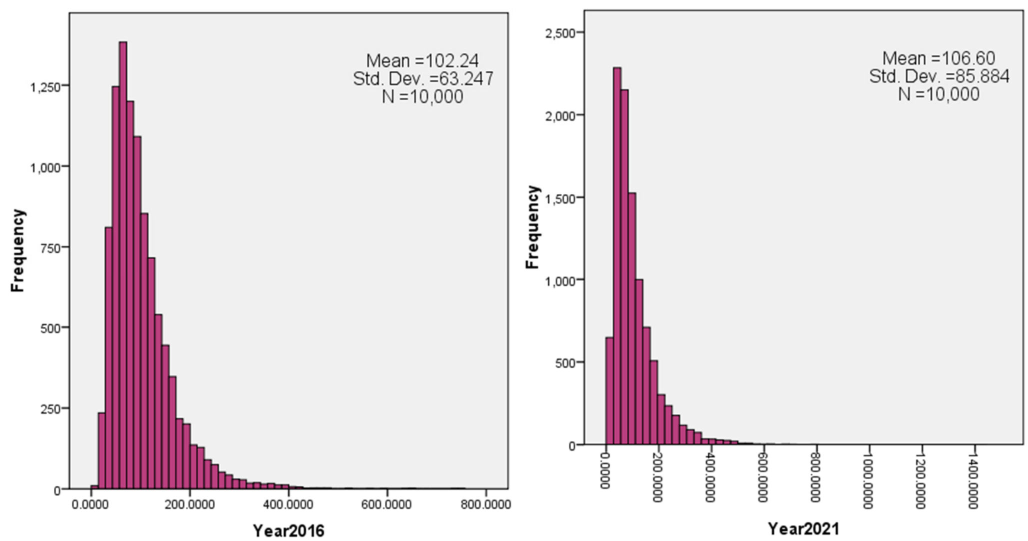

Figure 23. Distribution of the Energy Quantity Saving of 2016 and 2021 (σ_Q=20%)

4.2.3 General Energy Savings Pricing Model

In the general energy cost savings pricing model, the portfolio energy unit price at the t^{th} year (P_{Et}) also applies to the stochastic process as well as the total verified energy quantity savings (Q_t) at the same year. In the UMCP case, we assume the portfolio energy unit price at the t^{th} year (P_{Et}) and the total verified energy quantity savings (Q_t) are independent from each other.

The distributions of the energy cost savings for each year (σ_Q =1%) are displayed in the following Figure 24.

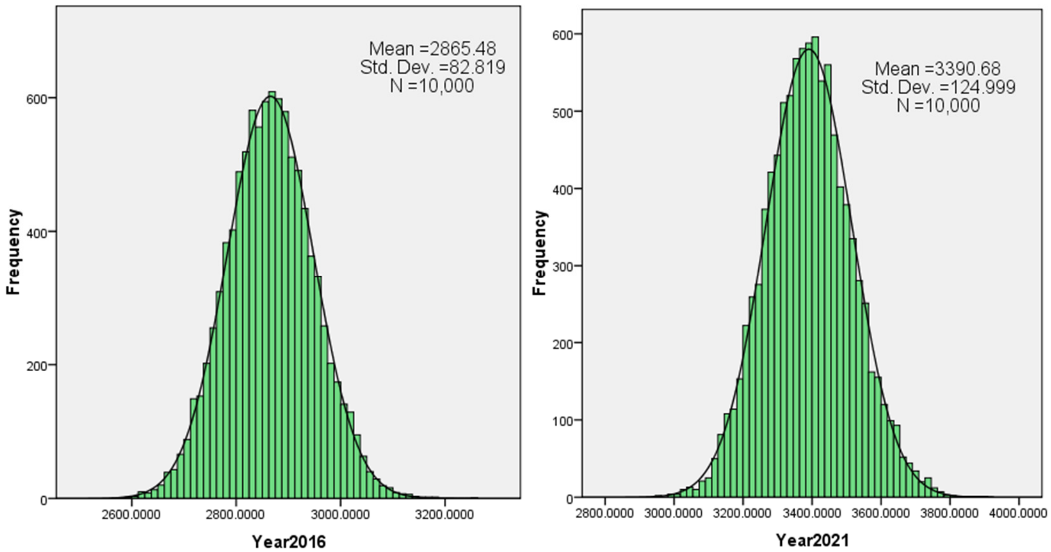

Figure 24. Distribution of the Energy Cost Saving of 2016 and 2021

(σ_Q=1%)

The distributions of the energy cost savings for each year (σ_Q =5%) are displayed in the following Figure 25.

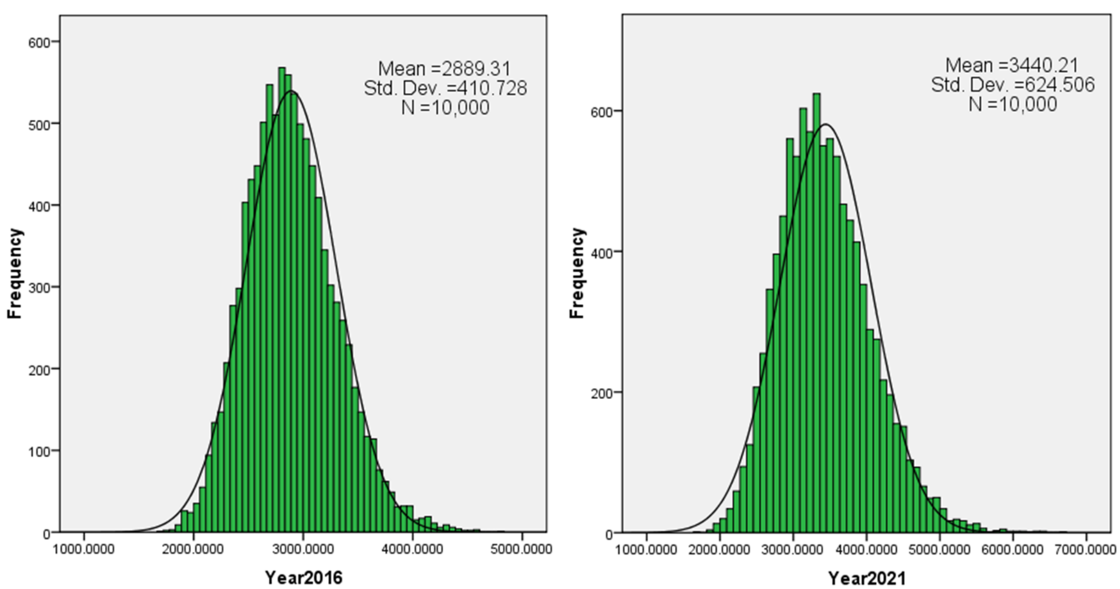

Figure 25. Distribution of the Energy Cost Saving of 2016 and 2021

(σ_Q=5%)

The distributions of the energy cost savings for each year (σ_Q=10%) are displayed in the following Figure 26.

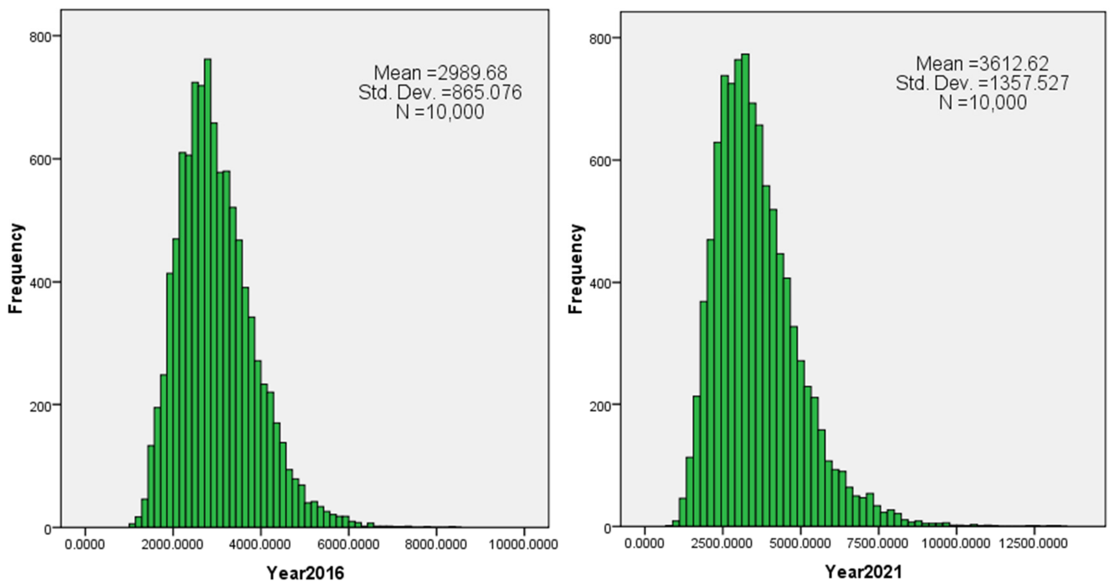

Figure 26. Distribution of the Energy Cost Saving of 2016 and 2021
(σ_Q=10%)

The distributions of the energy cost savings for each year (σ_Q=20%) are displayed in the following Figure 27.

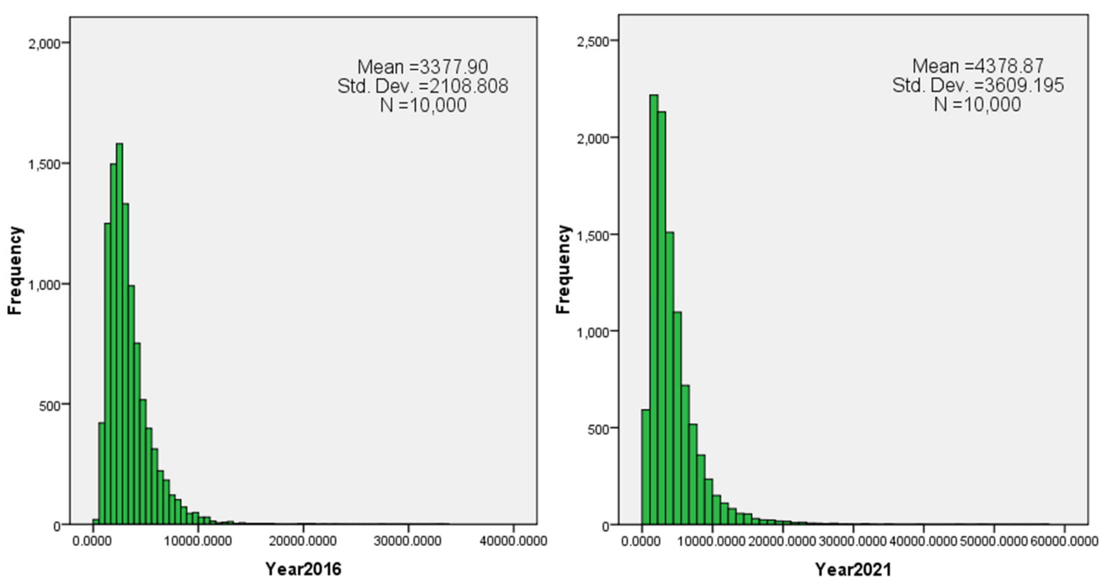

Figure 27. Distribution of the Energy Cost Saving of 2016 and 2021
(σ_Q=20%)

4.3 Simulation Results

Following discussions are primarily from Johnson Controls' perspective since ESCOs have more controlling on the project and also afford the potential loss risks from the guarantee. Based on the energy cost savings model, following simulation results have been reached, when the volatility of the energy savings quantity is at the 1%, 5%, 10% and 20% level (σ_Q=1%, σ_Q=5%, σ_Q=10%, σ_Q=20%), respectively. The discount rate here is considered as 10% (r =10%).

When the guaranteed annual energy savings stays constant (G_t = \$1,904,343), the following inner-relations between the client's proportion of the exceeding profit (α_1) and the sum of the ESCO's Extra Profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$) are displayed in Figure 28. Here, we find that they are negatively linear correlated at the certain facility performance volatility levels, which means the more proportions of the extra energy savings profit shared to the clients, the less extra profit could be held by ESCOs. There is only one point which could help the sum of the ESCO's extra profit stay at zero as Figure 28 shows. The Johnson Controls' guarantee combination (G_t = \$1,904,343; α_1=100%) meets the requirements when the volatility of the energy savings quantity is at the 1%, 5%, and 10% level (σ_Q =1%, σ_Q =5%, σ_Q =10%). If the some innovation technologies have been adopted in the project, Johnson Controls could think to share 10% the extra energy savings profit in order to avoid potential risks with the combination (G_t = \$1,904,343; α_1=90%)

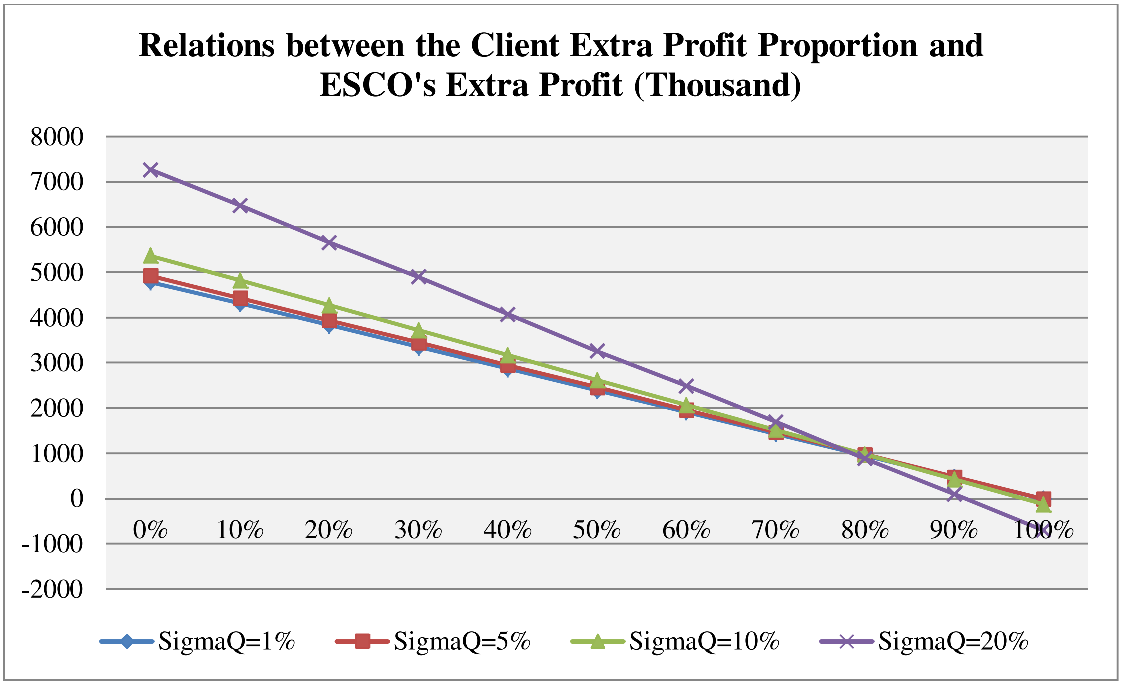

Figure 28. Relations between the Clients Sharing Proportion and ESCO's Extra Profit (G_t = \$1,904,343)

Here, we can conclude that for the UMCP case, given the Johnson Controls' guarantee of \$1,904,343 as the annual energy cost savings with the discount rate of 10%, the most competitive contract clause with minimum risk will be varied according to different facility reliability. From the linear relations between the client's proportion of the exceeding profit (α_1) and sum of the ESCO's Extra Profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$), when the volatility of the energy savings quantity is at the 1%, 5% and 10% level (σ_Q =1%, σ_Q =5%, σ_Q =10%), Johnson Controls has already reached the best guarantee contract which specifies as "if the energy savings were less than the guaranteed amount, Johnson Controls would pay the shortfall. And, if the savings went above the guarantee, UMCP would hold all the extra profit". When the volatility of the energy savings quantity is at the 20% level (σ_Q =20%), the later guarantee part will change to "UMCP would hold 90% of the extra profit and Johnson Controls will get 10%".

Also when the client's proportion in the exceeding profit (α_1=100%), Figure 29 displays the inner relations between the guaranteed annual energy savings (G_t) and sum of the ESCO's extra profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$).

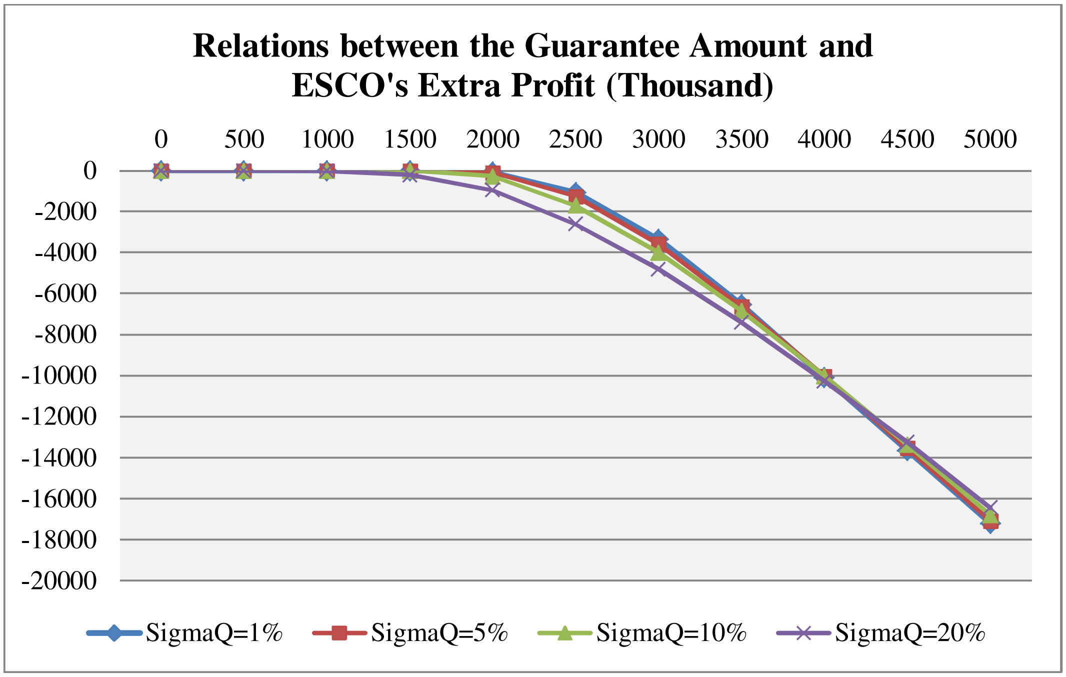

Figure 29. Relations between the Guarantee Amount and ESCO's Extra Profit

(α_1=100%)

We can conclude from Figure 29, given that the client holds all the extra profit beyond the energy saving guarantee (α_1=100%), the guarantee amount (G_t) and sum the ESCO's extra profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$) are negatively correlated. Also when the guarantee amount (G_t) stays at a low level, increasing of the guarantee amount (G_t) does not cause much effect on sum the ESCO's extra profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$). But as the guarantee amount going higher, the sum of the ESCO's extra profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$) decreases significantly. It would be very risky to increase the guaranteed saving amount when it is already at a high level and ESCOs should be really careful, no matter how reliable the installed ECMs performance are.

Based on the simulation result in Figure 28 and Figure 29 above, we can also reach the following Figure 30 which shows the inner relations between the energy savings guarantee amount (G_t) and the client's proportion in the exceeding profit (α_1). Similarly as the indifference curve in economics, each point on the curve here stands for a zero extra profit combination of the guaranteed saving amount (G_t) and the client extra profit proportion (α_1) for ESCOs. This curve helps deliver the quality work with minimum potential financial risk. As far as we can see, there is no significant difference on the guarantee amount when the client extra profit proportion stays low. For instance, the possible guarantee amount that ESCOs could make stays around $2,500,000 when client extra profit proportion changes from 0% to 70%. However, increase of the client extra profit proportion at a high level such as 90% will significantly decrease the possible guarantee amount that Johnson Controls could make on the energy performance contract. For the UMCP case, the Johnson Controls' guarantee combination (G_t = $1,904,343; α_1=100%) fits the curve when the volatility of the energy savings quantity stays at 1% (σ_Q=1%).

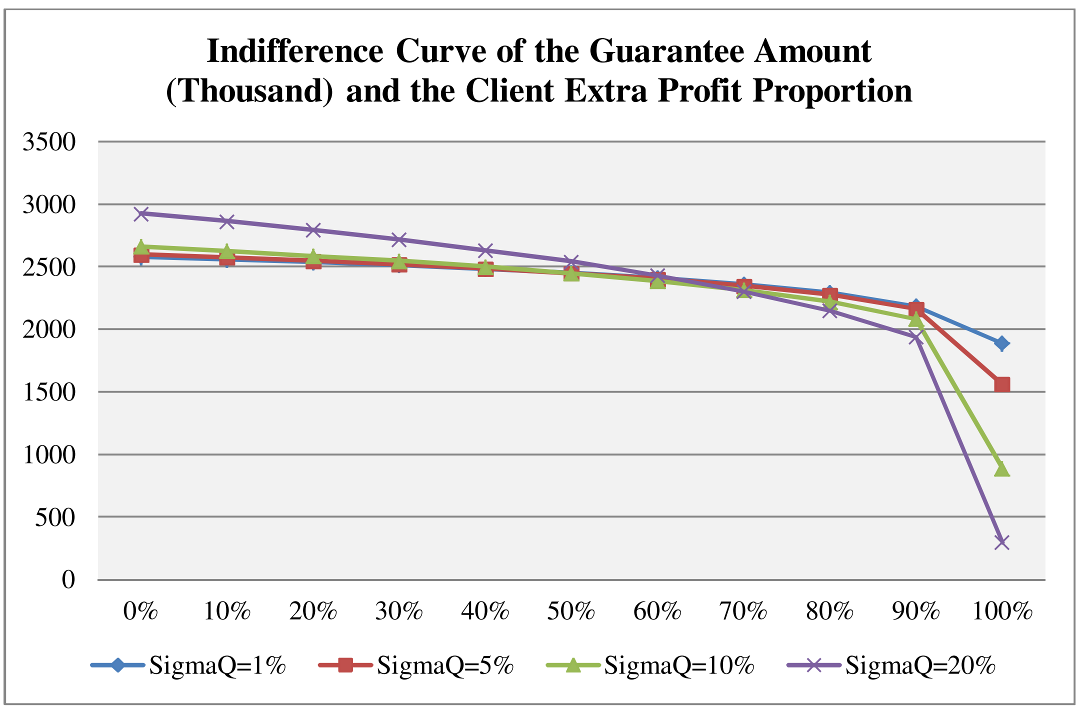

Figure 30. Relations between the Guarantee Amount and the Clients' Extra Profit Proportion

However it shall be very risky if some innovative energy conservation measures have been installed since the facilities performance may not stay that stable. According to Figure 30 above, we recommend Johnson Controls to change the guarantee combination from (G_t = \$1,904,343; α_1=100%) to (G_t = \$2,400,000; α_1=65%), which not only reduces the equipment reliability effect risk, at the same time, shows more competitive guarantee savings amount to the clients.

When the guaranteed annual energy savings stays constant (G_t = \$2,400,000), the following inner-relations between the client's proportion of the exceeding profit (α_1) and the sum of the ESCO's Extra Profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$) are displayed in Figure 31. The point which could help the sum of the ESCO's extra profit stay at zero moves to when the clients' extra profit proportion equals to 65%. The Johnson Controls' guarantee combination (G_t = \$2,400,000; α_1=65%) meets the requirements when the volatility of the energy savings quantity is at the 1%, 5%, 10% and 20% level (σ_Q=1%, σ_Q=5%, σ_Q=10%, σ_Q=20%).

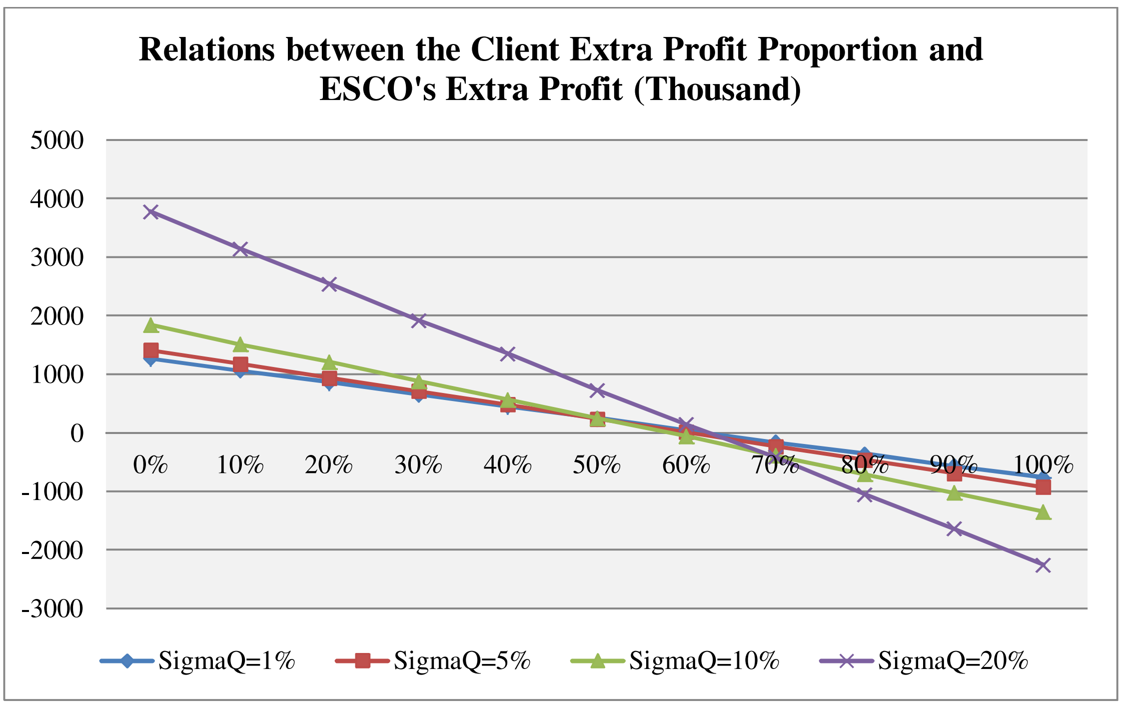

Figure 31. Relations between the Clients Sharing Proportion and ESCO's Extra Profit

Also when the client's proportion in the exceeding profit (α_1=65%), Figure 32 displays the inner relations between the guaranteed annual energy savings (G_t) and sum of the ESCO's extra profit ($\sum_{t=1}^{n}\frac{Profit'_{Et}-Profit_{Et}}{(1+r)^t}$).

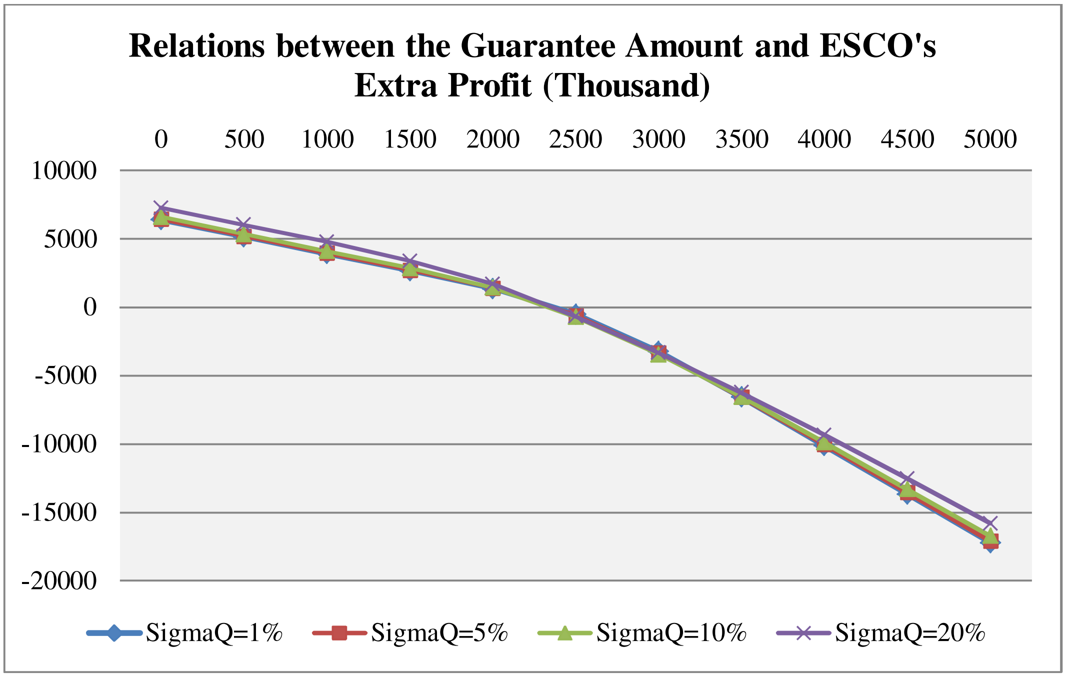

Figure 32. Relations between the Guarantee Amount and ESCO's Extra Profit

We can conclude from Figure 32, the when the client's proportion in the exceeding profit (α_1=65%), the guarantee amount should be set when the ESCO's extra profit equals to zero (G_t=\$2,400,000).

4.4 Case Discussion

Compared with the financial option pricing model, two different stochastic models have been used for the evolution process analysis of the portfolio energy unit price of the t^{th} year (P_{Et}) and the total energy savings quantity at the t^{th} year (Q_t) based on their respective characteristic features, fully considering the potential movement possibilities. Case data for estimation mainly comes from the project contract, the energy price report, Monte-Carlo simulation and the experienced engineers' subjective judgment.

We could also learn several things from the Johnson Controls and UMCP case study. The energy savings guarantee has changed the financial risks allocations in the energy performance contract. There are inner relations among the energy cost savings guarantee amount (G_t), the client extra profit proportion (α_1) and the ESCO's extra profit ($\sum_{t=1}^{n} \frac{Profit'_{Et} - Profit_{Et}}{(1+r)^t}$), given certain ECMs reliability level. All of them are important parameters that ESCOs should consider when they plan to make the energy savings guarantee in the project contract based on their completed feasibility estimation.

Chapter 5: Conclusions

5.1 Summary

Climate change and energy supply concerns have led many state and national leaders to support an increasingly prominent role for energy efficiency in energy policy. It has become one of the quickest and cheapest ways to increase the amount of energy available for use. This research has discussed about the energy performance contracting (EPC) mode which is a popular building energy efficiency service that Energy Services Companies (ESCOs) use the stream of future utility cost savings to repay their initial renovation investments. The general ESCO market segments and industry structure have also been reviewed as well as the real option theory development in the literature review part. EPC helps the risk-avoided clients take charge of the large initial capital investment for the project construction and installation. A comprehensive set of Energy Conservation Measures (ECMs) is provided according to the project situation and a minimum amount of annual energy savings guarantee is usually specified in the contract.

This thesis develops a systematic guarantee designing method for ESCOs to evaluate the potential financial risks, which comes from both the energy price volatility and the facility performance instability, during the decades of operation and maintenance period. Two types of energy savings guarantee models are identified according to their different risk factors and the guarantee underlying assets. The real option method has been adopted in order to analyze the evolution process with each influential parameter respectively and estimate the potential value of the energy savings guarantee.

This research also conducts an EPC case study of the University of Maryland, College Park (UMCP) campus in order to show the application of the proposed model. It is an energy cost savings guarantee contract with a 13-year operation and maintenance period signed by the client UMCP and the ESCO Johnson Controls. Finally, recommendations have been given to the ESCOs when they plan to make the energy savings guarantee in the project contract base on their completed feasibility estimation. Several important parameters and the inner correlations should be taken into consideration. The balance contract will help ESCOs reasonably allocate the estimation financial risks with successful contract negotiation.

5.2 Contribution of the Research

The framework proposed in this thesis is generally applicable to the flexible guarantee design of the long-operation period performance contracting, not only limited to the energy efficiency area. Several contributions of this research have been summarized as follows.

1. Identified the financial risk allocation changes that the energy savings guarantee has made in the energy performance contract.

After the in-depth review of the EPC background information, the inner relations among the predicted energy savings, the verified energy savings and the guaranteed energy savings have been explored based on the corresponding selected ECMs for usage. Potential financial risks come from both the energy price volatility and the facility performance instability during the decades of operation and maintenance period. Two types of energy savings guarantee models are also identified according to their different risk factors with the varied underlying guarantee.

2. Simulated the evolution processes for the possible annual energy savings amount from both the quantity and the cost perspectives.

Volatility causations for the annual energy savings in EPC mainly come from both the energy price rate and the renovation facility performance instability. Here the Geometric Brownian Motion (GBM) is assumed in this study as the stochastic process to represent the evolution process of the annual energy savings volume and the energy price rate. Simulations have also been adopted for the future status estimation where the risk factors vary stochastically.

3. Assisted ESCOs to develop optimal guarantee strategies in order to effectively mitigate the financial risk.

Based on the stochastic process framed and the energy savings volatility identified, the amount of energy savings guarantee specified in the contract has very tight relations with several parameters such as the energy cost savings guarantee amount, the clients' extra profit sharing proportion and the general guarantee present value, given certain ECMs reliability level. ESCOs should consider when they plan to make the energy savings guarantee in the project contract based on their completed feasibility estimation.

5.3 Future Research Development

Following are several important follow-on research directions:

- How to compliment the stochastic model considering the possible correlations between the energy price rate, the energy consumption quantity and the O&M cost. More EPC cases and data collections are still needed to complete the model;

- How to define the systematical inner relations among those parameters such as the energy cost savings guarantee amount, the clients' extra profit sharing proportion, the ESCO's extra profit and the ECMs reliability directly associated with motivational mechanism;

- How to apply the guarantee risk allocation framework to other kind of performance contracting projects such as the BOT (Build-Operate-Transfer) infrastructure project where some other kind of guarantees exist;

Appendices

Appendix I. Residential Sector Energy Price and Expenditure Estimates

Year	Primary Energy								Retail Electricity	Total Energy
	Coal	Natural Gas	Petroleum				Biomass	Total		
			Distillate Fuel Oil	Kerosene	LPG	Total	Wood			
	Prices in Dollars per Million Btu									
1970	1.14	1.06	1.39	1.54	2.08	1.54	0.66	1.22	6.51	2.10
1975	2.45	1.67	2.74	3.14	3.96	3.01	1.31	2.11	10.29	3.80
1980	2.90	3.60	7.02	8.32	7.82	7.24	3.10	4.50	15.71	7.46
1985	3.26	5.94	7.93	7.90	8.98	8.13	3.71	6.37	21.66	10.91
1990	3.01	5.63	8.01	7.46	10.79	8.66	3.59	6.21	22.96	11.87
1995	2.58	5.89	6.52	5.74	10.62	7.61	2.88	6.13	24.63	12.62
1996	2.53	6.16	7.47	6.33	12.04	8.79	3.30	6.60	24.50	12.72
1997	2.48	6.75	7.45	6.29	11.99	8.77	3.24	7.06	24.71	13.29
1998	2.46	6.61	6.44	5.25	10.79	7.70	2.80	6.72	24.21	13.47
1999	2.37	6.50	6.61	5.73	10.67	7.94	2.87	6.71	23.93	13.18
2000	2.24	7.64	9.92	9.13	14.26	11.36	4.32	8.37	24.14	14.26
2001	2.93	9.42	9.48	8.81	15.59	11.46	4.22	9.75	25.16	15.67
2002	2.59	7.69	8.60	8.26	13.17	10.20	3.83	8.12	24.75	14.69
2003	2.46	9.24	10.32	9.83	15.50	12.09	4.60	9.73	25.56	15.85
2004	3.03	10.47	11.72	11.33	17.56	13.59	5.22	11.01	26.22	17.06
2005	3.46	12.34	15.53	14.76	20.29	17.10	6.96	13.22	27.68	19.20
2006	3.51	13.35	17.89	18.59	22.83	19.66	8.02	14.48	30.49	21.54
2007	3.50	12.72	19.62	21.27	24.93	21.65	8.80	14.34	31.22	21.62
2008	4.62	13.50	24.36	25.55	29.36	26.53	10.93	15.87	33.01	23.14
	Expenditures in Million Dollars									
1970	236	5,272	2,603	459	1,124	4,186	68	9,761	10,352	20,112
1975	153	8,410	4,954	504	1,964	7,422	143	16,128	20,644	36,771
1980	90	17,497	9,234	887	2,331	12,451	678	30,716	38,458	69,174
1985	127	27,136	8,667	1,252	2,650	12,570	944	40,776	58,672	99,448
1990	93	25,439	7,839	477	3,591	11,907	878	38,317	72,378	110,696
1995	45	29,362	5,903	426	3,960	10,289	657	40,352	87,610	127,961
1996	41	33,219	6,920	562	5,314	12,796	781	46,837	90,503	137,340
1997	39	34,590	6,516	584	5,139	12,239	630	47,497	90,704	138,201
1998	31	30,875	4,975	569	4,309	9,852	484	41,242	93,360	134,602
1999	33	31,577	5,471	637	5,289	11,397	522	43,529	93,482	137,012
2000	24	38,959	8,980	864	7,440	17,283	843	57,109	98,209	155,319
2001	32	46,189	8,610	837	7,721	17,169	694	64,083	103,158	167,241
2002	31	38,490	7,393	495	6,661	14,549	639	53,709	106,834	160,542
2003	30	48,278	9,334	691	7,984	18,010	807	67,125	111,249	178,374
2004	35	52,265	10,830	961	8,474	20,264	940	73,503	115,577	189,080
2005	29	61,196	13,261	1,237	9,822	24,320	1,248	86,793	128,393	215,186
2006	22	59,834	12,738	1,233	9,559	23,531	1,309	84,695	140,582	225,277
2007	27	61,598	14,247	934	11,287	26,468	1,582	89,675	148,295	237,970
2008	37	67,490	16,162	544	15,231	31,937	2,056	101,520	155,433	256,953

Appendix II. Commercial Sector Energy Price and Expenditure Estimates

Year	Primary Energy										Retail Electricity	Total Energy
	Coal	Natural Gas	Petroleum						Biomass	Total		
			Distillate Fuel Oil	Kerosene	LPG	Motor Gasoline	Residual Fuel Oil	Total	Wood and Waste			
	Prices in Dollars per Million Btu											
1970	0.44	0.75	1.10	0.77	1.26	2.86	0.45	0.91	0.66	0.80	6.09	1.97
1975	1.31	1.32	2.42	2.32	2.62	4.66	1.91	2.40	1.31	1.68	10.11	4.07
1980	1.53	3.32	6.45	6.46	5.19	9.77	4.12	5.64	3.10	4.01	16.06	7.83
1985	1.77	5.34	6.33	8.18	9.43	9.01	4.50	6.50	3.71	5.54	21.30	11.64
1990	1.64	4.70	5.97	7.31	9.29	9.15	3.41	6.07	3.02	4.94	21.20	11.88
1995	1.55	4.94	4.70	5.55	9.42	9.40	3.14	5.18	2.25	4.85	22.29	12.63
1996	1.51	5.26	5.63	6.40	10.75	10.28	3.75	6.23	2.47	5.30	22.17	12.77
1997	1.51	5.67	5.28	6.18	10.97	10.01	3.27	6.16	2.43	5.59	22.03	13.04
1998	1.51	5.38	4.15	4.88	9.95	8.73	2.38	5.14	2.09	5.20	21.48	13.06
1999	1.51	5.22	4.65	5.33	9.71	9.45	2.69	5.62	1.89	5.15	21.01	12.86
2000	1.45	6.56	7.48	8.87	12.70	11.94	4.49	8.36	2.99	6.75	21.52	13.92
2001	1.57	8.32	6.70	8.38	13.72	11.50	4.06	7.96	3.22	8.05	22.99	15.56
2002	1.63	6.49	6.21	8.14	11.20	10.81	4.08	7.23	2.81	6.47	22.81	14.67
2003	1.59	8.07	7.62	9.80	13.23	12.26	5.30	8.71	3.48	8.01	23.54	15.64
2004	1.84	9.19	9.58	11.41	15.37	14.44	5.26	10.27	3.54	9.14	23.95	16.57
2005	2.25	10.98	13.63	14.96	17.95	17.86	7.48	13.68	4.67	11.19	25.40	18.61
2006	2.37	11.60	15.74	18.73	20.11	20.20	8.69	16.09	4.72	12.14	27.72	20.65
2007	2.47	10.98	17.24	21.13	22.19	21.94	9.71	17.73	5.54	11.87	28.27	20.75
2008	2.84	11.89	23.85	25.57	26.26	25.46	13.19	23.31	6.58	13.48	30.38	22.49
	Expenditures in Million Dollars											
1970	72	1,844	646	47	177	247	323	1,440	1	3,358	7,319	10,678
1975	191	3,385	1,423	114	329	415	939	3,219	3	6,799	16,157	22,956
1980	179	8,858	3,337	262	438	1,046	2,325	7,409	17	16,463	30,611	47,074
1985	243	13,368	3,995	268	842	866	1,025	6,996	22	20,633	50,092	70,725
1990	203	12,681	3,199	87	898	1,018	785	5,986	104	18,979	60,627	79,605
1995	181	15,383	2,250	123	967	170	445	3,956	106	19,625	72,481	92,605
1996	181	17,106	2,717	135	1,239	273	515	4,879	127	22,293	74,121	96,414
1997	195	18,755	2,344	152	1,244	428	363	4,531	125	23,606	77,153	100,758
1998	151	16,667	1,778	152	1,102	340	203	3,575	99	20,492	78,999	99,492
1999	154	16,351	2,038	143	1,283	269	197	3,931	104	20,539	79,141	99,681
2000	125	21,339	3,672	263	1,796	532	411	6,674	155	28,294	85,129	113,423
2001	139	25,879	3,404	263	1,844	430	284	6,225	145	32,388	93,402	125,790
2002	143	20,926	2,758	130	1,485	488	326	5,187	146	26,402	93,763	120,164
2003	132	26,411	3,668	183	1,964	735	589	7,137	188	33,868	96,263	130,132
2004	189	29,518	4,506	234	2,203	645	644	8,233	209	38,148	100,546	138,694
2005	215	33,838	6,098	323	2,226	817	866	10,331	258	44,642	110,522	155,164
2006	153	33,736	6,314	284	2,327	984	654	10,563	262	44,714	122,914	167,628
2007	174	34,005	6,620	194	2,522	1,342	732	11,410	305	45,894	128,903	174,797
2008	206	38,259	8,791	109	3,893	1,164	965	14,922	394	53,780	138,469	192,249

Appendix III. Simulation Results of the Clients Extra Profit Proportion and Sum of ESCOs' Extra Profit (G_t=$1,904.343)

Alpha1	ESCO Extra Profit (σ_Q = 1%)	ESCO Extra Profit (σ_Q = 5%)	ESCO Extra Profit (σ_Q = 10%)	ESCO Extra Profit (σ_Q = 20%)
0%	4794.78	4932.62	5372.31	7272.62
10%	4316.12	4438.49	4823.91	6478.68
20%	3835.55	3946.24	4276.42	5658.05
30%	3357.54	3453.1	3721.76	4902.75
40%	2875.56	2951	3173.93	4076.94
50%	2396.44	2464.9	2623.24	3264.3
60%	1917.14	1966.19	2068.85	2491.35
70%	1437.77	1474.72	1527.71	1699.31
80%	957.95	982.6	978.49	888
90%	478.13	487.26	425.46	103.19
100%	-1.42	-6.17	-123.05	-694.65

Appendix IV. Simulation Results of the Energy Cost Savings Guarantee and Sum of ESCOs' Extra Profit (α_1=100%)

Guarantee amount	ESCO Extra Profit (σ_Q = 1%)	ESCO Extra Profit (σ_Q = 5%)	ESCO Extra Profit (σ_Q = 10%)	ESCO Extra Profit (σ_Q = 20%)
0	0	0	0	0
500	0	0	0	-0.49
1000	0	0	-0.04	-26.37
1500	0	0	-7.53	-222.86
2000	-86.75	-106.52	-285.03	-955.61
2500	-1063.93	-1248.55	-1706.78	-2615.5
3000	-3357.79	-3577.77	-3991.48	-4810.7
3500	-6546.06	-6635.86	-6833.47	-7390.06
4000	-10093.14	-10014.12	-10017.8	-10262.43
4500	-13641.14	-13520.83	-13347.21	-13230.54
5000	-17195.54	-17065.73	-16775.74	-16417.35

Appendix V. Simulation Results of the Energy Cost Savings Guarantee and the Clients Extra Profit Proportion

Alpha1	Guarantee Amount (σ_Q = 1%)	Guarantee Amount (σ_Q = 5%)	Guarantee Amount (σ_Q = 10%)	Guarantee Amount (σ_Q = 20%)
0%	2579	2598	2661	2926
10%	2559.5	2575	2627	2865
20%	2537	2548	2586	2794
30%	2512.5	2518.5	2546	2718
40%	2484	2485	2501	2632
50%	2451	2447	2448	2541
60%	2411	2403	2386	2432
70%	2361	2347	2313	2305
80%	2294	2275	2219	2151
90%	2187	2164	2085	1940
100%	1889	1563	890	300

Appendix VI. Simulation Results of the Clients Extra Profit Proportion and Sum of ESCOs' Extra Profit (G_t=$2,400)

Alpha1	ESCO Extra Profit (σ_Q = 1%)	ESCO Extra Profit (σ_Q = 5%)	ESCO Extra Profit (σ_Q = 10%)	ESCO Extra Profit (σ_Q = 20%)
0%	1274.48	1416.58	1849.43	3785.57
10%	1069.52	1183.95	1512.91	3151.67
20%	865.35	942.79	1213.48	2545.94
30%	659.32	715.39	887.63	1925.71
40%	455.91	486.59	572.32	1357.06
50%	255.26	241.01	252.6	731.93
60%	48.98	19.21	-52.55	147.45
70%	-154.3	-225.26	-387.92	-409.91
80%	-358.08	-456.93	-700.44	-1044.78
90%	-561.55	-689.09	-1020.96	-1631.9
100%	-765.28	-921.74	-1342.81	-2246.87

Appendix VII. Simulation Results of the Energy Cost Savings Guarantee and Sum of ESCOs' Extra Profit (α_1=65%)

Guarantee amount	ESCO Extra Profit (σ_Q = 1%)	ESCO Extra Profit (σ_Q = 5%)	ESCO Extra Profit (σ_Q = 10%)	ESCO Extra Profit (σ_Q = 20%)
0	6412.57	6457.93	6623.96	7278.57
500	5168.52	5216.4	5368.79	6025.26
1000	3926.48	3973.39	4130.43	4796.75
1500	2683.12	2734.1	2882.82	3399.94
2000	1382.72	1419.1	1452.89	1711.21
2500	-494.53	-573.18	-706.61	-660.13
3000	-3227.39	-3323.28	-3428.65	-3321.25
3500	-6546.02	-6553.79	-6524.09	-6208.23
4000	-10091.86	-9996.43	-9856.71	-9321.74
4500	-13643.02	-13519.78	-13280.58	-12507.65
5000	-17195.55	-17072.04	-16695.85	-15792.73

Glossary

AEPCA	The Australasian Energy Performance Contracting Association
BOT	Build-Operate-Transfer
DFS	Detailed Facility Study
DOE	Department of Energy
DOT	Department of Transportation
ECM	Energy Conservation Measure
EOI	Expressions of Interest
EPC	Energy Performance Contracting
ESCO	Energy Service Company
ESPC	Energy Savings Performance Contracting
FEMP	Federal Energy Management Program
GBM	Geometric Brownian Motion
GHG	Greenhouse Gas
IPMVP	International Performance Measurement and Verification Protocol
IRR	Internal Rate of Return
LBNL	Lawrence Berkeley National Laboratory
MUSH	Municipal, University, School, Hospital
M&V	Measurement and Verification
NPV	Net Present Value
O&M	Operation and Maintenance
ORNL	Oak Ridge National Laboratory
RFP	Request For Proposal
UMCP	University of Maryland, College Park

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