Implementing energy performance contracting in the public school sustainable retrofit project

a decision support tool for EPC contract desing using Monte Carlo simulation and nonlinear programming

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Preface

This master graduation thesis elaborates on the applicability of energy performance contracting in the public school sustainable retrofit project. This research is conducted with cooperation with supervisors from Eindhoven University of Technology.

Energy in buildings is one of the most effective and helpful way to achieve energy saving in the whole society. After finalizing this research, I believe that I have got a better understanding about the energy efficiency in buildings and the mechanism of energy performance contracting. I hope that this effective business model could achieve more success not only in the Netherlands but also in my own motherland and I also wish that my research can make any contribution to the development of this new business area.

I want to thank my supervisors at Eindhoven University of Technology. Brano Glumac, for your scientific knowledge which helped me determining the research topic and following research methods for the thesis. During the whole process of finalizing this thesis, your feedbacks and suggestions helped me to structure the whole paper and keep improving it. Paul Masselink, for your knowledge and ideas helped me to get an insight about sustainability in the built environment. Every discussion with you not only helped me to gain professional knowledge but also lead me to a new way of thinking about my research topic. For professor Bauke de Vries, for your suggestions helped me improving this thesis.

I also want to thank my family and friends for providing me support during the whole graduation time. It is the support from you guys helped me to overcome this tough time.

Finally, I hope readers will enjoy reading this report.

Chenyang Kou
13th July 2015

Summary

This thesis is aimed at developing a decision support tool to help both parties within the ESCO to get an insight about the energy performance contracting (EPC) and providing an optimization contract design considering the key contract terms which affect the success on the public school retrofit projects.

The reasons for choosing this research topic are based on several following thinking. Firstly, energy efficiency and sustainability has been one of the most hot and interested topics in the construction management and urban development areas. Secondly, as Netherlands has already set its own goal toward the EU 2020 targets, energy efficiency in built environment is considered with most potential in energy savings. Thirdly, schools are facing with problems not only in high level of energy consumptions but also bad indoor environment quality in their buildings.

To solve these problems, sustainable retrofit activities should be taken by the schools. But in reality, many schools are stopped due to lack of financial support. At the same time, the energy performance contracting (EPC) provided by the energy service company (ESCO) has been seen as an effective business mechanism for achieving energy efficiency in built environment and solving financial problem for its client. Nevertheless, the implementation level of EPC in Netherlands is low. The main problem hinders the widely adoption of this business model is lack of awareness and trust of EPC by its potential client.

So based on the previous information, a decision support tool is developed in this thesis. It is aimed at helping users not only to get an insight about what is EPC and what are the most important issues in it but also get a support on contract design which means providing users with optimized key contract terms to success in the project.

To develop the decision support tool, firstly a literature review is conducted. The literature review reviewed scientific publications which focused on modeling techniques for EPC in public buildings. There are mainly two parts in the literature review, the review of modeling approaches and key variables in existing literatures. For the modeling approaches, there are many different approaches to solve corresponding problems for example financial problem or risk management problem in EPC projects. The research methods employed in this thesis are from the literature review considering the own research characteristics in the thesis. After determining the research methods, key variables needed to be used are also from the literature review part. In the variables part, it is mainly focused on the financial variables which influencing the EPC project, more specifically, influencing the net present value (NPV) of the project. After the literature review, the key variables are ready for model development.

As the decision support tool in this thesis is focusing on financial part of EPC project, so that NPV is employed as key evaluation indicator. NPV equations for both parties within the ESCO are formulated by previously defined key variables. As there are many uncertainties influencing the NPV during the whole project lifetime of the EPC project, Monte Carlo simulation is employed to deal with these uncertainties. The uncertain variables are generated from uncertain values into certain range of value and split into different

scenarios. Finally, considering the equations of the NPV for each side are non-linear equations, so that the optimization process employed non-linear programming to get the final result. The optimization process is performed by the professional software in Microsoft Excel®. The non-linear programming is performed to get the optimization result considering the key contract terms like contract period, sharing ratio of investment and profit under different scenario and NPV sharing strategies.

In order to test the applicability of this decision support tool, a case study is employed. The case study provided certain variable values and result of Monte Carlo simulation is used as uncertain variable values as data input. Under every scenario and NPV deviation strategy, the result provided 5 best options including contract period, sharing ratio of investment and profit values. These options can be used as information resource for further negotiation procedure in the decision making process. So the result verifies the usability of this decision support tool.

Due to the limited data resource and time, there are many limitations of this research. For the further research, a more detail analysis about the uncertainties within the NPV of project is one of the directions. Also as the decision making process not only just taking financial part of project into account, a broader decision support tool which considering the whole process of the decision making process in the EPC project in public school sustainable retrofit project is needed.

However, I hope this thesis could make any contribution to the promotion of EPC in the Netherlands and benefit the whole society in its own way.

Abstract

In the current world, saving energy in the whole society has been a global hot topic in people's daily life. Built environment is considered as the area which has the most potential for energy efficiency in the Netherlands. For the schools, the behindhand energy facilities on one hand lead to huge energy consumption, on the other hand, they also caused great problems of indoor environment quality in these schools. So that schools are with urgent need for sustainable retrofitting. The energy service company (ESCOs) and energy performance contracting (EPC) is considered as one of the most effective mechanism for achieving energy efficiency in built environment. But the implementation level of it is with a low level in the Netherlands due to lack of awareness and trust. So this thesis developed a decision support tool which aims at helping the users to get a better understanding about the EPC contract and its applicability in sustainable school retrofit project. More specifically, this decision support tool is focusing on the financial part of the decision making part and provides optimization contract design with key contract terms to users to help them in decision making. Firstly a literature review is conducted to identify all the key variables needed in the model. Then system dynamics and net present value (NPV) are employed to represent the financial interest of each party within the ESCO. Then Monte Carlo simulation is used to generate the range values of uncertain variables within the NPV equations. After that, this thesis used non-linear programming to finish the optimization process and get the final result. A case study is employed to verify the usability of this decision support tool. The result suggested that this decision support tool can provide the users with exact result which is expected in the research goal.

1. Introduction

1.1 Low implementation level of energy performance contracting in sustainable school retrofit project

In the current world, energy issues have already been one of the most critical problems in all the countries. It is not only influencing the short term economic development for the society, but also affecting the long term social and country safety and steady. To achieve the EU 2020 targets, every member state in EU has set their own energy policy and target. In the Netherlands, the buildings accounts for 30% of the energy consumption, which means that energy consumption in building plays an important role for achieving energy efficiency for the whole society.

More specifically, the energy consumption in schools is pretty high which with a high level potential of energy savings. The equipment and facilities such as ventilation, heating, lighting, air conditioning, insulation and energy control system are in a behindhand level. These situations not only result in a high level of annual energy consumption bill for schools, but also low level of indoor environment quality which has significant influence on students learning behavior. So that many schools are facing the urgent need for retrofitting or renovation activities to improve their indoor environment quality, reduce the energy consumption and the CO_2 commission. This kind of projects can be regarded as the sustainable school retrofit projects.

But decision making of such sustainable school retrofit projects is really complicated. The complicacy is reflected in the multiple involved stakeholders, numerous evaluation criteria and potential risks. When the likewise project start, related stakeholders are not only the school board, the local government and the contractors, but also the teachers, the students and their parents. All these people can be participated in and give their influence on the success on this kind of project. This means that a clearly stakeholder identification will help to specify the ambition of each side and the potential result which they will achieve.

Then when all these stakeholders sit together to negotiate the plan of such project, there are many aspects of criteria need to be taken into consideration. The Figure 1 shown below is an example of ambition map of a fresh school project in the Netherlands:

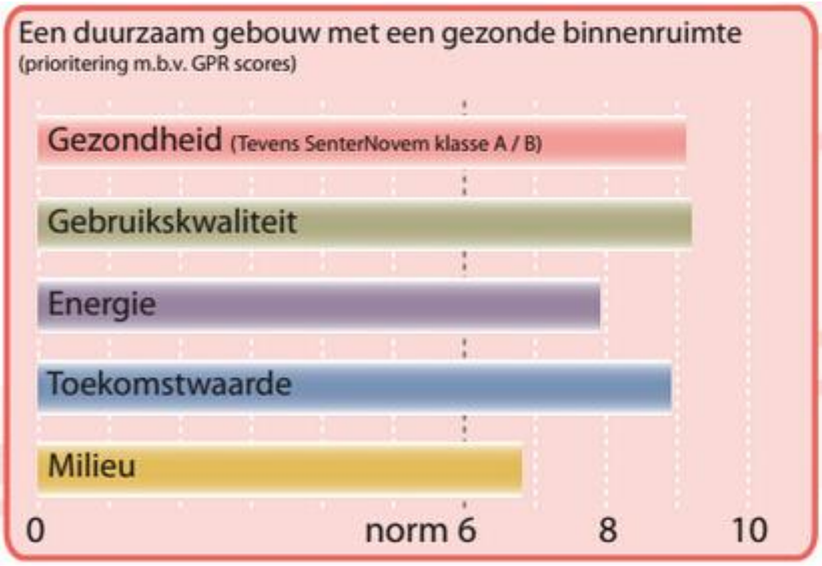

Figure 1. Ambition map of a fresh school project

First of all, it is the financial problem. All the improvement activities need the financial support. Without the money, nothing can be implemented from plan to reality. This is also the main problem that many schools are facing which means that they have the ambition to make things different, but the plan is abeyant without enough financial support. Then it is the ambitions need to be identified. This means that stakeholders need to negotiate what they want to achieve by the retrofit project, including how much CO_2 commission reduction, how much energy cost savings, how much indoor environment quality improvement and how the future of the school they want. These ambitions will decide what measures need to be taken and relative investment cost. There are also many risks involved in the project. For example, the legislation about the energy policy will directly affect the situations in the coming future on the school which means that some common techniques today may not be allowed to be used after several decades. Technique revolution also needs to be taken into consideration. Great innovations of new energy may totally change the energy market so that makes the renovation work worthless in a short term. The healthy influence is also one issue stakeholders need to negotiate. As the school is the place where our next generation group up, the health condition for them will directly has influence on the future of our society. So that it is not excessive to put no matter how much attention or investment on it.

So it is clear that making decision on the sustainable school retrofit project is a complicated work. Considering the information resource and time limitation, this graduation thesis chooses to focus on the financial part of decision making during the whole project decision making.

There are many ways to solve the financial problem. The energy performance contracting (EPC) provided by the energy service company (ESCO) is regarded as one of the most effective mechanism to achieve the energy efficiency in buildings. But the implementation level of EPC in schools is really low. One of the most common reasons is that the potential client has a low level of awareness about this EPC mechanism and lack of trust due to few successful example projects. So that in this graduation thesis the research problem will be focused on improving the awareness level of the EPC in the sustainable school retrofit project.

1.2 Research question

As already has introduced in previous, due to the low level of awareness and trust, implementation level of EPC in school sustainable project is still very low. So that if there is an available decision support tool which aims at helping the potential clients as well as the ESCO to get a better understanding about what is the EPC, how it can be used in the sustainable school retrofit project and what are the contract terms needed to be negotiated, of course the awareness about this mechanism will increase within the potential clients. So that the research question is formulated as:

"If it is possible to build a decision support tool for the partners within the ESCO to get an insight about the EPC and give an optimal EPC contract considering the key contract terms to success in the school sustainable retrofit project?"

To answer this main research question, there are some sub-questions need to be answered:

"What are the characteristics of public school sustainable renovation project?"

"What is the Energy Performance Contracting (EPC) and its pro's and con's compared with other funding methods?"

"What are the key variables in EPC contract and their interaction relationships?"

"How to optimize the EPC contract and how to evaluate it is optimized?"

"How the stakeholders can use this decision support tool?

1.3 Research design

1.3.1 Methodology justification

Literature study

To answer the first three sub questions, literature study will be employed to analyze the characteristics of the sustainable school renovation project, the EPC and its advantages and disadvantages and the key variables identification. The key variables of the EPC contract will be investigated and their interaction relationships need to be elaborated. After the literature study, the theoretical parts of this research should be prepared which means that for the following steps to build the net present value (NPV) equations of both parties, the needed variables are ready.

Monte Carlo simulation

As there is uncertainty variables included in the decision support tool, how to deal with uncertainties becomes a problem. The main uncertain variables are the energy price and discount rate which have directly influence on the NPV of the both parties within the ESCO. The stochastic diffusion process of these variables can be represented as the Geometric Brownian motion, so that based on the historical data, a time series analysis for these variables could be taken and by using the Monte Carlo simulation technique, the range value of these variables could be generated. The Monte Carlo simulation uses random numbers to select the random samples with the probability density functions of input data and carries out a large amount of simulations to generate the output values. After the

Monte Carlo simulation, the uncertain variables values will be provided for the next optimization step as data input.

Non-linear programing

The sub question 4 will be answered by applying non-linear programing. As the NPV equations of both parties within the ESCO are non-linear with several variables, to optimize the EPC contract needs the constraints of variables and objective of equations. The constraints of key variables will be defined by literature study. Meanwhile, the objectives of equations of NPV for both sides within the ESCO will be divided as different scenarios. By applying the non-linear programing, the equations can be optimized to get the best result so that the expected result will be provided.

1.4 Expected results

There will be two parts of the result. The first of the result will the range of uncertain variables from the time series analysis and the Monte Carlo simulation. These uncertain variables are the energy price and discount rate in the future project economic lifetime. By using this simulation result as data input, the optimization step will employ the non-linear programming to finish the optimization. The optimization result should be the optimal contract terms value of contract period, sharing ratio of the investment and profit by the both parties within the ESCO under different uncertain variables scenarios and stakeholder objects. This result will be formed as different options which can be provided to the model users as information resource to continue with negotiation on contract design. The result of this graduation thesis is believed helpful for the users to get a better understanding what are the key contract terms influencing the EPC project and how they affects the profitability of it.

2. Glossary

Energy efficiency

Energy efficiency is the ratio of energy service output compared with the input. It is mainly a technical process which is caused by the turnover of old equipment replacement by new efficient ones.

Sustainable school retrofit project

The sustainable school retrofit project refers to the project taken the school which aims at making its building more energy efficiency to achieve lower energy consumption, better indoor environment quality and lower CO_2 emissions. The measures open been taken are updating the HVAC system, lighting system, energy control system, insulation and so on. It is different with the energy natural project which focuses on achieving the self-sufficiency on energy consumption.

Indoor Environment Quality (IEQ)

Indoor environment quality (IEQ) is a concept that not only deals with thermal conditions but also goes much further, touching upon air quality, lighting and acoustics issues (Ghita, 2015). IEQ is regarded as depending on many variables such as temperature, relative humidity, air flow, air velocity, occupancy, concentration of pollutants, noise, lighting etc. These could be grouped into four aspects named as thermal comfort, indoor air quality, visual comfort and acoustic comfort.

Energy Service Company (ESCO)

In the report of Bertoldi et al. (2014), authors identified the ESCOs as ""a company that offers energy services which should include implementing energy-efficiency projects (and other sustainable energy projects)." Here the energy services provided by the ESCOs include a series of activities such as: project development and implementation, energy analysis and audit, general contracting, financing, project management, risk management, monitoring and verification of saving, training, operation and maintenance services and so on (Gan, 2009).

Build-operate-transfer (BOT)

For the other contract type, BOT, essentially it is a model that private investors financed, designed and constructed the project and during the concession period, the private investors operate the project and using the revenue to pay back loans and receive profit (Khanzadi, 2012).

Energy Supply Contracting (ESC)

The Energy Supply Contracting refers to the efficient supply of energy such as heating, electricity and others. Compared with the EPC, the ESCO pays more attention on the supply aspect, but not on the end user performance so that it does not bear such risks under performance control (Pätäri, 2014).

Contract Energy Management (CEM)

The Contract Energy Management means "the managing of some aspects of a client's energy use under a contract that transfers some of the risk from the client to the contractor (usually based on providing agreed 'service' levels" (Sorrell S. , 2005)

Energy Performance Contracting (EPC)

The EPC was defined in Directive 2006/32/EC as "a contractual arrangement between the beneficiary and the provider (normally an ESCO) of an energy efficiency improvement measure, where investments in that mea- sure are paid for in relation to a contractually agreed level of energy efficiency improvement."

Guaranteed saving EPC

In the guaranteed saving model, usually it is the client provide with project budget and the ESCO does not finance it, and the ESCO guarantees that the energy consumption saving will be enough to cover the initial investment and earn profit (Bertoldi P. R., 2005). If the actual energy saving is less than the pre guaranteed level, the ESCO needs to compensate the short fall to the client (Lee P. L., 2015)

Shared saving EPC

In the shared saving model, the ESCO design, finance and implement the project, then in return get the pre-determined share of energy consumption savings (Bertoldi P. B.-K., 2014). The specific amount of sharing percentage is usually depended on the length of contract, the share of investment and risk allocated.

Net Present Value (NPV)

The net present value is the method which uses cash flows considered both the amount and timing of the project to reflect the financial ability (Yu, 2013). It is normally calculated as the sum of present value of all future cash money during a certain time minus the initial investment cost (Mørck, 2014).

Monte-Carlo Simulation (MCS)

Monte Carlo Simulation refers to the computational algorithm which depends on the large numbers of repeating the random sampling to generate the distribution and probability of such uncertain variables values.

System Dynamics (SD)

System dynamics is a method and mathematical modeling technique "for framing, understanding and discussing complex issues and problems over time, dealing with internal feedback loops and time delays that affect the behavior of the entire system." (Glumac, 2015)

Geometric Brownian motion (GBM)

Geometric Brownian motion process is focusing on the percentage changes and commonly used in uncertainty modeling which shares the random and statistical nature of the motions (Deng Q. Z., 2014). It is commonly employed to describe the stochastic diffusion process of commodity derivatives pricing like oil, electricity and stock.

Non-linear Programming (NLP)

Non-linear programming is the process of solving an optimization problem in which some of the objective functions or constraint functions are nonlinear. Normally the objective functions need to maximized or minimized.

3. Modeling techniques for Energy Performance Contracting (EPC) within public buildings

3.1 Problems hinder the EPC implementation in the sustainable school retrofit projects

In the current world, energy efficiency has already been a hot topic. Saving energy will not only help to slow down the global warming but also contribute to national economy developing. The EU has established an indicative target of 20% energy saving by 2020 for energy efficiency (Commision, 2014). Buildings accounts for almost 30% of the energy consumption in the Netherlands (Ministry of Economics Affairs, 2011). The energy is mainly used for heating, cooling and electricity for lighting and appliances.

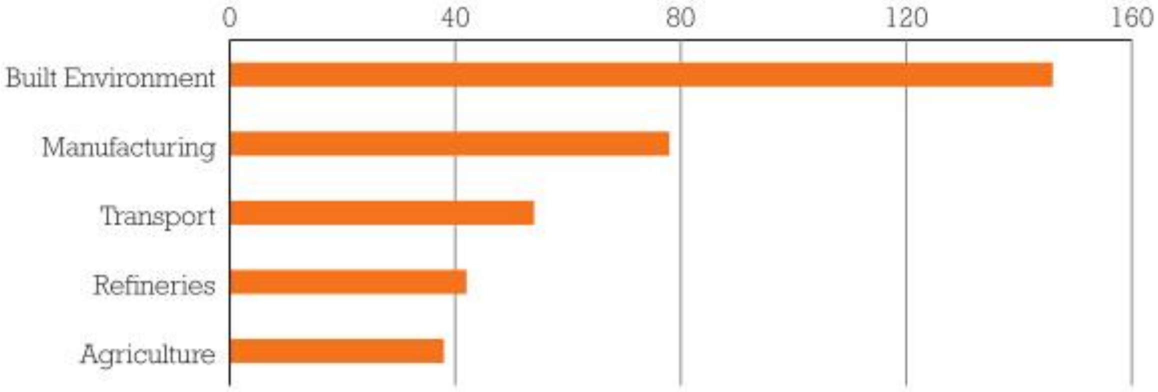

Figure 2. Saving potential up to 2020 in Netherlands (Peta joules per year)

As can be seen in the Figure 2, built environment have the greatest potential for energy savings in Netherlands. The most important sectors for saving energy in built environment are insulation, residential heat, energy efficiency lighting, ventilation and air conditioning (Hieminga, 2013). The Dutch government is reinforcing the national energy saving policy for existing and new building by implementing the European Energy Performance of Buildings Directive. In the EU Energy Efficiency Directive (2012/27/EU), the public sector needs to be the good example and implementing well-planed, high quality deep renovations in all of its buildings.

So building energy consumption plays an important role in implementing energy efficiency in the whole society. Particularly, school buildings, is facing the urgent need for energy sustainable retrofitted for mainly two reasons.

Firstly, the energy consumption in existing schools is huge and it is often not optimized. Numerous studies have been done to analyze the energy consumptions in schools including the amount of consumption, type of energy, ways of usage and measures to improve the energy used in school buildings. For example, Desideri et al. (2002) examined a group of schools buildings in a province in central Italy and concluded that if all the optimal energy consumption measures could be valid, the thermal energy saving could get to 38% and electric energy consumption saving could be over 46%. The energy consumption in school buildings are mainly used for heating & cooling, lighting, ventilation and so on. The high level of current consumption and potential for reduction is due to the facts such as low efficiency heating system (Desideri U. P., 2002), low efficiency envelope (De Santoli, 2014), uncontrolled ventilation system and un-close fitted windows (Butala, 1999). Figure 3 shows the average energy use profile of schools in the United States as an example.

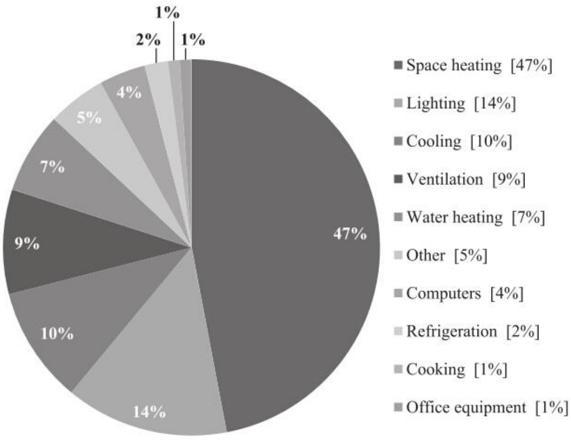

Figure 3. Average energy use profile of United States schools

Secondly, the indoor environment quality (IEQ) in school buildings is very poor and it does not meet the required standards. The IEQ has a directly influence on students health and learning performance. In the advisory report taken by Health Council of the Netherlands, the environmental factors such as temperature, noise, air movement and carbon dioxide (CO_2) concentration, especially the CO_2 as indicator of ventilation and air quality, have obviously effect on the health and cognitive performance of pupils in the classroom. The target CO_2 concentration in Netherlands is 1200 ppm, but in fact, as randomly detected in Dutch classroom, it is approximately 2000 ppm. It is obviously that the bad indoor air quality has become an unavoidable and crucial problem in primary schools in Netherlands (Netherlands H. C., 2010).

There are already many schools took their actions to make things changed. Measures can be taken to improve indoor environment quality and energy efficiency performance in school buildings varies in different schools renovation or retrofit projects, but there still could be some measures in common of these projects. Updating the current HVAC systems (Gao, 2014), window replacement (Buvik, 2014), using efficiency lighting system (Ardente, 2011) and improving the insulations (Bull, 2014) and envelope (Reiss, 2014) are the most recommended measures as results indicated in scholar studies.

The main barrier hinders schools to implement their sustainable retrofit project is the lack of finance support. The investment cost of improving the existing heating, ventilation, air conditioning and lighting system remains in a high level (Dascalaki, 2011). Many facts such as energy price fluctuation, irreversibility and split of stakeholder interests makes the investment for building renovation project complicated (Kumbaroglu, 2012).

3.2 ESCO and EPC – an appropriate mechanism for sustainable school retrofit project

The energy service companies (ESCOs) are considered as an effective approach to achieve energy efficiency in the whole society. Compared with the traditional mechanisms, applying the ESCOs could provide clients with the following obvious benefits.

Firstly, the ESCOs usually offer the turnkey services. This means that the ESCOs play the role of not only a contractor, but also a project manager, guarantor, financer and so on (Bertoldi P. B.-K., 2014). As the ESCO contacts with subcontractors directly, the client just needs to pay its attention on selecting the successful choice on ESCO companies and leave the continuous work to the ESCO companies. This will simplify the contractor selection process and monitoring.

Secondly, the choice of applying ESCO provides the client with additional financial support. In the tradition mechanisms, the client can only use the internal fund in their organization or get loan from the bank. But the ESCO could provide the client with finance support. There are mainly three options of financing in ESCO model: ESCO financing, third party financing and customer financing. This means that if the client chooses to use ESCO mechanism, it will get the opportunity to have additional finance resource to cover the financial gap to achieve the energy efficiency.

Thirdly, applying the ESCO could help client transfer risk out of itself to others, the ESCO. Since the remuneration of ESCOs is directly tied to the energy savings achieved and the ESCO is responsible for guaranteeing the energy saving cost, the ESCO will do its best to reduce the energy consumption as contracted, otherwise its profit will be affected (Bertoldi P. B.-K., 2014). So the client does not need to pay as much attention as it doing the project itself to achieve the energy efficiency in its ambitions.

Finally, for the sustainable school retrofit projects, it is obviously that the advanced technologies and maintenance experience are what the client needs. The ESCOs take comprehensive measures to achieve energy savings such as high efficiency lighting, high efficiency heating and air conditioning, efficient motors and variable speed drives, and centralized energy management systems (Lee M. K., 2003).

Even though ESCO has been treated as an effective and practical mechanism to achieve energy efficiency, but the implementation level of ESCO is still low in EU, especially in the Netherlands. There are several barriers limiting the widely adoption of this approach provided in (Bertoldi P. B.-K., 2014) report:

The low level of awareness by local authorities leads to the problems caused by legislative framework including the public procurement rules.
The international accounting rules restrict financing opportunity.
Difficulties in accessing finance due to economy recession in EU.
The mistrust related to lack of standardization of ESCO
The low and fluctuating energy price

3.2.1 Pro's and Con's of implementing EPC within ESCO in sustainable school retrofit project

The ESCOs provide different types of contract with client to achieve energy efficiency. Energy performance contracting, also known as EPC, is the most common and widely used ESCO contract in the world. Compared to other types of contract, such as energy supply contracting (ESC), build-own-transfer (BOT), Chauffage, EPC here is more suitable for sustainable school retrofit projects. The EPC commonly has two different forms: the guaranteed saving model and shared saving model. The preference of these two EPC models is mainly depended on the financial ability of the client; usually the client with lack of capital would prefer the shared saving ones because the ESCO could help it to cover the financial problem.

The main difference between ESC and EPC are the scope of energy used that the ESCO can control. Figure 4 and Figure 5 below show the difference:

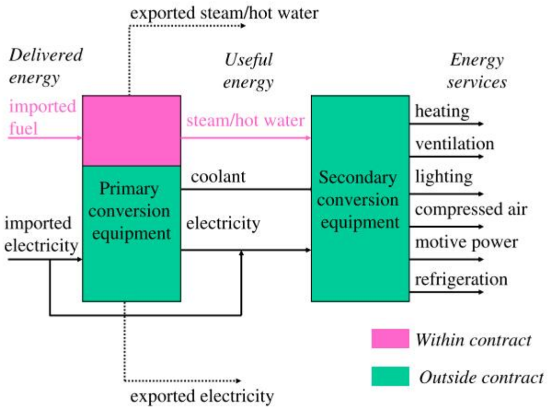

Figure 4. Scope of the energy supply contract

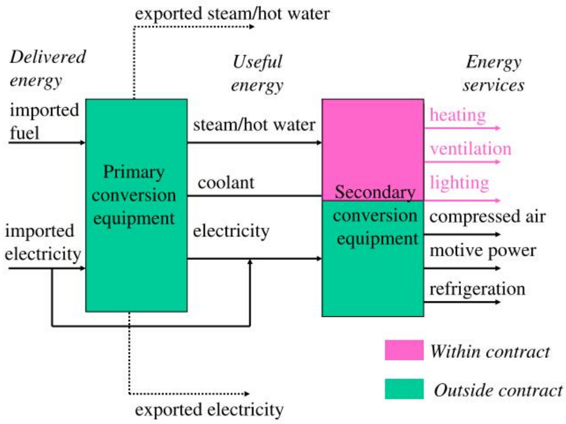

Figure 5. Scope of the energy performance contract

In (Bertoldi P. B.-K., 2007)report, the authors explained the difference between the ESC and EPC. In ESC, the ESCO mainly focus on the primary energy use and associated control equipment, for example in the Figure 4, the supply of fuel is controlled by the ESCO. As a result, the ESCO has little or no control on the demand of useful energy and limited control on delivered energy. In contrast, the EPC, also the performance contracts, gives the ESCO more control on final energy services and therefor on the useful and delivered energy (Sorrell S. , 2007). Consequently, in the EPC contract model, the ESCO focus more on end use of equipment hence the control of energy use is more powerful. Back to the sustainable school retrofit project, the project is mainly focusing on replacing and updating the operation systems such as heating, ventilation and lighting system, so in this kind of project, EPC is obviously more suitable.

For the other contract type, BOT, one of the most important characteristics of this model is that the private investors make profit directly depending on their concession in the project, for example, the toll fee in highway project. The common BOT projects are such as highway, airport, canal and other infrastructure. But for the sustainable school retrofit project, it is not a project that can make profit in this direct business model. Students do not need to pay for attending public schools and central and local government are funding the schools. The profit is from the achieved energy saving cost from energy performance controlling by the ESCO. So in this view, BOT is not a good choice for sustainable school retrofit project compared with EPC.

So as a conclusion, in recent ESCO market and considering the characteristics of sustainable school retrofit project itself, the EPC is the most appropriate choice in all the available contract types.

Low level of awareness is one barrier that hinders EPC implementing in more areas. According to the interviews, unfamiliar with the contract terms in the overseas standard documents makes the potential client question the risks in EPC project as a consequence a low level of interested in EPC (Lee P. L., 2015). In Netherlands, due to lack of successful example, EPC projects are considered as complex and expensive compared with alternative methods (Bertoldi P. B.-K., 2014). The other one of the key barriers to profit in EPC project are the potential disputes over the guarantee cost savings and uncertainties about realizing the guaranteed savings (Deng Q. J., 2015).

3.3 Modeling approaches in existing study literatures

Since there are limited studies about applying modeling approaches to do the research of EPC, here the scope of literature study will expand to other forms of performance-based contract projects, for example the BOT project. The common issue in these performance-based projects is that the initial investments are paid back by the future performance which is with risks and uncertainties (Deng Q. Z., 2014). So the studies on other performance-based projects will provide supports and valuable experiences on the research of EPC project.

Previous studies for these performance-based contract projects are mainly focusing on two aspects: the financial problem or profitability of the project and risk management of the project. Studies about the financial problems of the project mainly paid attention on the concession period determination of the project and investment decisions making. While studies about the project risk management were mainly about risk analysis and assessment. Most of models are dealing with quantitative problems and few of them are qualitative. Approaches and techniques will be reviewed by the category of the problems they can solve.

3.3.1 Approaches and techniques employed to research on the financial problem in the EPC project.

The financial problems in the EPC projects which were focused on were mainly about the determination of contract period and the investment decision making. Similar problem is the determination of concession period in BOT project so it is also involved in this part of literature review. The review of literature will be based on these two problems.

When dealing with financial problem of determining the concession period in BOT projects and contract period in EPC projects, the net present value (NPV) is one of the mostly employed approaches, individually or combined with other approaches. Ng et al. (2007) built a simulation model by using NPV and IRR as the indicators to help public sector to determine an optimal concession period to get a win-win situation and reasonable risk allocation. In their model, the expected IRR was used as input for the simulation model, and after sufficient rounds of simulation with the software Matlab®, a frequency distribution curve related to the concession period could be computed to help the public sector for decision making. In another study taken by Suhonen et al. (2013), NPV is employed to investigate the profitability and risk allocation in the shared saving ESC project for both partners namely the ESCO and the client. By simulating the model with a case study, the result indicated that duet to the low level of profit, the ESCO business model is challenging in the North Finland.

But in most cases, the NPV approach is employed with combination of other approaches. For example, a study taken by Mostafa et al. (2010) used the fuzzy Delphi techniques to determine the BOT project concession period. The fuzzy Delphi technique was mainly employed to define the values of different factors which have impact on the NPV of BOT project considering a group of experts' opinion. After calculating the NPV of project, fuzzy approach was applied to give the result of concession period determination. Monte Carlo simulation technique is the other usually used technique with NPV in studies. Yu et al. (2013) developed a decision support system in their study to determine the length of concession period to help both public and private partners to analyze the financial returns and risk sharing in BOT project. In the model, the pre-identified influential factors for BOT project were represented in the NPV equations and by using the Monte Carlo simulation technique the model gave an generated the length of concession period which balancing the interest of both sides. A dataset of a simulated highway project was used for the model. In the study of Deng et al. (2014), Monte Carlo simulation with NPV were also applied to determine the contract period, but this decision model was developed for building the EPC. Monte Carlo simulation was conducted to deal with the uncertainty of investment cost, energy saving amount and energy price in the future contract period. More specifically, Geometric Brownian motion was used to represent the operation and maintenance cost coefficient of the project. Also the authors used a campus case to verify the applicability of their model.

Game theory is another approach employed by scholars to solve the contract period determination problem. Zhang et al. (2008) applied game theory in their study to determine the contract period of EPC project. The authors calculated the investment benefit represented as equations from both the view of the client and the ESCO. After playing the game, the Equilibrium that both sides got was the optimal contract period. This decision-making model would help the partners a better cooperation in the EPC project. Also Qian et al. (2014) developed a bargaining model for the ESCO and the client to negotiate the optimal contract period and energy saving revenue-share ratio. The bargaining game was solved by using the Revers Solving Method. Specifically, the energy price in the future was calculated by Geometric Brownian motion. A sensitivity analysis was then applied to investigate the influence of factors such as energy saving amount and energy price. There is also a study combined the game theory with NPV approach together. Bao et al. (2014) built a bargaining model which used game theory and NPV to determine the concession period of a BOT project, particularly the project was with incomplete information for decision makers. NPV for both the public and private partners where represented by the equations, then the utility values of payoffs for the both side were the NPV for them. Then in a bargaining game, the two sides played a game and found the Equilibrium in the end. Considering this model was built for the project with incomplete information regarding uncertainty, the authors used a hypothetical example to verify the applicability of the model. In the other study integrated game theory with Monte Carlo simulation techniques, Hanaoka et al. (2012) built a simulation model which aims at assisting the reasonable concession period of the BOT project. Monte Carlo simulation was performed to give a range of concession period and bargaining game theory was used to identify the most reasonable one. These studies proved that mathematical approach is not the only method that could solve the economic problems in the performance-based project. As there was negotiation existing between the different partners, game theory based modeling approaches could also give solutions to these economic problems in some specific situations.

Fuzzy logic is also used in studies to deal with the same problems. Ng et al. (2007) applied fuzzy set theory with IRR to build a fuzzy multi objective decision model to help the public sector to determine an optimal concession period in the BOT project. Fuzzy set theory here was aiming to evaluate the concession items in a range of numerous possible scenarios developed by the authors. Due to the lack of available data, the authors used a hypothetical example to verify the operation of the model. The fuzzy logic was also employed with combination of system dynamics and NPV by Khanzadi et al. (2012) to build a model which was aimed at determining the concession period of the BOT project. System dynamics here was used to investigate the complicated relationships between all factors which have the influence on the project’s NPV. It was model on qualitative aspect. Due to the lack of historical data, fuzzy logic was employed to determine the relationship of some influential factors. Using system dynamics for the qualitative model also appeared in the study of Capelo et al. (2011) which focusing on investigate the key variables influencing the EPC adoption on micro and macro levels. So fuzzy set theory and its expand approaches could help researchers dealing with the complicated relationship between potential solutions or options, so if the future researchers want to focus on the complicated relationships, it should be helpful to employ the fuzzy set theory.

From the previous reviewed studies, it indicates that only using NPV approach to make analysis and decision for the BOT or the EPC projects in public buildings or infrastructures is not accurate enough. NPV should be integrated with other approaches and techniques to finalize the specific research goal. But the NPV is still the most preferred economic indicator by the scholars. This traditional approach is easily understood and widely scope of application. IRR can also play an effective role when dealing with these kinds of economic issues. There are also other financial evaluation approaches such as present value, cash flow applied in the scholar studies. The choice of employing these approaches is based on the researchers’ own preference and their research goal

After the review of literature about the determination of contract or concession period in of the project, the other financial problem which refers to the investment decision making will be reviewed.

There is a multi-objective optimization model developed by Malatji et al. (2013) to help investors to make decision for energy-efficiency building retrofitting project. The model was formulated with the equations represented the NPV and solved by the genetic algorithms (GA). A sensitivity analysis was also applied to analyze the influence of related factors and it proved that this model was robust. Li et al. (2014) built a theoretical bargain model between the client and the ESCO to find the relationship of the contract terms of EPC such as contract period, share of investment and profit and so on. NPV of both sides was represented in equations with all the relevant contract terms. After set up the equations of NPV, the authors solved the model using non-linear programming, specifically Karush–Kush–

Tucker condition in their model, based on the objectives of the both partners. The result of the study suggested that the capital investment was the major influential factor in the EPC project in china and appealed for more effective financial mechanism.

The real option approach is the other promising tool to evaluate the options and flexibility in infrastructure project (Cheah, 2006). A study by Garvin et al. (2004) analyzed the ability that the real option approach could help the public sectors make a better evaluation of the investment. Two option pricing method was introduced in the study, namely the continuous-time model and discrete-time model. After implemented in a case study from USA, the feasibility of the built model was demonstrated. In the study taken by Cheah et al. (2006), contract terms which have influence on the success of project such as concessions, risks and reward arrangement were treated as a form of real option. Monte Carlo simulation of a cash flow was applied to evaluate the provided real options values. The authors implement their model to a Malaysia-Singapore Second Crossing project and proved that this model worked well. Real option approach even can be used with combination of NPV. Kumbaroglu et al. (2012) integrated NPV, Monte Carlo simulation and real option approach to evaluate the optimal economical retrofit investment options for energy savings in buildings. The NPV still was used as economic indicator representing the profitability of the project. Monte Carlo simulation mainly dealt with the value of uncertainties existing in the project, for example the energy price in the future. Real option investment appraisal was used as dynamic sequential approach when making the decision of retrofit investment. The real option approach cannot be used in modeling without the support of other approaches or techniques which dealing with financial or uncertainty issues. Real option was mainly used to exercise the certain action when facing the uncertainty (Cheah, 2006).

3.3.2 Approaches and techniques employed to research on the risk management problem in the EPC project

The studies which focus on the risk management problem in the BOT and EPC project are mainly in two aspects: risk analysis and risk allocation.

When dealing with the risk analysis, the approaches mentioned in previous subsection are also applied. Lee et al. (2013) paid their attention on evaluating the probability of the energy performance short fall during the EPC contract period. Sensitivity analysis was employed to found out the most influential factors which affect the energy consumption amount in the building and Monte Carlo simulation was performed to analysis the energy saving with all selected factors during the post retrofitted period. The result from a case study suggested that the possible energy saving amount was from 2.86% to 10.8% in 1 year period after retrofitted. Arnold et al. (2015) employed Monte Carlo simulation method to analyze the economic risks in renewable energy infrastructure project. By combining the traditional financial analysis, the NPV, with the Monte Carlo simulation, the conceptual design of investment project was optimized considering the investment returns and risk allocations. Also a simulation model developed by Deng et al. (2015) was amid at assisting the design of the cost guarantee saving in EPC project. Monte Carlo simulation was employed to investigate the uncertainties within the energy cost saving. Specifically, the Geometric Brownian motion was used to simulate the energy price in the future contract period. Moreover, in study taken by Burhenne et al. (2013), authors used NPV to do the cost-benefit analysis and Monte Carlo simulation to determine to uncertainty model inputs such as design specifications in a building performance.

Real option still can be used to solve this kind of problem. Brandao et al. (2008) employed NPV and option pricing method to build a model which aimed at evaluating the government guarantees in infrastructure project. Different guarantees levels were seen as different options. The values of guarantees were simulated by Monte Carlo simulation and to determine the optimal one option was used the option pricing method. Shang et al. (2008) developed a real option model by using NPV and B-S model to evaluate the uncertainty of the EPC project. The value of option is composed with the NPV of project and option property value. Even though the B-S pricing model was not very accuracy, but it was still better than other option value evaluation method.

Meanwhile, in the study of Yik et al. (2004), the authors proposed a conventional performance contract to replace the EPC in order to reduce the failure probability. Key factors which had the influence on the performance contract were investigated and a parametric analysis was done to get an insight of all these factors. In order to identify and assess the risks in the BOT project, Ebrahimnejad et al. (2010) conducted a fuzzy multi attribute decision making model. Firstly the influential risk factors were identified. To solve the problem, the Fuzzy Linear Programming Technique for Multidimensional Analysis of Preference (FLINMAP) combined with Fuzzy Technique for Order Preference by Similarity to Ideal Solution (FTOPSIS) were employed as the methods to rank the risks in the project. A case study was applied in the end and the result showed that if with more alternatives than criteria, the FLINMAP would perform better than FTOPSIS.

For the problem of risk allocation, Carbonara et al. (2014) developed a simulation model aiming at giving a win-win solution to both public and private sectors and sharing fair risk. The model using NPV to represent the financial concern of both sides and Monte Carlo simulation approach was employed to simulate the uncertainties in the project, specifically, the discount rate. In their study, the model was verified with a BOT port project in Italy as a case study.

As the name indicating, the performance-based project such as BOT and EPC is facing great uncertainties in its internal level and external level. For example, the traffic volume during the concession period is the major influential uncertainty variables for the BOT highway project and the future energy price plays the same role in the EPC project. So when building the model which aims at solving the problems in performance-based projects, these uncertainties should never be ignored. Monte Carlo simulation has proved its applicability and suitability when dealing these uncertainties problems. Geometric Brownian motion could also provide support for those variables influenced by stochastic factors.

The review of existing modeling approaches and techniques is end up here. Review of key variables in these public performance-based projects will be presented in the next section.

3.4 Key variables in the EPC project

As already has been reviewed in the previous sub-section, there are numerous modeling techniques in the existing literatures of the study about performance-based contract project in the public sectors. In the BOT and EPC projects, some variables are the common ones and some of them are own in their projects but there is tight similarity between them. Regardless the varieties of model types and techniques, the variables in these models could be classified into two types: the deterministic variables and the uncertainty variables.

The first groups of variables are the capital investment cost and annual operation and maintenance (O&M) cost. These two variables compose the mainly investment of the performance-based projects (Deng Q. Z., 2014).

The capital investment is one of the most basic and important variable in all the performance-based projects and is also regarded as initial investment in some studies. No matter the studies aiming at optimization of the concession or contract period of the project, decision making of the investment of projects or the risk management, a clear identification of the capital investment is needed. In some studies, the capital investment is regarded as the up-front cost which means that it will be paid at the beginning of the project (Malatji, 2013, Qian, 2014, Yik, 2004). Some other studies also regarded capital investment as annual (Mostafa, 2010).This fact determines how the capital investment will be calculated in the NPV of project. On one hand, the capital investment has the negative contribution to the NPV of the project. On the other hand, the capital investment is considered as contributed to the energy saving amount of EPC project (Deng, 2014).

Normally, the annual operation and maintenance cost is considered as high relative with the capital investment cost which means that normally the higher capital investment will lead to higher annual operation and maintenance cost. In the study of Deng et al. (2014), the authors link the O&M cost and capital investment with a coefficient which followed a Geometric Brownian motion. In Khanzadi et al. (2012) study, the authors investigated the how the maintenance cost is proposed by system dynamics.

Another variable as expected return rate shows the expectation of the investors on their investment. Normally, the expected return rated is associated with the capital investment (Yu, 2013). So these two variables are often used to deal with the problems of investment decision making in the performance-based contract projects.

The second groups of variables is related to the time period of the projects, such as the project economic life, concession period in BOT project and contract period in EPC project.

The project economic life normally is longer than the concession period or the contract period, so that the project can provide remainder value to the client in EPC project and public sector in BOT project. From the aspect of them, the longer project economic life will provide more remainder value after the ESCO or the private investor deliver the project to them. But usually longer project economic life needs more capital investment.

Determination of contract period in the EPC project has been one of hottest research problem in related studies. An appropriate contract period of a EPC project is the significant success factor due to its crucial influence on the investment return and risk allocation on both the public and private partners. If the contract period is estimated accurately, the risks during the concession period such as energy price, energy saving amount, discount rate can be controlled better. Normally, the contract period is composed by the construction period and operation period. Existing studies employed modeling techniques such as Monte Carlo simulation, game theory, real option, system dynamics to help solve the problem of determination of the concession period. Likewise, the concession period of BOT project plays the same role of the contract period in EPC project.

The third groups of variables are macro-level economic uncertain variables such as interest rate, inflation rate, exchange rate and discount rate. Normally, these variables have the direct influence on the value of the project and they are considered one of the uncertainties of the success of the projects.

In the study of Yu et al. (2013), the discount rate was considered as affected by the interest rate and inflation rate and these two variables have a high level of correlation with each other and specifically, the real discount rate was as the inflation rate deducted the interest rate. Hannaoka et al. (2012) treated exchange rate as a function of inflation rate. These variables may fluctuate due to the change of governmental policies and economy conditions. So when using these variables, researchers normally assumed them as risk-free level or estimated them using simulation approaches. For example, Cheah et al. (2006) in their study used a risk-free rate instead of adjusted discount rate. Yu et al. (2013) used actual values of interest rate and inflation rate in their study regarding the complex and low accuracy of simulation of these variables. Burhenne et al. (2013) dealt the inflation rate with Monte Carlo simulation. Normal probability distribution was also applied to the interest rate and inflation rate (Hanaoka, 2012, Thomas Ng, 2007).

Then the next group of variables are the uncertain variables which influencing the income of the projects. They play the same role in EPC and BOT projects.

In the EPC project, the energy price and energy saving amount are the variables which determine the project income for the whole project lifetime. The energy cost saving, which equals to energy price multiply the energy saving amount, is the majority income for the ESCO in the EPC project.

The energy price in EPC project is influential uncertain variable. Since in the EPC project, the profit is mainly from the energy saving cost and it is determined by the energy price and energy saving amount in every year, the importance of energy price should not be ignored. In Kumbaroglu et al. (2012) study, the energy price change rate was simulated by a Monte Carlo simulation based on different distributional assumptions. Likewise, Monte Carlo simulation also applied to simulate the gas price in Burhenne et al. (2013) study. The Geometric Brownian motion is another common approach used to simulate the energy price (Deng, 2015). The energy saving amount is normally negotiated by the ESCO and the client after an energy audit taken by the ESCO on the object building. With more capital investment for the project, the better equipment and technologies could be applied for the project, so scholars make a positive link between the energy saving amount and capital investment (Li, 2014). Also, energy saving amount in the EPC project is treated as the uncertain variable due to the probability of failure in end user performance and ageing of the energy conservation measures. Geometric Brownian motion is also employed to simulate the energy saving amount in the existing literature (Deng, 2015).

In contrast, in the BOT infrastructure project, specially the highway project, there are two variables are considered as the same role of energy saving amount and energy price in EPC project. They are the traffic volume and toll fee. These two variables contribute to the majority income of the project.

The traffic volume, also known as traffic flow, is the amount of automobiles move through the highway, usually counted in annual. Normally, the traffic volume will decrease as the toll fee increases because people will choose other transportation method when facing more expenses. The traffic volume is an uncertain variable that is not easy to estimate with high level of accuracy. NG et al. (2007) estimated the traffic volume in their study following a normal distribution with a standard deviation. Cheah et al. (2006) used Monte Carlo simulation to simulate the traffic volume in their model. The toll fee, also known as toll/tariff regime, like the traffic volume, is an uncertain variable. Even though it will be fixed when the public and private negotiating the contract, it is still affected by the macro level economic variables such as inflation rate and interest rate (Hanaoka, 2012). Monte Carlo simulation is employed when dealing with the toll fee (Thomas Ng, 2007).

As mentioned in the previous, there are two types of ECP project: the guaranteed saving EPC and shared saving EPC. In the shared saving EPC, the ESCO needs to negotiate with the client about the sharing ratio of profit in the project. Normally, the sharing ratio of investment is also determined. These two variables are positively related, which means that with a higher share of the investment, a higher share of profit is requested. The preference of sharing amount is depended on the both partners risk undertaken and profit chasing will.

Furthermore, transaction cost is the other variable influence the implementation of EPC project. In the study of Sorrell et al. (2007), transaction cost was categorized into the external market level and internal organization types. But due to the complexity and individual, transaction cost did not appear in the studies of modeling the EPC project. But still, it is a variable that hinders the EPC a wider area of application.

So in conclusion, variables in the existing models of performance-based contract projects can be summarized in the Table 1 below:

Table 1. Variable description

Variables	Category			Reference
	Deterministic	Uncertain	Negotiating	
Capital investment	X			Deng et al. (2014), Mostafa et al. (2010), Carbonara et al. (2014)
Operation and maintenance cost	X			Capelo et al. (2011), Mostafa et al. (2010)
Expected return rate	X			Khanzadi et al. (2012), Mostafa et al. (2010)
Project economic life	X			Khanzadi et al. (2012), Qian et al. (2014)
Concession period			X	Bao et al. (2014), Hanaoka et al. (2012), Mostafa et al. (2010), Yu et al. (2013)
Contract period			X	Deng et al. (2014), Suhonen et al. (2013), Li et al. (2014), Qian et al. (2014)
Interest rate		X		Malatji et al. (2013), Arnold et al. (2015), Brandao et al. (2008) Kumbaroglu et al. (2012)
Inflation rate		X		Ng et al. (2007), Arnold et al. (2015), Brandao et al. (2008), Kumbaroglu et al. (2012)
Discount rate		X		Qian et al. (2014), Ng et al. (2007)
Exchange rate		X		Shang et al. (2008), Hanaoka et al. (2012)
Traffic volume/ traffic flow		X		Garvin et al. (2004), Brandao et al. (2008), Hanaoka et al. (2012)
Toll fee / toll regime	X			Hanaoka et al. (2012), Yu et al. (2013)
Energy price		X		Deng et al. (2014), Deng et al. (2015), Zhang et al. (2008)
Energy saving amount		X		Yik et al. (2004), Deng et al. (2015)
Sharing ratio of investment			X	Li et al. (2014)
Sharing ration of profit			X	Li et al. (2014)
Transaction cost	X			Capelo et al. (2011)

3.5 Summary

In this part of literature review, firstly, studies on the urgent need of sustainable retrofit for public schools was reviewed. The great potential for energy saving and poor indoor environment quality make the schools with no choice but to retrofit their buildings. But for the public schools, lack of financial support hinders these schools with implementing their retrofit projects. The ESCO, specifically, the EPC, is considered as the appropriate and effective mechanism for these sustainable school retrofit projects. But the low level awareness of this mechanism, unfamiliar with the economic and risks in the project lead to the seldom implementation of EPC for these kind of project. Then existing literatures for promoting the awareness, understanding about the essence of performance-based contract and support for decision making about the investment and optimization were reviewed. The qualitative and quantitative modeling techniques such as system dynamics, Monte Carlo simulation, game theory were firstly listed and related variables in these models were then summarized. This literature study provides a better understanding of modeling technique choice for the research problem in this thesis.

4. Decision support tool for sustainable school retrofit project using EPC

4.1 Introduction

In the current days, many schools are facing the stress from the urgent need of sustainable retrofitted or renovated. There are mainly two reasons leading to the current situation. On one hand, many schools were built in several decades ago which means that the energy efficiency in these schools are in a low level and the energy consumptions are high. On the other hand, poor indoor environment quality in many schools, especially in the schools which have been used for a long time has significant influence on students' health both physically and psychologically.

Energy performance contracting (EPC) within the ESCO has been regarded as an effective mechanism which can help its client to achieve energy efficiency. For the schools which have the need to retrofit or renovate its buildings, the ESCO is professional to provide them with energy efficiency measures such as updating energy facilities and control system, operating and maintenance, staff training and other services. But in fact, the implementation level of EPC in sustainable school retrofit project is still low. Low level of awareness and lack of trust for this EPC mechanism has already been one of the mainly problems hinders the widely spread of EPC in market, especially in the Dutch market. Many schools are suffering with poor indoor environment quality but cannot take actions to make things changed due to the lack of capital support. So if there is something could help the public, especially the potential clients to improve their awareness of the EPC, opportunities could be grasped and current situation would be improved.

To help the client to achieve a better understanding how the EPC works and advantages it can provide, several scholars have done researches and studies about the EPC related financial or risk management problems. Suhonen et al. (2013) built the model which focused on the aspects of profitability and risk sharing of ESCO business on heating system in Finland. The result suggested that ESCO as a business model is not attractive enough in current business climate. Shang et al. (2008) developed a B-S model instead of traditional net present value approach to evaluate the EPC project with uncertainties during the future time. There are some more specific researches for the EPC project. Li et al. (2014) used the theoretical model with Monte Carlo simulation to investigate the influence of contract terms such as contract period, sharing ratio of investment and revenue on the success of EPC project in China. The determinations of contract period and risk analysis are the most interested topics. Deng et al. (2014) employed Monte Carlo simulation techniques dealing with uncertainties in the EPC contract and built the optimization model to determine the optimal contract period based on the balance of profit sharing for both ESCO and its client. Zhang et al. (2008) did their research for the same topic but in a different way. They used game theory to determine the best contract period for the both sides. Qian et al. (2014) developed the bargain model with net present value of both sides in the contract to research on the energy saving and profit sharing strategies in EPC project. Likewise, strategies design of cost saving guarantee in EPC project was solved by Monte Carlo simulation and net present value approach by the Deng et al.(2015).For the risks, Lee et al. (2013) made their focus on the risk of energy saving short fall during the contract period in EPC project by using Monte Carlo simulation and sensitivity analysis. It can be concluded that previous scholars were mainly focusing on the profitability of the EPC project and related problems when they tried to contribute the spreading of awareness and understanding of the EPC mechanism. Uncertainties and risks cannot be ignored when dealing these kinds of researches, but for every study, relevant uncertainties or risks was simplified to some extent due to the scope of the study itself.

In this thesis, the focused problem is also the financial ability when implementing EPC in the sustainable public school retrofit project which aims at improving the awareness level of EPC for public and the spread of implementation of this mechanism. The energy supply company and the school together are the both parties which formulate the ESCO. A decision support tool is developed to help both the energy supply company and the school to get a clear overview of the profitability when using EPC for their project. This decision support tool takes the uncertainties of energy price and discount rate floatation into account during the whole economic lifetime of the project. Monte Carlos simulation is employed to deal with these uncertainties values and gives different scenarios based on the ranges of uncertainty values. The net present value (NPV) for both the energy supply company and the school is calculated in the equations with all relevant variables. Based on the objects that the both parties want to achieve in the project, the decision model will use non-linear programming to give the optimal result considering the contract period, sharing ratio of investment and profit by each party in contract. The outcome will be formulated as options which are provided to users for decision making and negotiation.

This thesis is organized as following: the identification and introduction of all the variables used in this decision support tool are represented in section 4.2. Section 4.3 shows how the decision support tool is designed and basic assumptions in it. In section 4.4, the decision support tool is developed. Section 4.5 uses a case study as data input and shows the variability of this decision support tool. Finally, the discussion is drawn in section 4.6.

4.2 Variables of the decision support tool

This decision support tool is aimed at helping the both parties within the ESCO to get a better understanding about the EPC contract terms which will influence on the success of the project, especially from the economic aspect. Here two parties in the model are the school and energy supply company. These two parties together build the ESCO. Because the public school is the target client which implements EPC in this model, so the school here is refers to the combination of roles of school board and local municipality. In the ESCO, the energy supply company makes investment to provide financial support of the project and be responsible for the energy performance of project during the contract period. It takes the determined sharing of energy costing savings as profit. For the school, as part of the ESCO, it also makes investment which is limited by the budget. Also as the client of ESCO, the school updates the equipment and enjoys the provided operation and maintenance services. Moreover, the energy cost savings is also part of the profit taken by the school as the determined sharing ratio. Their relationship could be simplified as the Figure 6 shown below:

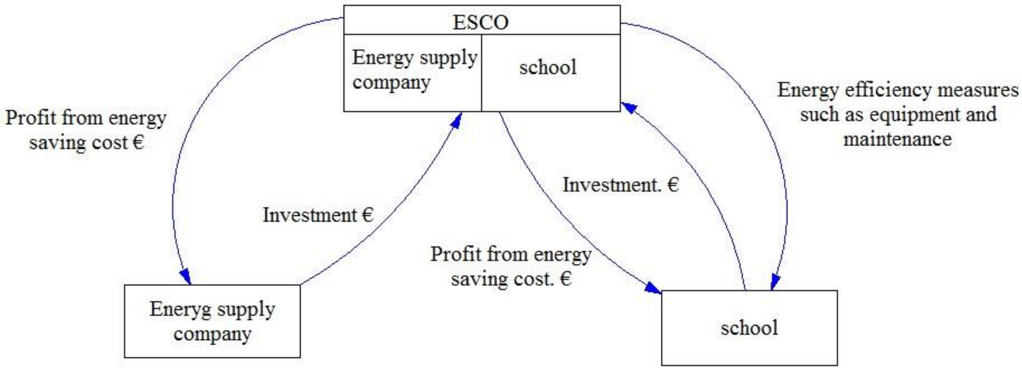

Figure 6. Relationship of both parties involved in the ESCO

Most of the variables included this decision support tool are identified from the previous literature studies (e.g. contract period, sharing ratio of investment, energy price). The other few variables are from the real life experience. Definition and description of each variable will be presented and in the end all of them will be summarized in the table based on their category.

1. Contract period (Deng Q. Z., 2014): the contract period refers to the period during which the ESCO provides investment and services to the client and sharing the profit from energy cost saving with its partners in the contract. In the EPC project, the contract period is one of the main variables which influencing the success of the project for several following reasons. Firstly, it is related to the risk control, because longer contract period will increase the potential risks and uncertainties. Secondly, the both parties have interest conflict on this variable. The ESCO prefers the longer contract period in order to get more profit. In contrast, the client prefers the shorter contract period because as the economic life of project is pre-predetermined, the client can get more profit due to the fact the energy saving cost is totally own by the client after the contract period ends. So the contract period should be considered as a variables which directly influencing the profit and risk allocation for both partners and it is one of the key contract terms that both parties have to negotiate when building the EPC contract.

2. Project economic lifetime (Qian, 2014)*:* the project economic lifetime is considered as the expected period that the project is useful to the owner, specifically in the sustainable school retrofit project, it is regarded as the energy efficiency measures economic lifetime. But due to fact that most EPC implementing in school project contains not only one simple measure but with multiple combination measures, the economic lifetime of project cannot be identified as a single period. In this model, it is made as an assumption that the project economic lifetime is a deterministic variable which is determined by the capital investment. Normally, there should a positive interrelationship between the capital investment and economic lifetime of project, due to fact that the capital investment is used for the energy efficiency measures so that more investment could lead to better equipment and longer lifetime of these measures.

3. Energy efficiency measures: the energy efficiency measures can be mainly divided into three types: the equipment, the building and the human behavior. The equipment here refers to updating or replacing the existing energy using equipment with advanced energy efficiency ones. The equipment normally includes lighting system, HVAC system, energy management system and so on. The building refers to renovation of buildings, such as roof and envelope with better insulation. The human behavior can be regarded as human attitudes and habits towards saving energy use. All these three types of measures have influence on implementing energy efficiency, but in the EPC project, it is considered that professional staff will be responsible for monitoring and operating the energy use in order to guarantee the energy cost saving, so the effect of human behavior can be ignored in this model, just left the equipment and building as main energy efficiency measures to be investigated. Moreover, the influence of energy efficiency measures is resulted as the energy saving amount and capital investment. So in the developed model the energy efficiency measures is not shown as a variable.

4. Initial capital investment (Deng Q. Z., 2014): the initial capital investment in the EPC project is mainly used for the purchasing the energy efficiency measures. Other related costs such as salaries for construction or installation workers, transaction cost during project negotiating and cost for training school equipment management staff are also considered as included.

5. School budget for the project: the school budget for the project refers to the capital investment support limitation from the school aspect which means that the capital investment from the school side should not exceed the budget. It is a deterministic variable because in the real world, the budget for the school is pre-determined based on its ambition and government budget for education. In the developed model, this variable will be used as a constraint variable to limit the sharing ratio of the investment by the school.

*6. Annual operation and maintenance cos*t (Capelo, 2011): the annual operation and maintenance cost is the cost used for operating and maintenance of the implemented energy efficiency measures during the whole project economic lifetime. In most conditions, the ESCO is responsible for the operation and maintenance activities during the contract period. After the contract period, the client needs to take over of these activities by itself, so the annual operation and maintenance cost is owned by the client. The operation and maintenance may increase as time goes by due to the aging of equipment and measures.

7. Energy saving amount (Yik, 2004): the energy saving amount is the amount of energy consumption which equals to current energy consumption amount minus the energy consumption amount after implementing energy efficiency measures. Before the school and the energy supply company come together to negotiate the contract terms of EPC project, firstly, the school needs to employ the energy service company to take an energy audit for the target buildings. This energy audit is aimed at investigating the current energy consumption conditions in the target buildings and providing the analysis of potential energy saving amount and corresponding measures. So on one hand, the energy saving amount conducted in the EPC contract is determined by the current energy consumption condition in project, on the other hand, it is also determined by the initial capital investment because the capital investment decides how much and on what level the suggested efficiency measures will be implemented in the project.

8. Energy price (Zhang, 2008): the energy price refers to the price of energy which the target school buildings is consumed. The energy could be such as electricity, natural gas, water, fuel oil and so on. It differs from own specific situation in schools. The energy price directly influences the profitability of the EPC project. The energy supply company benefits from the energy cost saving it achieved and the energy cost saving is considered as the energy price multiplied by the energy saving amount achieved in every year during the project. So there is a positive relationship between the energy price and the energy cost saving. The energy price is considered as an uncertain variable because it is influenced by the global energy production, inflation rate and other renewable type of energy.

9. Annual non-energy cost savings: the implemented energy efficiency measures will not only result in energy consumption amount savings, but also the reduction of other non-energy cost savings. For example, the operation and maintenance cost could reduce due to the better updated equipment and more professional operating staff. The other indirect savings such as reduction of healthy problem cost of teachers in school can also be part of the non-energy cost savings. But in real life case, most of the non-energy cost savings is estimated as the operation and maintenance cost savings.

10. Equity market risk premium (Brealey, 2011): the equity market risk premium is the average return which the investors require over the risk-free rate to accept the higher variability in returns which are common for equity investment.

11. Risk-free interest rate (Cheah, 2006): the risk-free interest rate only takes the time value of money and inflation into account. Since there is no investment that is genuine risk-free, the risk-free interest rate can approximately equal to the long-term debt instruments issued by financial healthy governments, for example, in this model, the government bond of United States is used as the risk-free interest rate in the case study.

12. Discount rate (Qian, 2014): the discount rate is the ratio when bring the expected profit in the future to the present money value. It plays a critical role in the determination of net present value (NPV) of the project. There are many ways to determine the value of discount rate and it is really difficult to choose one. In this model, the discount rate is regarded as influenced by the equity market risk premium and risk-free interest rate. As the equity market risk premium and risk-free interest rate are the uncertain value in the future, the discount rate is also regarded as an uncertain variable in the model.

13. Sharing ratio of the investment (Li, 2014): the school could choose the energy supply company to provide financial support, so there will be a sharing ratio of the investment within the ESCO between both parties. When the school decides to bring the ESCO into the investment part, the ratio of sharing investment between these both parties will be the critical contract term which needs to be negotiated because the capital invested is directly determining the profitability and risk allocation for both parties.

14. Sharing ratio of the profit (Li, 2014): in the shared saving EPC project, both parties within ESCO share the achieved energy cost saving during the contract period, as explained in previous, the energy cost saving is the resource that the ESCO cover its investment and earn the profit, so an appropriate ratio of sharing the profit is important. In the guaranteed sharing EPC, it can be regarded that the sharing ratio of the profit is 100% by the ESCO side.

15. NPV of the energy supply company: the NPV of the energy supply company in this model refers to the sum of annual present value of the project during the whole contract period.

16. NPV of the school: the NPV of the school in the model refers to the sum of annual present value of the project during the whole project economic lifetime.

17. NPV deviation: the NPV deviation denotes the difference of NPV between both parties and it will play as a negotiation indicator variable which shows the different strategies of NPV distribution. θ can be represented as the equation $\theta = \left|\frac{NPV_E - NPV_S}{NPV_E}\right|$.

Table 2. List of variables in the model

Name	Symbol	Category		
		Deterministic	Uncertain	Negotiating
Economic life of project	N	**X**		
Initial capital investment	I_C	**X**		
School budget for the project	I_B	**X**		
Annual operation and maintenance cost	I_{OM}	**X**		
NPV deviation	θ			**X**
Energy saving amount	M_S	**X**		
Non-energy cost savings	I_N	**X**		
Energy price	P_E		**X**	
Risk-free interest rate	R_i		**X**	
Equity market risk premium	R_m		**X**	
Discount rate	R		**X**	
Contract period	T_C			**X**
Sharing ratio of the investment by the energy supply company	α			**X**
Sharing ratio of the profit by the energy supply company	λ			**X**
NPV of the ESCO	NPV_E			**X**
NPV of the school	NPV_S			**X**

All the important variables are already shown. The energy efficiency measures are not employed in the model as already explained. The rest variables are categorized into three types: the deterministic, the uncertain and the negotiating variable. For the deterministic variable, it means that it will be predetermined when both parties in the project start building the contract. For the uncertain variable, it mainly refers to the energy price and discount rate during the whole project due to the variability nature of them. For the negotiating variable, it refers to the variable that both parties will focus on when influencing their interest of the project. In the end, they are summarized in the Table 2 shown in previous.

4.3 Decision support tool design

This thesis seeks to solve the problem of determining the optimal contract period, sharing ratio of the investment and profit by both parties within the ESCO based on different scenarios and objects. The problem is considered as a complex problem, due to the nature of non-linearity, complicacy and stochasticity. There will be four steps for this decision support tool. The first step (shown in Figure 7) is developing step during which all the key variables are identified and the NPV equations for both parties within the ESCO will be formulated by using the variables and parameter. The output of this step will be the input for the next step. The second step of the model is the simulation step. Variables with stochastic evolution process are considered as the uncertain variables and their values during a certain time will be generated by using time series analysis and Monte Carlo simulation technique. Then it comes to the third optimization step. By using the simulation result of uncertain variables as the data input meanwhile with the deterministic variables values from the case study, this step will employ non-linear programming to optimize the object NPV from each party in the contract. The optimization is based on the objects of each side that wants to achieve and scenarios of uncertain variables value. These previous three steps are what this thesis focuses on. The outcome of optimization will be several options including the NPV of both parties and corresponding contract period, sharing ratio of investment and profit. Then it comes to the forth step, the negotiation step. In this step, both parties will use the outcome of optimization to negotiate and finally get the agreement about the contract terms of the project. This is how the decision support tool is developed and will be used. The model design is explained step by step as shown in the following Figure 7

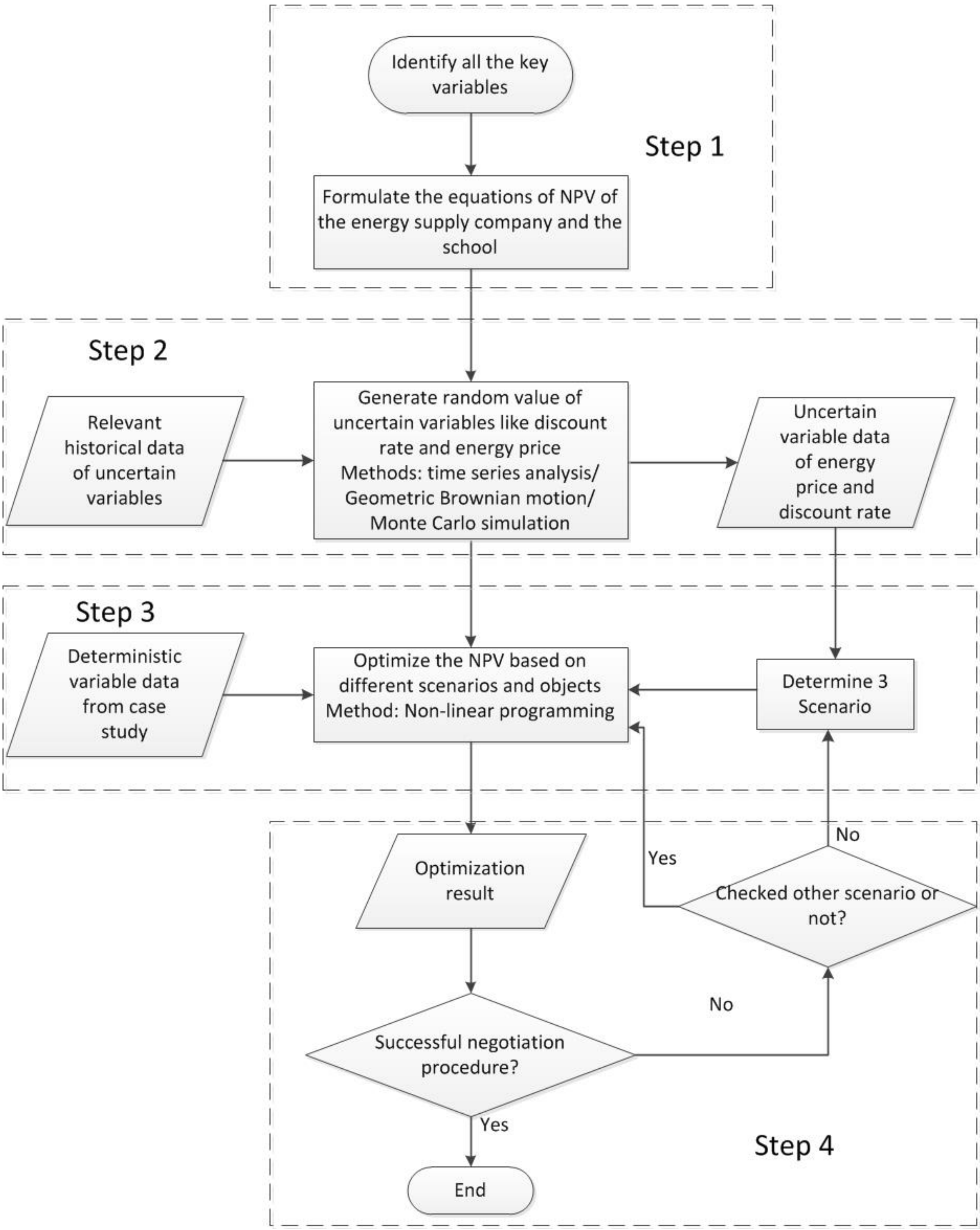

Figure 7. Decision support tool design

Uncertainties and risks both from external and internal of the project itself have influence on the future project success. External influencing factors are such as national or international policy towards energy efficiency, competitive renewable energy promotion and competitive funding mechanisms. Internal influencing factors are such as risks of failing with achieving the estimated energy saving performance, ending of project economic lifetime in advance and financial crisis in the energy supply company. These risks cannot be ignored in real life, but considering the complexity of optimization problem in this model, it is important to make several assumptions to simplify the model to some extent so that to keep the research into a specific scope. For this thesis, the decision support tool is mainly focusing on the economic aspect of EPC project in school, so there are basic assumptions made in the model.

4.3.1 Assumptions

Assumption 1: the energy saving amount is guaranteed during the whole project economic lifetime. In real fact, the achieved energy saving amount is influenced by the end user behavior, energy supply company staff controlling and monitoring process, the condition of implemented energy efficiency measures and so on. As this model is dealing with the EPC contract within ESCO, it is assumed that the estimated energy saving amount will achieve consistently so the risk to achieve determined energy saving amount is ignored.

Assumption 2: the contract period length will not exceed the project economic lifetime. For the energy supply company, if the contract period length is longer than the project economic lifetime, it means that after the equipment or envelope insulation is scraped, they will still be responsible for supply services to the school but without any profit from the energy efficiency measures. This is at a loss so that will not be accepted by the energy supply company as a profit seeking role. For the school, it also prefers the shorter contract period length than project economic lifetime, because will benefit more in a longer period during which itself own the energy cost saving. So from both parties within the ESCO, it makes sense to assume that contract period is shorter than the project economic lifetime. In real life cases, the insulation lifetime could be 30-40 years and even lighting system for school could still last for 15 years, but normally the contract period of these project seldom exceeding 15 years.

Assumption 3: all the investment happens at the beginning of project, which can be regarded as the initial capital investment. It means that during whole project lifetime, there will not be any other investment related to the project.

4.4 Methods

In previous subsection, all the relevant variables have been identified. It means that for the first step of model has already been done partly. These variables are all influential variables that affect the decision making for both parties of the EPC contract, particularly on the financial aspect.

4.4.1 Formulate NPV equations with system dynamics

Firstly, system dynamics is employed in the model. System dynamics is a simulation methodology enables users to understand and visualize the complex inter structure and dynamic changes during a certain period. Causal loop diagram or stock and flow diagram can both represent the system dynamics model. In this thesis, the stock and flow diagram about both parties' NPV is shown to help users to get a better understanding how the pre-defined variables influencing the NPV. In Figure 8, the stock and flow diagram represents the relationships of identified variables.

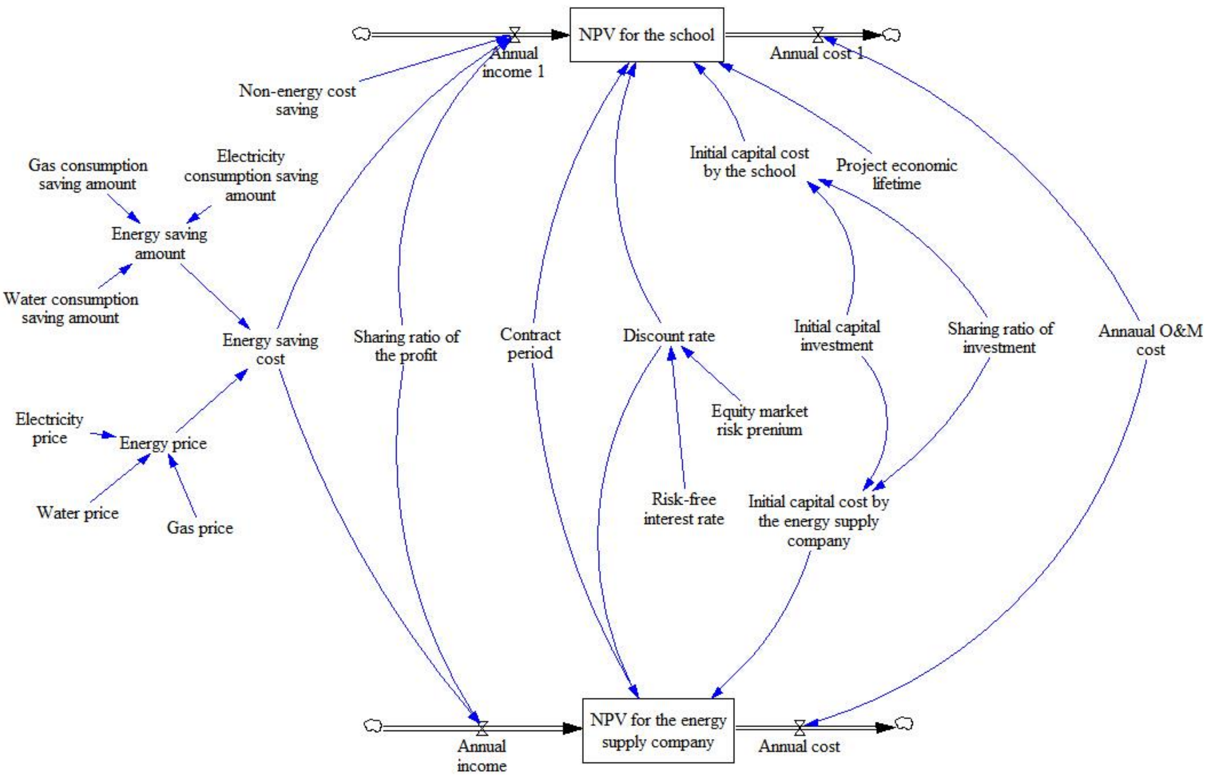

Figure 8. Stock flow diagram of variables affect the NPV of both parties within ESCO

As the can be seen from the Figure 8, the NPV of the school and the energy supply company is affected by these variables directly or indirectly. For the both parties, their NPVs are affected by the variables of initial capital investment, energy saving amount, energy price, contract period, discount rate, annual operation and maintenance cost, sharing ratio of investment and profit. For the school, its NPV particularly is affected by three more variables, the project economic lifetime, budget for the project and non-energy cost savings. Interrelationships between the variables and NPV are complex. The NPVs of the school and energy supply company are regarded as the stocks in the diagram and influential variables mainly affect the NPV from three areas, the annual cash inflow which is the profit, the annual cash outflow which is mainly the operation and maintenance cost and final one is the directly influential variable on NPV. This stock and flow diagram provides model users a visualizing picture with key influential variables which affect their NPV. It also helps to formulate the NPV equations for both parties mathematically and provides support for next step of model development.

Then it comes to formulate the equations NPV for both the school and energy supply company within the ESCO. The net present value (NPV) is one of the most common methods for evaluation of financial viability of project. There is standard equation to calculate the project NPV as shown in following:

$$NPV(t) = \sum_{t=0}^{N} \frac{I(t) - C(t)}{(1+r)^t} \tag{1}$$

where $NPV(t)$ is the net present value in year t, $I(t)$ =income of year t, $C(t) =$ cost in year t, $r =$ discount rate and N = the project economic lifetime. But this is just the standard equation to calculate the NPV, in this decision support tool, equations of NPV for the school and the energy supply company will be formulated based on different variables.

For the school, its NPV equation could be divided into two parts: within the contract period and after contract period. During the contract period, the school does not need to take activities for energy using control, operating and maintenance because the energy supply company will take over all of these activities. So that the annual income for the school will be the shared energy cost saving from the project and there is no cost. Moreover, the non-energy cost savings, mainly the cost savings from the operation and maintenance cost is also regarded as the income part for the school. When the contract ends, the school will be responsible for the operating and maintenance activities, so that annual cost during these years will be the operation and maintenance cost, and the annual income becomes the whole achieved energy cost saving plus the non-energy savings. As the whole capital investment happens at the beginning of the project, the NPV of the school needs to minus the initial capital investment by its side. Furthermore, the initial capital investment by school should not exceed its budget; this will be used as the constraint in the optimization process. So the NPV of the school in the project will be shown as the following equation:

$$NPV_S = \sum_{t=0}^{N} \frac{I_S(t) - C_S(t)}{(1+R)^t} - I_{CS} \tag{2}$$

where NPV_S stands for the net present value of the school in the EPC project, respectively; N denotes the project economic lifetime; I_{CS} = initial capital investment by the school; $I_S(t)$= income of year t by the school; $C_S(t)$= cost of year t by the school. As already explained in previous, the Eqs. (2) Should be divided into three parts shown as Eqs. (3), (4) and (5):

$$NPV_{S1} = \sum_{t=0}^{T_C} \frac{M_S(t) \cdot P_E(t) \cdot (1-\lambda) + I_N(t)}{(1+R)^t} \tag{3}$$

$$NPV_{S2} = \sum_{t=T_C+1}^{N} \frac{M_S(t) \cdot P_E(t) + I_N(t) - I_{OM}(t)}{(1+R)^t} \tag{4}$$

where NPV_{S1}stands for the net present value of the school during the contract period, and NPV_{S2} stands for the net present value of the school after the contract period. $M_S(t) =$ energy saving amount at year t; $P_E(t) =$ energy price at year t; $\lambda =$ sharing ratio of profit by the energy supply company; $I_{OM}(t) =$ annual operation and maintenance cost at year t; $I_N(t) =$ Annual non-energy cost savings; $N =$ project economic lifetime; $T_C =$ contract period; $R =$ discount rate .

Moreover, the initial capital investment by the school I_{CS} is calculated as the Eqs. (5):

$$I_{CS} = I_C \cdot (1 - \alpha) \tag{5}$$

Where $I_C =$ initial capital investment of the project; $\alpha =$ sharing ratio of the investment by the energy supply company.

So the NPV of the school in EPC project can be represented as Eqs. (6):

$$NPV_S = \sum_{t=0}^{T_C} \frac{M_S(t) \cdot P_E(t) \cdot (1 - \lambda) + I_N(t)}{(1 + R)^t} + \sum_{t=T_{C+1}}^{N} \frac{M_S(t) \cdot P_E(t) + I_N(t) - I_{OM}(t)}{(1 + R)^t} - I_C \cdot (1 - \alpha) \tag{6}$$

For the energy supply company, within the ESCO it provides the investment to project and make profit by the energy saving cost. The NPV of energy supply company is within the contract period. The shared energy saving cost is the annual income and operation and maintenance cost plays the role of annual cost. Like the school, the energy supply company makes initial capital investment at the beginning of the project. So the NPV for the energy supply company could be represented as the following Eqs. (7):

$$NPV_E = \sum_{t=0}^{T_C} \frac{I_E(t) - C_E(t)}{(1 + R)^t} - I_{CE} \tag{7}$$

Where NPV_E stands for the net present value of the energy supply company in the EPC project, respectively; $T_C =$ contract period; $I_E(t) =$ income at year t of the energy supply company; $C_E(t) =$ cost at year t of the energy supply company; $I_{CE} =$ initial capital investment by the energy supply company; $R =$ discount rate. The I_{CE} can be calculated by the Eqs. (8):

$$I_{CE} = I_C \cdot \alpha \tag{8}$$

Where $I_C =$ initial capital investment of the project; $\alpha =$ sharing ratio of the investment by the school. According to the previous explanation, the Eqs. (7) equals to the Eqs. (9):

$$NPV_E = \sum_{t=0}^{T_C} \frac{M_S(t) \cdot P_E(t) \cdot \lambda - I_{OM}(t)}{(1 + R)^t} - I_C \cdot \alpha \tag{9}$$

Where $M_S(t) =$ energy saving amount at year t; $P_E(t) =$ energy price at year t; $\lambda =$ sharing ratio of profit by the school; $I_{OM}(t) =$ annual operation and maintenance cost at year t; $T_C =$ contract period; $R =$ discount rate .

Here the equations of NPV for both parties within the ESCO have already formulated, for next step, values of the uncertain variables need to be simulated.

4.4.2 Model simulation with time series analysis and Monte Carlo simulation

There are many uncertainties and risks affect the success of the EPC project both on the external level and internal level of the project itself. In this decision support tool, the risks which are taken into account are the fluctuation of energy price and the discount rate.

The Geometric Brownian motion (GBM) is a widely used approach to describe the stochastic diffusion process of the commodity price changes. There are many previous studies employed it to represent and estimate the commodity price. In the study of Deng et al. (2015) which was aimed at strategic design of energy saving cost guarantee in EPC project, the authors used Geometric Brownian motion to predict the energy price during the project contract. Garvin et al. (2004) employed the GBM to represent the stochastic process of interest rate in their model. So in this model, the Geometric Brownian motion is also applied to represent the diffusion process of the energy price and discount rate during the EPC project.

As already has been introduced in previously, the energy price type included in the decision support tool is determined by the energy efficiency measures which implemented in the sustainable project. Even though the measures vary from installation of equipment to reconstruction of the insulation, the result of these measures can be resulted as energy saving amount in every year. Normally, energy saving achieved in the school ESCO project are the electricity, gas, water and fossil oil. To describe the energy price stochastic diffusion process in the future, the energy price is formulated as the following equation:

$$dP_E(t) = \mu\, P_E(t)\, dt + \sigma P_E(t)\, dW_P(t) \tag{10}$$

$$d\ln P_E(t) = \left(\mu - \frac{\sigma^2}{2}\right) dt + \sigma\ dW_P(t) \tag{11}$$

$$P_E(t) = P_{E0} exp\left[\left(\mu - \frac{\sigma^2}{2}\right) t + \sigma\, dW_P(t)\right] \tag{12}$$

where the Eqs. (12) is derived from Eqs. (10) and (11). In the Eqs. (12), there are three inputs. P_{E0} is the initial energy price when the project starts. $dW_P(t)$ is the standard Wiener process, or saying the Brownian motion, $dW_P(t) = \varepsilon\sqrt{dt}$, where $\varepsilon \sim N(0,1)$ is a standardized normal distribution. μ in the Eqs. (12) is the annual energy price drift effect and the σ is the annual energy price volatility effect. These two parameters can be derived from the historical data of corresponding energy price.

For the other uncertain variable, the discount rate, it is also difficult to determine it. Risks of investment should be taken into account so that it influences the discount rate. So in this model, a risk-adjusted discount rate is used to calculate the NPV of the project. According to Brealey et al. (2000), the authors gave a recommend equation to calculate the discount rate as below:

$$R = R_i + \beta \cdot R_m \tag{13}$$

where R_i is the risk-free interest rate and the R_m is the equity market risk premium. The parameter β represents the returns of a certain company behave in relation to the return of the relevant market benchmark. The R_i risk-free interest rate in this model is the project local country 10 years government bond which is a stochastic variable. Likewise, the R_m equity market risk premium is assumed as following the Geometric Brownian motion, so that like the energy price, the equation for equity market risk premium and risk-free interest rate can be formulated as the following equations:

$$dR_i(t) = \mu\, R_i(t)\, dt + \sigma R_i(t)\, dW_P(t) \tag{14}$$

$$R_i(t) = R_{i0} exp\left[\left(\mu - \frac{\sigma^2}{2}\right)t + \sigma\, dW_P(t)\right] \tag{15}$$

$$dR_m(t) = \mu\, R_m(t)\, dt + \sigma R_m(t)\, dW_P(t) \tag{16}$$

$$R_m(t) = R_{m0} exp\left[\left(\mu - \frac{\sigma^2}{2}\right)t + \sigma\, dW_P(t)\right] \tag{17}$$

where the R_{m0} and R_{i0} are the initial value of equity market risk premium and risk-free interest rate when the project starts. Parameters of μ and σ in the Eqs. (14) and Eqs. (17) are the drift effect and volatility effect which will be derived from historical data of R_{i0} and R_m. It is important that the value of parameter β in the model is equal to 1 because that for the overall market, the summation of all returns of individual stocks equals to the overall return of the market.

To use GBM, a time series analysis of the historical data is needed to generate the drift and volatility affect parameter. The Monte Carlo simulation technique will be employed to simulate to range value of these two variables in this model. The outcome of this simulation process will provide the range value of two variables and they will be chosen and combined as different scenarios. For the next step optimization process, the values of different scenarios will be the input to optimize.

4.4.3 Model optimization with non-linear programming

Based on fulfilling the objects and goals of both parties within the ESCO, the decision support tool is aimed at providing both parties with optimized contract period, sharing ratio of investment and profit which are regarded as important contract terms needs to be negotiated. The model will help the school and energy supply company to have a better understanding about the key problems they need to consider when building the EPC contract and an optimal solution based on their ambitions.

For the school, it is considered as taking the ambition of achieving required energy consumption reduction and indoor environment quality improvement as the most important goal in this project. So that for the school, as long as the ambition of project could be ensured, their expectation on profitability of the project is not the most important key factor needs to be taken into account when making decision. It just needs to ensure the NPV of the project on the school side is positive, in some particular situation, the negative NPV can also be accepted. Comparing with larger NPV, the school is more interested in maximizing the level of energy consumption reduction and indoor environment quality improvement within its limit budget on capital investment.

For the energy supply company, as the enterprise, it is its nature to seek for maximal profit during its business. So that based on ensuring the school's ambition, the energy supply company will try to make their NPV of the project as large as possible. Of cause in the real life case, it needs to bid with other business competitors, so that the outcome of the model could provide different offers to satisfy the school preference in order to get the maximal profit. It will be elaborated in the next subsection.

Before the optimization process, firstly different scenarios need to be identified. As have already been explained, the outcome of Monte Carlo simulation of energy price and discount rate will combined as different scenarios. Here three scenarios are identified.

Table 3. Scenario table

Scenario	Discount rate	Energy price
1. Optimistic scenario	Minimal	Maximal
2. Regular scenario	Regular	Regular
3.Pessimistic scenario	Maximal	Minimal

So the optimization process of the decision support tool can be represented as the following Figure 9:

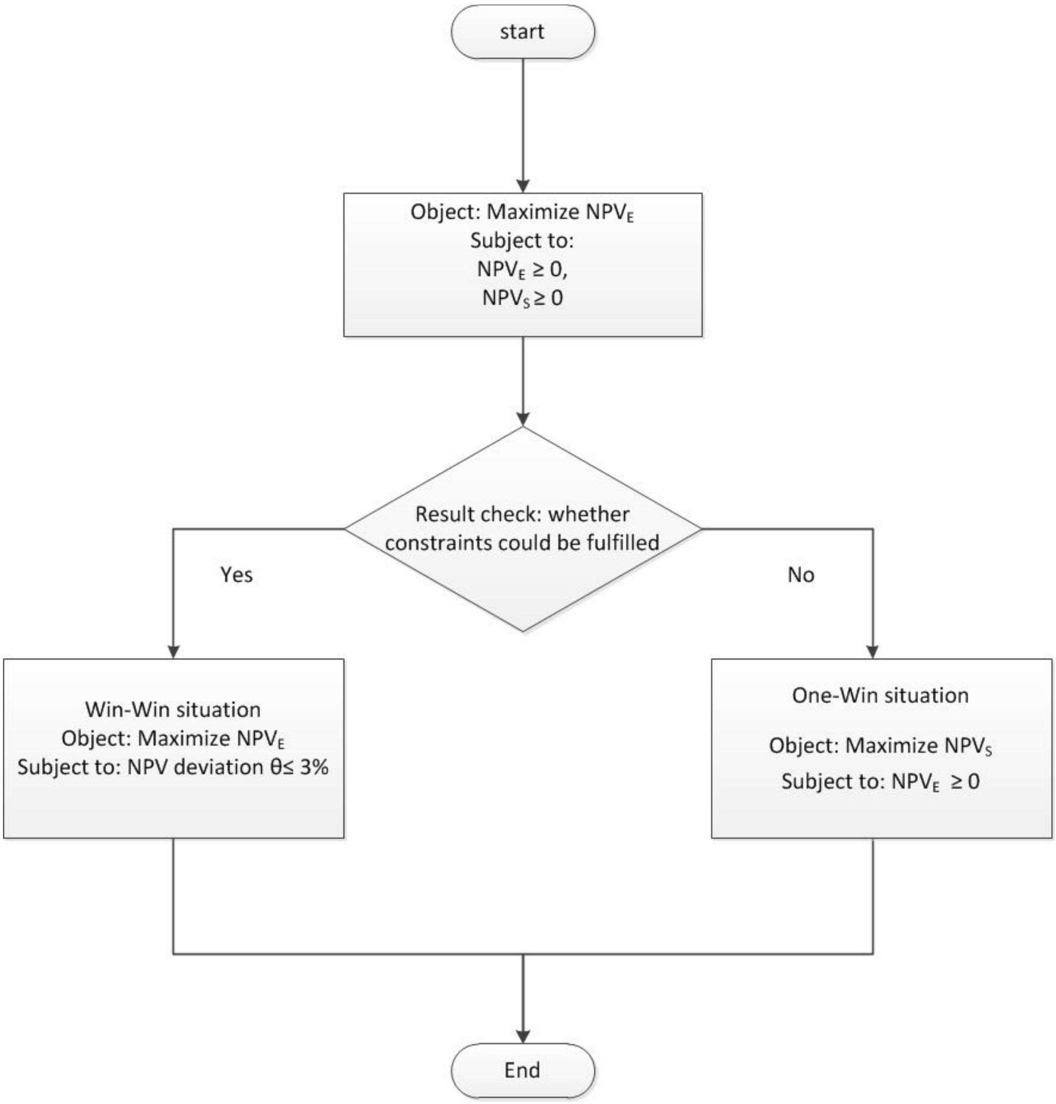

Figure 9. Optimization process of decision support tool

Under every scenario, at the beginning of the optimization, a test will be performed to investigate the profitability of project. In detail, it is to maximize the NPV of the energy supply company meanwhile ensuring the NPV of both parties is positive. This step is to check under a certain scenario, is it possible to make sure both parties could achieve the positive NPV. If it is feasible, it means that both the energy supply company and the school could earn money from project. This will lead to a win-win situation. Then the work comes to maximize the NPV of the energy supply company at the same time keeps the NPV deviation θ of both parties smaller than 3%, which means a 50/50 NPV distribution strategy. Here the NPV distribution is represented as "NPV_E/NPV_S" which means that if the NPV distribution is 50/50 it means that the NPV of the energy supply company and the school both account 50% of the total NPV of the project. There will also be the 25/75 and 75/25 NPV distribution strategy for optimization under different scenarios. To be specific, the different NPV distribution strategy related with θ is shown below:

$$\theta = \left|\frac{\mathrm{NPV_E} - \mathrm{NPV_S}}{\mathrm{NPV_E}}\right| \tag{18}$$

When NPV distribution strategy is 50/50, then $\theta \leq 0.03$

When NPV distribution strategy is 25/75, then $1.97 \leq \theta \leq 2.03$
When NPV distribution strategy is 75/25, then $0.64 \leq \theta \leq 0.70$

The value determination of θ is depended on how the two parties define their NPV distribution strategy.

If it is not feasible to ensure the both parties get positive NPV, then it becomes the one-win situation which means that only one party can make the positive NPV and the other one has to accept the negative NPV. As already has discussed previously, as the enterprise which seeking profit, the energy supply company will not involve in the project if it cannot make profit from the project. On the other hand, the school which pays more attention to achieve its ambitions on energy consumption reduction, CO_2 emission reduction and indoor environment quality improvement, could accept the negative NPV under a terrible scenario. So the optimization becomes to maximize the NPV of the school which means to reduce the capital loss to the greatest extent meanwhile ensuring the positive NPV of energy supply company to make sure it could make profit from the project.

There are some common constraints for the optimization process regardless it is under which scenario. Firstly, the sharing ratios of investment and profit are obviously between 0 and 100%. But in reality, the energy supply company will share at least 50% of the profit to ensure the profit. Meanwhile, in order to provide enough capital support, the sharing of investment ratio by energy supply company should also be larger than 50%. Secondly, due to the investigation of EPC project database, most of project contract period is between 5 to 15 years, so the constraint for contract period is $5 \leq T_P \leq 15$. Thirdly, the variation of both the ratios of investment and profit shared by both parties is 5%, because too accurate level of variation for example in 1% makes little difference between the NPV results. It will take users too much time and energy to make decision with these small variations. Particular constraint for every scenario will be explained in the result part.

The result of the model will be the optimized NPV of energy supply company and school also corresponding optimized contract period length, sharing ratio of investment and profit. As the equations of NPV by both parties are non-linear, so that the optimization problem turns to the non-linear programming problem. It will be solved by the add-in program @RISK® with Microsoft Excel®. The results will also be analyzed under different scenarios to check their profitability and provide users more information for decision making and negotiating.

4.5 Results and findings

4.5.1 Negotiation procedure

The previous three steps are the main part of this thesis focuses on, but there still needs a step about how the model users could use this model to help them, so the negotiation procedure will be introduced. Even though it is not as detail as previous steps, it is still the important part of the model. After the optimization step, the optimized results which are represented as different options will provide users the optimal result of NPV by both parties and their contract period, sharing ratio of investment and profit. The school and the energy supply company need to negotiate in order to pick up a particular one option as their agreement on the contract terms.

When facing the provided the different options which are under different scenarios and NPV distribution strategies, the first thing for decision support tool user needs to do is to select a particular scenario. It is recommended to choose the Regular scenario as starter because this scenario is close to the real life but without the extreme situations.

After selected the scenario, then the both parties move into the first round of negotiation: the negotiation on the NPV sharing distribution strategy. If the energy supply company is the more powerful one, then they may get the agreement on the 25/75 strategy due to the nature of profit seeking by the energy supply company. Of course, if the school is on a in a more powerful situation, then they may pick up the 50/50 strategy even 75/25 strategy. Before the beginning of this round negotiation, both parties must have a clear overview about their own goal and baseline on their NPV of the project.

Then in the next step they start to negotiate to select one specific option from provided top 5 options. Here it needs to explain that the number of optimization options under different scenarios and NPV distribution strategies may range from 2 to 20 or even more, but due to fact that there may be very little difference between two options, the result will provide the top 5 different options to the users. It is also for the consideration of saving time and energy for the both parties of decision makers.

Now it comes back to the negotiation on selection of particular option. As the scenario and NPV deviation have already been on an agreement for both parties, the NPVs of the provided 5 options do not vary in a large range, so the negotiation will focus on the key contract terms: the contract period, the sharing of investment and profit. It is recommended that they start their negotiation on the contract period because the different contract period will not only affect the NPV but also directly lead to different level of potential uncertainties and risks in the future. It plays a significant role in the influence on the success on the project because these uncertainties and risks not only influencing the financial area but also other areas of the project. On the contrary, even though the both parties, especially the energy supply company, will have their own preference on the amount of investment and profit, but these two contract terms just limit their influence mainly on the NPV. This negotiation on contract period depended on the both parties' preference and trade-off. After the contract period is determined, it is depended on the real case to decide whether a further negotiation is needed because it is possible that there is more than one option including their satisfied contract period. Then both parties can go on the negotiation on the other two contract period.

After they select a particular option, the final step of both parties need to do is to check the performance of this option under different scenarios to see whether they are satisfied with it or not.

Nevertheless, the both negotiating parties can use the results of optimization process as the information resource for their decision making. If they get an agreement on one particular option, then the decision making process ends. If they cannot get an agreement after the negotiation, then the both parties need to go back on the optimization results and choose other options under different scenarios and NPV distribution strategies to re-start the negotiation procedure.

4.5.2 Case study and data input

To verify the usability of this decision support tool, a case study is employed. Due to the low level of implementation of EPC in public school project in the Netherlands, the case employed in this thesis is from a United States college. The Western State College of Colorado took energy efficiency measures included an energy management system upgrade, retro-commissioning of buildings, CO_2 sensor for ventilation control, air handing unit retrofit, water conservation, window replacement, lighting retrofit and control with the help from the one ESCO. The overall investment of the project was about $1.5 million. As already has been shown in previous part, there are still some variables value missing, because it is difficult to get such detail data from published case information. So the other deterministic variable values are used as assumptions. The whole project cost will be covered by the initial capital investment, which means that project cost equals to the initial capital investment. The project economic lifetime is assumed as 20 years. From the others similar cases, it can be assumed that the annual operating and maintenance cost is as 5% of the energy saving cost and the non-energy saving cost equals to it. It means that the operation and maintenance cost achieve a 50% reduction which is credible due to other known cases. Moreover, the school budget for this project is missing so that this constraint is ignored in the case study. So from the case study, the necessary deterministic variables value is complete. Details about this project are shown in the Table 4 below:

Table 4. Details of the case study

Name	Unit	Value
1. Project cost	$	1535388
2. Annual electricity saving amount	KWh	1852190
3. Annual natural gas saving amount	therm	65544
4. Annual operating and maintenance cost	$	5% of the energy saving cost
5. Project economic lifetime	Year	20
6. Non-energy cost saving	$	5% of the energy saving cost

On the other hand, the uncertain variables historical data for Monte Carlo simulation is also needed. The historical electricity price and natural gas price data are from the Colorado historical industrial customer energy price. The risk-free interest data used in the model is the U.S 10 federal bonds. The equity market risk premium is also the calculated historical data by scholars. All the historical data will be shown in the appendix.

4.5.3 User interface

Decision support tool							
No.	Variable	Category	Unit	symbol	Value		
1	Economic life of project	deterministic	year	N	20		
2	Initial capital investment		$	I_C	1.535.388		
3	Annual operation and maintenance cost		$/year	I_{OM}	12822,29939		
4	Energy saving amount		therms/year	A_S	65544		
			Kwh/year		1852190		
5	Non-energy cost savings		$/year	I_N	12822,29939		
					Senario 1 Optimistic	Senario 2 Regular	Senario 3 Pessimistic
6	Energy price	Uncertain	€/therm	P_{EE}	2,8082	1,1517	0,6845
			€/Kwh	P_{EN}	0,1215	0,0977	0,077
7	Discount rate			R	0,0869	0,0963	0,1099

Figure 10. User input interface of the decision support tool

The Figure 10 shows the user input interface of the decision support tool. As can be seen from the figure, the first category variables are the input data from the case, which means that the user needs to fill in the data from their own project. The second category variables are the uncertain ones which will be provided by the time series analysis and Monte Carlo simulation. When using the decision support tool, the pre-generated value of these variables will be grouped as different scenarios and data used as input for the model is followed the scenario. Then it is the user output interface of the decision support tool. The negotiating variables values are the optimization result which will provide the user as the decision making and negotiation information resource. The result part are the corresponding NPV of both parties within the ESCO due to the given contract period, sharing ratio of investment and profit. The simulation and optimization process are dealt with professional software within the Microsoft Excel® and is not introduced in detail here. The Table 5 shown below is the user output interface.

Table 5. User output interface of the decision support tool

Scenario 1: Optimistic		50/50 NPV distribution strategy with maximal NPV_E				
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	1151798.70	1131301.78	10	0.50	0.80	0.02
2	1146749.46	1136351.02	10	0.90	1.00	0.01
3	1142641.64	1140458.85	9	0.55	0.85	0.00
4	1140333.15	1142767.33	8	0.60	0.95	0.00
5	1132090.20	1151010.29	7	0.55	1.00	0.02
Scenario 1: Optimistic		75/25 NPV distribution strategy with maximal NPV_E				
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy	Sharing ratio of the profit by the energy	θ

				supply company	supply company	
1	1760904,66	522195,82	10	0,50	1,00	0,70
2	1703496,34	502329,04	15	0,75	0,90	0,71
3	1697719,54	501390,64	14	0,90	1,00	0,70
4	1689175,77	509934,41	14	0,80	0,95	0,70
5	1689091,77	516733,61	15	0,65	0,85	0,69

Scenario 1: Optimistic			25/75 NPV distribution strategy with maximal NPV_E			
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	569095,98	1714004,50	9	0,60	0,85	2,01
2	567675,94	1715424,54	8	0,60	0,70	2,02
3	567444,66	1715655,82	7	0,85	0,95	2,02
4	547654,89	1636223,52	12	1,00	0,75	1,99
5	546054,05	1653056,13	14	0,70	0,55	2,03

Scenario 2: Regular			50/50 NPV distribution strategy with maximal NPV_E			
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	356444,53	347728,27	9	0,50	0,80	0,02
2	356369,42	347803,38	10	0,55	0,80	0,02
3	356186,80	347986,01	7	0,55	1,00	0,02
4	354617,70	349555,10	9	0,55	0,85	0,01
5	353083,30	351089,50	10	0,50	0,75	0,01

Scenario 2: Regular			75/25 NPV distribution strategy with maximal NPV_E			
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	523052,71	181120,10	10	0,65	1,00	0,65
2	519766,59	184406,22	10	0,60	0,95	0,65
3	506773,71	152696,06	14	0,80	0,95	0,70
4	505046,46	154423,31	14	0,55	0,75	0,69
5	503745,75	151419,11	13	0,70	0,90	0,70

Scenario 2: Regular			25/75 NPV distribution strategy with maximal NPV_E			
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply	θ

					company	
1	166400,95	496995,57	15	0,80	0,75	1,99
2	164499,03	490665,83	13	0,80	0,80	1,98

Scenario 3: Pessimistic			Maximal NPV_S		
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company
1	4431,81	-45850,31	8	0,50	0,85
2	5523,87	-46942,37	10	0,50	0,75
3	11187,49	-52606,00	9	0,50	0,80
4	13424,99	-54843,50	9	0,60	0,95
5	17674,61	-59093,11	10	0,60	0,90

4.5.4 Results

4.5.4.1 Simulation result

To get the result of the case study, the first process is to use time series analysis and Monte Carlo simulation technique to generate the uncertain variables value of energy price and the discount rate. Firstly, the historical data of these variables need to be found and then the drift and volatility effect of these variables will be calculated. Then by using Monte Carlo simulation, their value in the coming 20 years during the project economic lifetime will be generated. It needs to mention here that in the case study, the case is assumed to begin at year 2015 and after the 20 years project economic lifetime, it is year 2034. Based on the simulated values, different scenarios including these variable values will be shown then used as input for the optimization process.

In the Table 6 below, the drift affect μ and volatility affect σ of four uncertain variables: the risk-free interest rate, the equity market risk premium, the electricity price and the natural gas price are shown. The risk-free interest rate data used here is the historical United States 10 year bond rate. The implied equity market risk premium for U.S market is used for equity market risk premium. The electricity price and natural gas price are the historical local Colorado industrial customer price.

Table 6. Drift affect μ and volatility affect σ of uncertain variables

	drift affect μ	volatility affect σ
1. risk-free interest rate	0.0606	-0.033
2. equity market risk premium	0.0428	0.0253
3. electricity price	0.0114	0.0243
4. natural gas price	0.0704	0.0771

Based on the Eqs. (10) to Eqs.(15), the Monte Carlo simulation is performed 100000 trials for every variable within the Microsoft Excel® using RiskAMP®. As the simulation is aimed at to generate the range value of the variables within the 20 years project economic lifetime, the selection of maximal and minimal value is based on the value range of each year value in the simulated 20 years.

As already introduced before, the discount rate equals to the risk-free interest rate plus the equity market risk premium rate, so the simulation result of discount rate is the summation of these two variables. In the Appendix A, the details about annual discount rate can be indicated, which included the minimal value, median value, maximal value and mean value. The same kind of result about the electricity price and natural gas price are also shown in the Appendix B and C.

As the equations for all these variables described, their stochastic process follows the normal distribution. For the normal distribution, the skewness between -1.5 and +1.5 and kurtosis between 1.5 and 4.5 are considered as acceptable (Tabachnick, 2013). All the simulation results of uncertain variables fall into this range, so that it proves the results are acceptable and reliable.

The main outcome of this simulation process is the three scenarios with combination of different values of uncertain variables shown as Table 7 below:

Table 7. Scenarios with uncertain variable values

	Discount rate (%)	Electricity price ($/KWh)	Natural gas price ($/therm)
Scenario 1. Optimistic	8.69	0.1215	2.8082
Scenario 2. Regular	9.63	0.0997	1.5174
Scenario 3. Pessimistic	10.99	0.077	0.6845

The Optimistic scenario is defined as the situation with highest energy price and lowest discount rate, which represent the optimistic economic environment for EPC project to make profit. On contrast, the Pessimistic scenario is defined as the situation with lowest energy price and highest discount rate, which will lead to negative effect on the NPV of both parties. Here all the used values are the mean value of every variable annual simulation result. The Regular scenario is considered as the mean value between these two scenarios.

4.5.4.1 Optimization result

Then it comes to the optimization step. Followed by the optimization step, the first step is to test the profitability under every scenario. The detail process has been introduced in previous section so that here the test step result is just provided. The result indicates that under the Optimistic and Regular scenario, it is feasible to carry out a win-win situation and under the Pessimistic scenario it is only possible to take a one-win situation.

Under the Optimistic scenario, the optimization problem can be represented as:

Object: Maximize NPV_E

Subject to: $0.5 \leq \alpha \leq 1$, $0.5 \leq \lambda \leq 1$, $5 \leq T_P \leq 15$,

Then optimization result is shown as the Table 8 below:

Table 8. Optimization result under the Optimistic scenario

1. 50/50 NPV distribution strategy with maximal NPVE						
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	1151798.70	1131301.78	10	0.50	0.80	0.02
2	1146749.46	1136351.02	10	0.90	1.00	0.01
3	1142641.64	1140458.85	9	0.55	0.85	0.00
4	1140333.15	1142767.33	8	0.60	0.95	0.00
5	1132090.20	1151010.29	7	0.55	1.00	0.02
2. 75/25 NPV distribution strategy with maximal NPVE						
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	1760904.66	522195.82	10	0.50	1.00	0.70
2	1703496.34	502329.04	15	0.75	0.90	0.71
3	1697719.54	501390.64	14	0.90	1.00	0.70
4	1689175.77	509934.41	14	0.80	0.95	0.70
5	1689091.77	516733.61	15	0.65	0.85	0.69
3. 25/75 NPV distribution strategy with maximal NPVE						
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	569095.98	1714004.50	9	0.60	0.85	2.01
2	567675.94	1715424.54	8	0.60	0.70	2.02
3	567444.66	1715655.82	7	0.85	0.95	2.02
4	547654.89	1636223.52	12	1.00	0.75	1.99
5	546054.05	1653056.13	14	0.70	0.55	2.03

It can be concluded from the result that under the Optimistic scenario, the total NPV of the project is about $2283100 in 20 years project economic lifetime. In most options, the energy supply company takes the majority of profit. For the decision making by contract parties, they need deeper negotiation on the specific contract terms. At the same time, it also means that will be different options for users to use for the next round negotiation.

Under the Regular scenario, the optimization problem can be represented as:
Object: Maximize NPV_E
Subject to: $0.5 \leq \alpha \leq 1$, $0.5 \leq \lambda \leq 1$, $5 \leq T_P \leq 15$,
Then optimization result is shown as the Table 9 below:

Table 9. Optimization result under the Regular scenario

1. 50/50 NPV distribution strategy with maximal NPVE						
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	356444.53	347728.27	9	0.50	0.80	0.02
2	356369.42	347803.38	10	0.55	0.80	0.02
3	356186.80	347986.01	7	0.55	1.00	0.02
4	354617.70	349555.10	9	0.55	0.85	0.01
5	353083.30	351089.50	10	0.50	0.75	0.01
2. 75/25 NPV distribution strategy with maximal NPVE						
Option No.	NPVE	NPVS	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	523052.71	181120.10	10	0.65	1.00	0.65
2	519766.59	184406.22	10	0.60	0.95	0.65
3	506773.71	152696.06	14	0.80	0.95	0.70
4	505046.46	154423.31	14	0.55	0.75	0.69
5	503745.75	151419.11	13	0.70	0.90	0.70
3. 25/75 NPV distribution strategy with maximal NPVE						
Option No.	NPV_E	NPV_S	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company	θ
1	166400.95	496995.57	15	0.80	0.75	1.99
2	164499.03	490665.83	13	0.80	0.80	1.98

Compared with the Optimistic scenario, the obvious difference is the total NPV of project reduction, specifically, under the Regular scenario, the total project NPV is about \$704173 in 20 years. It is 30.84% of the Optimistic scenario total NPV.

As already has been introduced in previously, when the decision support tool users get the optimization result, after the negotiation, finally they reach on an agreement about selection of a particular on option provided from the optimization result. After both parties select particular one option, they also need to check the performance of this particular one option under every scenario.

Here the option 1 provided under Regular scenario with 50/50 NPV distribution strategy will be selected as the example to shown the performance test for option under different scenario. This option provided the contract period with 9 years, and the sharing ratio of investment and profit by the energy supply company are 0.5 and 0.8.

There are three figures shown below:

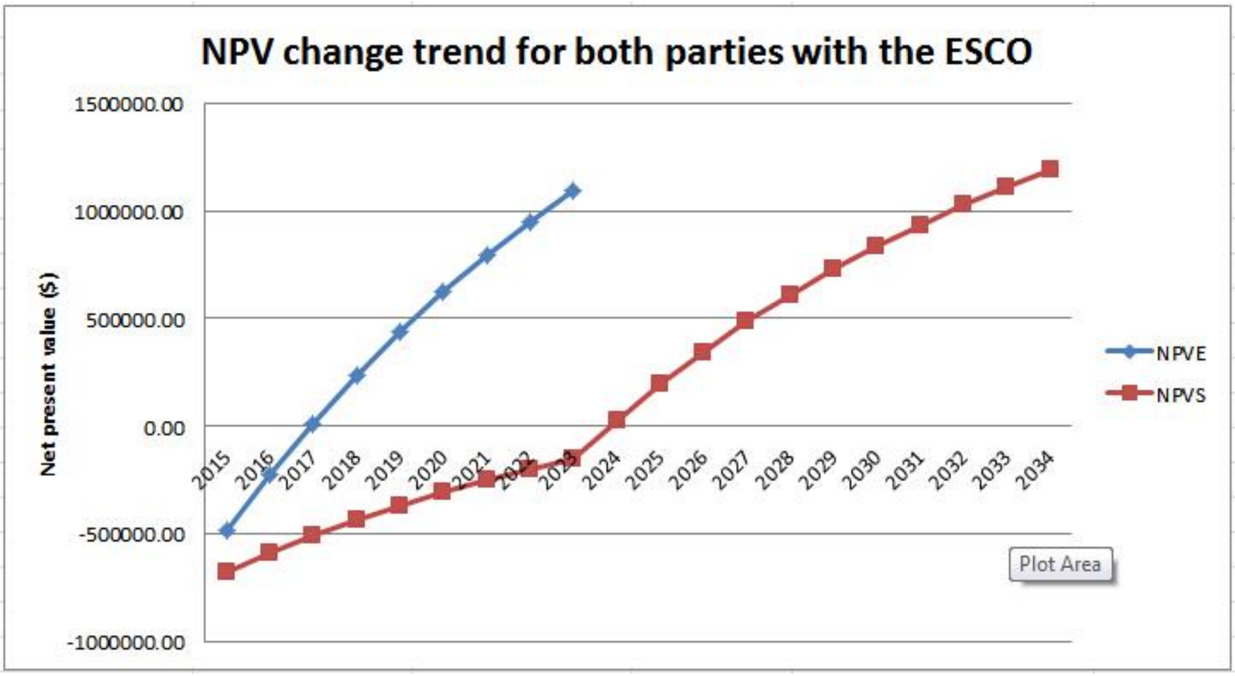

Figure 11. NPV change trend for both parties under the Optimistic scenario

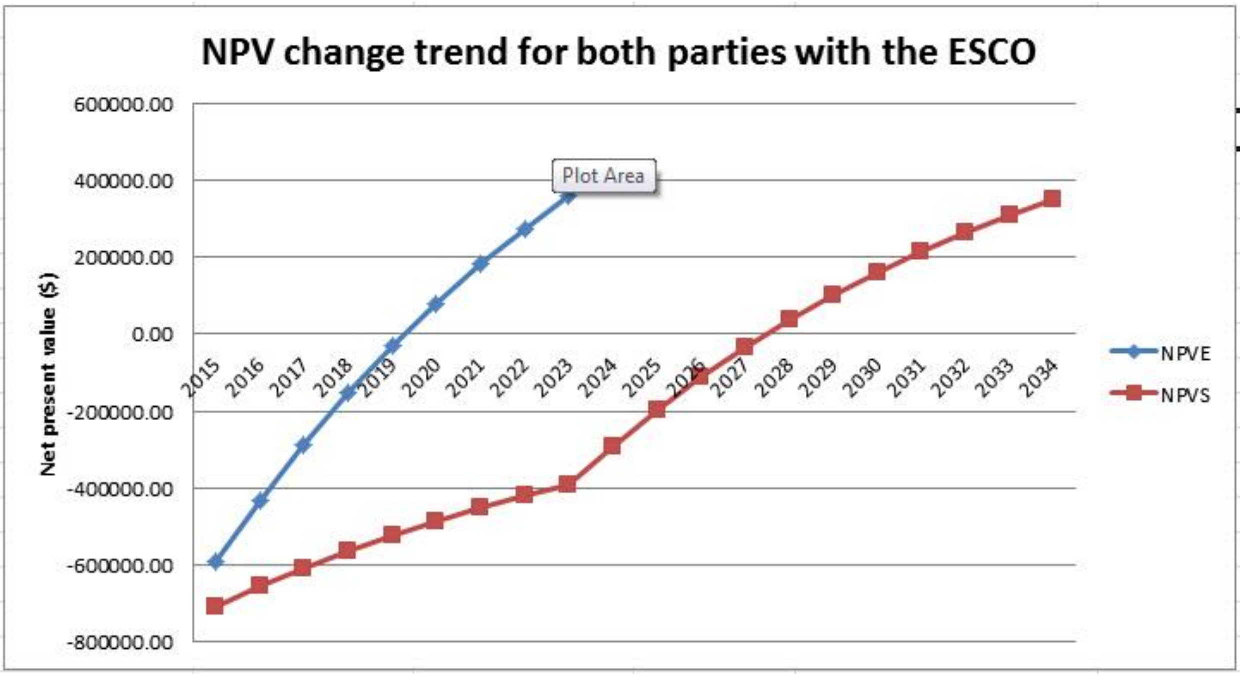

Figure 12. NPV change trend for both parties under the Regular scenario

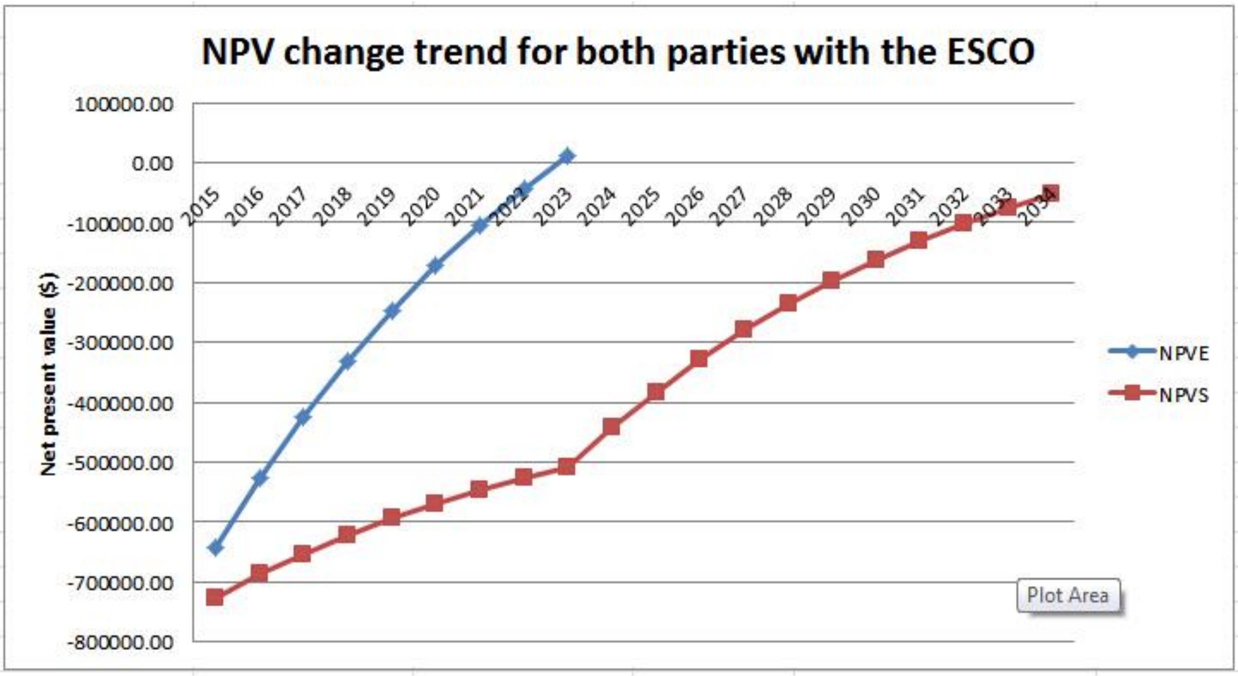

Figure 13. NPV change trend for both parties under the Regular scenario

As can be seen from the figures, there are some conclusion can be drawn. Firstly, it is obviously that after the contract period ends, the NPV increasing trend for the school grow up sharper than before, this is due to fact that after the contract period the school starts enjoy all the energy saving cost all by itself as income. Secondly, compared with the Optimistic scenario, NPV for both parties turn from negative to positive is approximately 3 years later under the Regular scenario. Finally, even under the pessimistic scenario, the NPV of the energy supply company still reach to positive at the final year of the contract period, and the NPV of the school also reaches nearly the zero. This means that this provided option could be a good one to be selected for negotiation due to its good performance on profitability for the both parties within the ESCO.

Under the Worst scenario, the optimization problem can be represented as:
Object: Maximize NPVs
Subject to: 0.5 ≤ α ≤ 1, 0.5 ≤ λ ≤ 1, 5≤ TP ≤ 15, NPVE≥ 0
Then optimization result is shown as the Table 10 below:

Table 10. Optimization result under the Pessimistic scenario

Maximal NPVS					
Option No.	NPVE	NPVS	Contract period	Sharing ratio of the investment by the energy supply company	Sharing ratio of the profit by the energy supply company
1	4431.81	-45850.31	8	0.50	0.85
2	5523.87	-46942.37	10	0.50	0.75
3	11187.49	-52606.00	9	0.50	0.80
4	13424.99	-54843.50	9	0.60	0.95

5	17674.61	-59093.11	10	0.60	0.90

Under the Pessimistic scenario, the total NPV of the project is negative, specifically, it is $-41418 in total. This means that the whole project will loss capital during its project lifetime. Even though the school can accept negative NPV in this situation, it still needs to minimize its capital loss to a lowest level. So the option 1 may be picked without hesitated compared with the option selection under other scenarios.

4.6 Discussion

From the generated simulation result and the optimization result, there are some conclusion can be drawn and further discussion will be indicated.

Firstly, this decision support tool showed its usability by employing the case study. The uncertain variables which are assumed following the Geometric Brownian motion can be estimated by the Monte Carlo simulation. But considering there are many factors affecting the future energy price, only predicting the energy price by the historical data is not accurate enough. The risks should be paid on more attention with specific risk management analysis so that the financial analysis of EPC project can be more accurate.

Secondly, from the optimization result, it can be indicate that for the energy supply company, it needs majority sharing of the energy saving cost as income for profit, so that the options provided are mostly with high sharing ratio of the profit by energy supply company. This means that for the sustainable school retrofit project, guaranteed saving EPC model is more suitable than shared saving EPC model.

Thirdly, one of the problems that have not been taken into account seriously is about the negotiation process after both parties get the result. Even though the optimization result is just related to the financial part of the project, it still needs a complex negotiation procedure to select a particular one to make an agreement on the final contract decision making. The estimation of decision making procedure in this graduation thesis is not comprehensive.

Finally, as has already been introduced, the decision making for sustainable school retrofit project is very complex. Only focusing on the financial part is not enough, especially for the school part, which may pay more attention on the healthy conditions of students, the better environment improvement and CO_2 emission reduction. For the further research, it will be better to combine all the interest parts into consideration for the decision making analysis of the EPC project stakeholders. Furthermore, in this thesis, if there were a stakeholder analysis about the both parties within the ESCO, the optimization objects and negotiation procedure will be more clear and purposeful.

5. Conclusion

5.1 Societal

When the decision support tool has been developed and tested its usability, it is time to look back to the research question settled in the beginning. This decision support tool employed the main variables which will appear in the sustainable school retrofit project by using EPC. The risks of uncertainties about project profitability are dealt with Monte Carlo simulation method which converts the stochastic distribution of variable in the future to the certain values under different scenarios. Other identified variables also can provide the users with a clear understanding about what are the key contract terms in EPC project and how they influence the success of the project. In this level, it is believed that this decision support tool can help the potential client to improve their awareness and trust level about this EPC mechanism.

For the school, this decision support tool can help it to negotiate with energy supply company to build up the ESCO and sign the contract when it is interested in implementing EPC in its school retrofit project. The EPC will help the school cover the financial support limitation and achieve a better and professional control in energy consumption and CO_2 emission. Of cause, the professional services provided by the ESCO could help the school achieve its ambitions on the other aspects such as improvement of indoor environment quality and reduction of air pollution in classrooms. This is not just financial benefit, but also the benefit for the whole society, because as the students are our hope in the future, their studying and living condition improvement will definitely result in a better performance of them.

For the energy supply company who aims at expanding their business area, this decision support tool would be helpful when they introduce their business models of EPC to potential client to get a clear understanding about this mechanism in a short time. Moreover, it can also use this decision support tool for itself to analyze and estimate the profitability of the project which it is interested in. The multi options provided as the optimization result could provide the energy supply company more choices when it is facing with other competitors during the tender procedure.

5.2 Scientific

When using Geometric Brownian motion to represent the stochastic diffusion process of the uncertain variables such as the discount rate and the energy price, it can be concluded that this method is more suitable for the variables which existing in a well-developed mature market with nor much risks, especially the risks which can overturn the whole market. For example, the natural gas or the electricity price may have a violent changes if there is revolutionary new energy resource appears, then they their position in the energy market may falls quickly so that lead to a decrease in their price. Compared with the energy price, the simulation for risk-free interest rate and equity market risk premium is more reliable, because even though there are stochastic changes in these variables, they are more stable due to the government influence and overall economic situations.

The previously studies which aims at determining the optimal EPC contract terms especially the contract period design are seldom using non-linear programming this mathematical approach but more with game theory or bargain games. The optimization result proved the previous hypothesis that non-linear programming can help with this non-linear NPV equations optimization problem. The expected result has been generated successfully. The advantages of using non-linear programming is that it can provides more detailed result about the negotiating contract terms such as contract period and sharing ratios. Moreover, users can change the objective functions depending on their own preference on interest and estimation for the future. This makes the non-linear programing with wide usability for users. So when the users get the optimized result as the information resource to begin bargaining or negotiating with their partners, they will save their time and energy and be an advantageous position. So that for the contract design problem within the ESCO, to determine the key contract terms by using non-linear programming can provide detail information result.

5.3 Further research

For the further research, there are some areas which were ignored or not done in this thesis can be paid attention by the researchers.

Firstly, for the EPC project which will be implemented in sustainable school project, a more detailed risk analysis should be applied with this decision support tool. Even though this thesis has already taken some risks during the project into consideration, it is still not enough to cover all the potential uncertainties. There are more variables influencing the success of the project, they are not only on the financial aspect, but also on the legalization, technology, human behavior aspects.

Secondly, it is needed to investigate the feasibility of EPC mechanism in other school retrofit projects, not only the sustainable project which aims at improving the existing equipment or insulation energy efficiency levels, but also the energy natural buildings and schools. Due to the current situation, energy natural may be a more a concept than feasible action, but considering the retrofit project should be useful for at least next twenty or thirty years, whether the energy natural retrofit activities are better and feasible choice needs to be taken into consideration.

Finally, decision making for sustainable school retrofit project is complex. Stakeholders need to make trade-off between all of their interests to get a final agreement on whether starts this project or not. So that financial condition is just one of the numerous areas that the school needs to take into account, others such as impact on health condition improvement for students and teachers, energy consumption reductions, CO_2 emission reductions, legalization risks, technique revolution risks should also be part of the decision making. So that for the further research, if researchers could develop a tool which integrating all these stakeholders interested areas together, it will be beneficial for the schools to achieve better energy performance and indoor environment quality in shorter terms. The multi-criteria evaluation could be a possible option which can combine more different kinds of interests as criteria into the whole decision making process.

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Appendix

A Simulation result of discount rate R

Simulation result of discount rate R

R	Year	Min	Median	Max	mean
8,7138	2015	7,364384	8,692301	10,14308	8,691554
8,1389	2016	7,060661	8,743881	10,77778	8,749923
8,0423	2017	6,689947	8,806023	11,28292	8,815071
7,9455	2018	6,512478	8,873228	11,98557	8,886936
8,0080	2019	6,258914	8,943058	12,20001	8,965853
7,6639	2020	6,279835	9,022891	12,81831	9,051563
7,2712	2021	6,115117	9,106565	14,02875	9,14395
7,3104	2022	5,90198	9,199384	14,11598	9,243269
7,3029	2023	5,717957	9,297817	14,5237	9,349475
7,1077	2024	5,74536	9,402347	14,92066	9,46248
7,2920	2025	5,466438	9,516498	15,30455	9,582736
7,0379	2026	5,418938	9,635231	16,26774	9,709421
7,2023	2027	5,451943	9,766704	16,44937	9,843519
6,8994	2028	5,397365	9,900889	17,49221	9,98472
6,8039	2029	5,465794	10,04048	19,20166	10,13276
7,1777	2030	5,393873	10,18924	18,96687	10,28835
7,1198	2031	5,270519	10,34014	19,93422	10,45112
7,4471	2032	5,279664	10,49512	20,36281	10,62108
7,8689	2033	5,335232	10,66456	20,55993	10,79839
7,76	2034	5,52	10,84	21,15	10,98

B Simulation result of electricity price

Simulation result of electricity price P_{EE}

P_{EE}	Year	Min	Median	Max	Mean
0,0776	2015	0,0714	0,0770	0,0822	0,0770
0,0806	2016	0,0725	0,0789	0,0855	0,0789
0,0815	2017	0,0734	0,0808	0,0887	0,0808
0,0829	2018	0,0742	0,0827	0,0921	0,0828
0,0845	2019	0,0748	0,0847	0,0955	0,0848
0,0874	2020	0,0761	0,0868	0,0989	0,0868
0,0889	2021	0,0767	0,0889	0,1016	0,0889
0,0914	2022	0,0776	0,0911	0,1051	0,0911
0,0942	2023	0,0803	0,0933	0,1086	0,0933
0,0972	2024	0,0816	0,0955	0,1108	0,0956
0,1001	2025	0,0835	0,0979	0,1150	0,0979
0,1036	2026	0,0851	0,1002	0,1178	0,1003
0,1060	2027	0,0864	0,1027	0,1228	0,1027
0,1115	2028	0,0868	0,1051	0,1261	0,1052
0,1142	2029	0,0877	0,1077	0,1300	0,1078
0,1187	2030	0,0886	0,1103	0,1346	0,1104
0,1239	2031	0,0897	0,1130	0,1371	0,1131
0,1283	2032	0,0911	0,1157	0,1402	0,1158
0,1315	2033	0,0927	0,1185	0,1468	0,1187
0,1344	2034	0,0954	0,1214	0,1488	0,1215

C Simulation result of natural gas price

Simulation result of natural gas price P_{EN}

P_{EN}	Year	Min	Median	Max	Mean
0,7736	2015	0,4547	0,6830	0,9836	0,6845
0,8165	2016	0,4583	0,7344	1,1456	0,7373
0,8427	2017	0,4295	0,7893	1,3878	0,7943
0,8964	2018	0,4049	0,8478	1,5295	0,8556
0,8968	2019	0,4285	0,9114	1,8079	0,9213
0,9974	2020	0,4598	0,9794	2,1642	0,9926
0,9687	2021	0,4253	1,0532	2,4697	1,0692
0,9131	2022	0,4994	1,1326	2,8700	1,1520
0,8986	2023	0,5072	1,2167	3,1990	1,2409
0,9075	2024	0,5138	1,3082	3,4581	1,3368
0,9221	2025	0,5241	1,4067	4,1349	1,4396
0,9451	2026	0,5440	1,5111	4,4354	1,5503
0,9137	2027	0,5489	1,6241	4,9747	1,6700
0,9458	2028	0,5761	1,7458	5,5713	1,7987
0,8855	2029	0,5896	1,8762	5,9312	1,9372
0,9774	2030	0,6006	2,0162	6,4475	2,0861
1,0123	2031	0,6400	2,1662	6,7536	2,2471
1,0082	2032	0,6249	2,3300	7,9350	2,4204
1,1924	2033	0,6054	2,5051	8,4293	2,6064
1,3287	2034	0,6377	2,6913	9,7760	2,8082

D Historical data of electricity price

Historical electricity price data

year	electricity price (€/Kwh)
1993	0,0452
1994	0,0456
1995	0,0459
1996	0,0435
1997	0,0428
1998	0,0434
1999	0,0438
2000	0,0425
2001	0,0448
2002	0,0452
2003	0,051
2004	0,0511
2005	0,0574
2006	0,0588
2007	0,0597
2008	0,0665
2009	0,0639
2010	0,069
2011	0,0706
2012	0,0695
2013	0,0734

E Histrorical data of natural gas price

Historical natural gas price data

year	Gas price ($/KCF)	Gas price ($/therm)
1997	3,02	0,302
1998	2,55	0,255
1999	3,08	0,308
2000	4,68	0,468
2001	6,59	0,659
2002	4,79	0,479
2003	4,46	0,446
2004	6,54	0,654
2005	8,68	0,868
2006	11,53	1,153
2007	7,21	0,721
2008	8,76	0,876
2009	6,57	0,657
2010	5,84	0,584
2011	6,42	0,642
2012	5,79	0,579
2013	5,9	0,59

F Historical data of United States Equity market risk premium data

United States Historical Equity market risk premium data

year	Equity market risk premium rate (%)
1994	3,55
1995	3,29
1996	3,2
1997	2,73
1998	2,26
1999	2,08
2000	2,87
2001	3,62
2002	4,1
2003	3,69
2004	3,65
2005	4,08
2006	4,16
2007	4,37
2008	6,43
2009	4,36
2010	5,2
2011	6,01
2012	5,78
2013	4,96
2014	5,78

G Historical data of United States risk-free interest rate

United States Historical risk-free interest rate data

year	Risk-free interest rate (%)
1994	5,75
1995	7,78
1996	5,65
1997	6,58
1998	5,54
1999	4,72
2000	6,66
2001	5,16
2002	5,04
2003	4,05
2004	4,15
2005	4,22
2006	4,42
2007	4,76
2008	3,74
2009	2,52
2010	3,73
2011	3,39
2012	1,97
2013	1,91
2014	2,86