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A Real Option Model to Evaluate Investments in Combined Heat and Power (CHP) Projects

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Abstract

Cogeneration technologies such as Combined Heat and Power (CHP) have promising features for providing the electrical energy that various industries require while reducing emissions and other environmental impacts of these industries. Investments in CHP systems require substantial implementation costs followed by a relatively long period of recovering the invested capital through savings in utilities bills. Appropriate timing of CHP system investments can reduce capital expenses and enhance returns on investments. An appropriate investment valuation method is needed to identify the appropriate time to implement a given CHP system and to find the values of properly scheduled investments. Real options analysis provides the ability to deal with investment timing under uncertainty. Existing real options models have several limitations when it comes to decision making about investments in CHP systems. In this research, some the theoretical limitations of current real options models are overcome. A new real options model to evaluate investment options for CHP systems under uncertainty is created. This model is tailored to the context of investment decision making for cogeneration technologies including CHP systems. The primary contribution of this research to the body of knowledge is the application of a method to estimate the volatility of CHP investments subject to uncertainty; and an investment valuation approach to identifying the best time to implement CHP systems and to determine the investment value. It is expected that this work will contribute to the state of practice by presenting a new valuation tool that help in making hard investment decisions and will therefore increase the likelihood of achieving global sustainability goals.

Keywords: Combined Heat and Power (CHP), Flexibility, Investment Evaluation, Real Option Analysis (ROA), Uncertainty

1. Introduction

Electricity power is vital for economy development. The electricity sector, on the other hand, is one of the largest sources of greenhouse gas (GHG) emission in the world. It is estimated that in the United States 31% of the total GHG emission in 2013 was generated by electricity sector (Department of states 2014). GHG emission has become a universal concern as a key factor contributing to climate change. Concerned about dangerous effects of climate changes, a breakthrough and legally-bonding agreement was signed by 196 countries at the Paris conference in December 2015. The agreement set out a plan to limit global warming to below 2 degrees Celsius by various means including the reduction of GHG emission (Robbins 2016). Increasing energy efficiency in the industry, buildings and transport sectors and reducing the coal-fired power plants are among the main steps suggested in order to reduce the GHG emission (IEA 2015). Cogeneration using Combined Heat and Power (CHP) technology is an approach to generate electricity and useful thermal energy in a single integrated system on site. In a CHP system the wasted heat generated in conventional power generation could be recovered as useful heat power (Chittum and Kaufman 2011). CHP is an efficient way of energy production with many benefits as in the following:

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- Increase the generation efficiency -from 30-35% in traditional power generation systems to 90%- (Rong and lahdelma 2011);
- Decrease the fuel consumption between 10 to 40% (Madlener and Schmid 2003); and
- Reduce the wasted energy in grid which could have a significant impact as in many countries such as United States more than 15% of the generated electrical energy is wasted in grids (EIA 2010).

In spite of the benefits, considerable barriers exist to the development of CHP. Among these barriers is the economic feasibility of investment in CHP systems. Investment in CHP systems often requires a considerable implementation costs with a low-rate return of capital investments over a relatively long time (Kashani et al. 2014). There are many uncertain factors such as installation costs, electricity and natural gas prices that affect the value of investment in CHP systems. Benefits in a CHP system is based on the electricity saving in the system. The natural gas and electricity prices are both subject to uncertainty. These prices are usually estimated based on historical price data. Evidence suggests that generally there are differences between actual and projected energy prices (EIA 2010). Moreover, installation cost of a CHP system is not stable over time. The installation costs are subject to uncertainty but generally expected to decline over time. A tradeoff analysis between electricity saving benefits and implementation costs of CHP system must be conducted to evaluate the economic feasibility of investment in CHP systems. In order to do so, a proper investment valuation approach is needed. Conventional investment valuation methods such as Net Present Value (NPV), Return On Investment (ROI), and Payback Period (PP) (Datta and Kumar 2015, Guo et al.2014) have two major gaps in evaluation of investments under uncertainty including implementation of CHP systems. First, conventional investment valuation methods do not incorporate the uncertainty of key investment factors such as costs of installation, and costs of inputs such as electricity and gas. Second, using the conventional investment valuation methods, the value of flexibility in timing the investment in CHP systems is omitted (Kashani et al. 2014). Current investment valuation methods assume that the investment in CHP could be made only on a now-or-never basis meaning that if the investment is not favorable at present, it should be taken of the list of investment alternatives. Consequently, conventional methods do not recognize the value of investment timing and cannot determine the most appropriate time to invest in projects such as implementation of CHP systems. Nevertheless, in reality an investment could be implemented at point in time when installation cost is lower compared to the present value of energy cost savings. In this paper, a new approach for valuation of investments in CHP systems is proposed. This proposed approach is based on the Real Option theory. It is fine-tuned according to the characteristics of investments in CHP systems. The model considers the uncertainty about energy cost saving benefits resulting from uncertain electricity and natural gas prices as well as the installation costs. This approach could be used as a proper tool to evaluate the CHP systems investment. Utilizing the proposed approach, the optimum installation time can be identified by simulating the CHP systems investment under uncertainty. So, investors could have a better understanding of benefits of CHP systems implementation than conventional methods of evaluating. The rest of this paper is summarized as follows. Section 2 provides a brief overview on state of knowledge in investment valuation approaches. Section 3 describes the proposed real options approach. In Section 4, an illustrative example is provided to highlight the capabilities of the proposed approach. Section 5 provides a brief conclusion on this research.

2. State of Knowledge

The most commonly-used methods of investment valuation are NPV, IRR and PP (Datta and Kumar 2015, Guo et al.2014). Despite the popularity of the abovementioned methods, they have serious limitations in evaluation of combined heat and power generation systems. First, these methods do not incorporate the uncertainty about future energy savings benefits resulted from the implementation of CHP systems. The uncertainty about future energy savings benefits is stemmed from the uncertainty about a variety of factors including future energy demand levels, future electricity prices, and future gas prices. Second, current methods do not consider the value of flexibility in timing the investments. Nevertheless, CHP investments could be implemented at any time in the future when the situations are favorable. Appropriate investment timing can reduce the implementation costs and provide a better capital return (Kashani et al. 2014). Ignoring the flexibility in timing the investment as well as the uncertain factors in CHP investment can lead to the underestimation of investment values. Underestimating the value of investments in CHP systems can lead to the elimination CHP systems as viable alternatives for reducing energy consumptions and GHG emissions. The real options theory is an appropriate alternative valuation method that can be used to overcome these limitations. Real options theory is based on stock option pricing method in finance (Myer 1977). Stock options are contracts sold in the market, giving the buyer the right, but not the obligation to buy or sell a determined amount of stock with a predetermined price (Ammerlaan 2010). Myer (1977) states that the future investment by corporations is comparable to a financial option and could be analyzed likewise. Real option analysis has been used by academics and practitioners for more than 30 years in investment analysis on projects with uncertainty. Fleten and Nasakala (2010) investigated a natural gas power plant investment utilizing real option analysis under the uncertainty of electricity and gas prices. Ashuri et al. (2011) applied the real options theory on solar panel investment under uncertainty. When it comes to the valuation of CHP investments, an appropriate real options approach is needed. This approach should utilize a mechanism to systematically estimate the project volatility as a key factor in project evaluation. This approach should also utilize an appropriate mechanism to identify the optimum time to implement the CHP system. Besides, this approach should provide the risk profile of investment in the CHP systems. Considering the importance of investment in energy systems like CHP, creating more appropriate investment valuation methods is highly important in order to avoid over and under investments. In the rest of this article, a new real options approach for evaluating investments in CHP systems is presented. The proposed model takes into account the uncertainties of investment, provides a risk profile, and determines the optimum implementation time of investment.

3. Methodology

The proposed CHP investment valuation approach, takes into consideration the uncertainty about future electricity and natural gas prices, as well as the variation of CHP system implementation costs over time. Moreover, it provides the risk profile of the investment along with the optimum implementation time. The main steps of our methodology contain:

- Develop a binomial lattice and conduct Mont Carlo simulation in order to characterize the uncertainty about future electricity price
- Simulate scenarios for future natural gas prices
- Develop an experience curve model for the future CHP installation costs
- Identify the optimum investment time
  Develop the risk profile of investment in CHP system

3.1. *Develop a binomial lattice and conduct Mont Carlo simulation in order to characterize the uncertainty about future electricity price*

Implementing a CHP system, leads to energy saving benefits resulted from a reduction in need for electricity provided by the gird. To estimate these benefits, the electricity price should be estimated over the investment horizon. In order to estimate the future price of electricity, a binomial lattice is created (Kashani et al. 2014). A Mont Carlo simulation on the binomial lattice can be conducted in order to characterize future energy price movements and the resulting energy saving benefits over time. The binomial lattice provides a structure on which different random paths of electricity price could be generated in each iteration of the simulation. The binomial lattice defines the probable prices in specified basic period (Δt), for example Δt could be a month or a year. The electricity price (R) at the beginning of each period could be a multiple of u ($u>1$) for the upward movement or a multiple of d ($0<d<1$) for the downward movement. The upward and downward movement have different probabilities, p ($0<p<1$) for upward movement and 1-p ($0<1-p<1$) for downward movement. This pattern continues period by period until the end of investment horizon (Figure 12). The parameters of u, d and p could be obtained from expected annual growth rate (α) and the annual volatility (σ) of electricity price data –equation 1 to 3- (Kashani et al. 2014). After the creating electricity price lattice, different random paths are generated on this lattice in each iteration of a Monte Carlo. For each electricity price path, the electricity saving benefits can be calculated by multiplying the projected electricity price by the amount of electricity generated by a given CHP system.

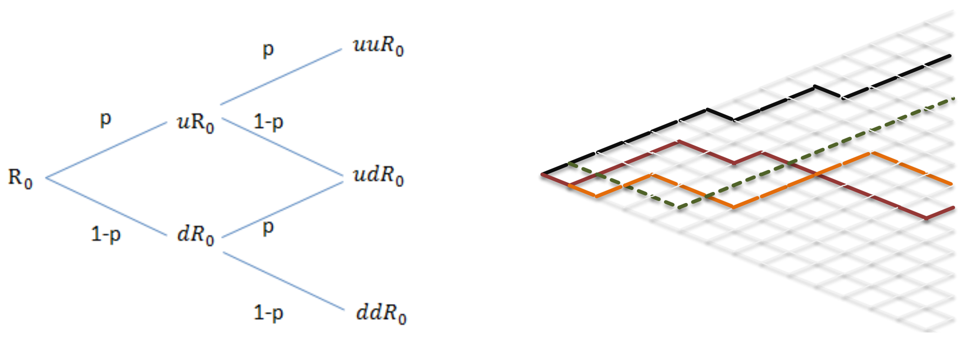

Figure 12: Electricity price binomial lattice (Left) and Random paths on the electricity binomial lattice (Right)

$$u = e^{\sigma\sqrt{\Delta t}} \tag{1}$$

$$d = e^{-\sigma\sqrt{\Delta t}} \tag{2}$$

$$p = \frac{e^{\alpha\Delta t} - d}{u - d} \tag{3}$$

3.2. *Simulate Scenarios for future natural gas price*

In a CHP system the generated heat is used on site for electricity generation purposes. In order to estimate the costs associated with providing required natural gas, the amount of natural gas needed for heating is calculated and multiplied by the estimated natural gas price in each year. In order to estimate the natural gas price, various scenarios can be created. These scenarios are obtained from of reliable models utilized by the academicians and practitioners. By conducting Monte Carlo simulation, scenarios can be randomly picked and energy costs can be calculated.

3.3. *Develop an experience curve model for the future CHP installation costs*

At present, CHP generated energy is relatively more expensive compared to energy provided from conventional sources. However, it is estimated that the implementation cost of CHP systems would decrease over time due to innovation and learning-by-doing effects (de La Tour 2013). The experience curve is a widely used tool in order to characterize the changes in the costs of technologies over time. The experience curve demonstrates that the production cost of a new technology is decreased by accumulation of experience measured by cumulative production. The experience curve is simply demonstrated by the following formula (Weiss 2010; Hartley 2010):

$$P_t = P_0 \cdot Y_t^{-E} \tag{4}$$

Where Pt is the implementation cost at time t. P0 is the price of first unit. Yt is the cumulative production in MW up to year t, and 2-E is progress ratio (PR). PR shows the amount of cost reduction after each doubling of the cumulative production. The estimation of E is based on historical data and expert's opinion. In this article the implementation cost of CHP system is not constant over time and decreased over years using experience curve. The average experience rates for energy supply technologies are often around 20% (Patel and Blok 2013). It means by doubling of cumulative production of CHP systems the implementation cost reduced by 20%.

3.4. *Identify the optimum investment time*

In the proposed approach, the CHP system could be implemented whenever the present value of energy saving benefits exceeds the implementation costs. A minimum electricity price boundary is used to determine the optimal time of investment. This minimum electricity price boundary is developed using the method described in Kashani et al. (2014). The optimum time to invest in the CHP system is whenever the electricity price, for the first time passes the minimum electricity price boundary.

3.5. *Develop the risk profile of investment in CHP system*

The investor’s risk profile is developed using a Mont Carlo simulation. In each iteration, an electricity price and a natural gas price path are randomly generated. Then, using the minimum electricity price boundary, the present value of investment is calculated considering the optimal time for implementing the CHP system. The resulting distribution of present value of investment can be used for investment decision making.

4. Example

An illustrative example is presented to demonstrate the capabilities of the proposed real options approach. In a hospital, the annual average heat and electricity consumption are 56.2 and 12360 MWh. An 800 Mw CHP unit is being considered for this hospital. The implementation cost of this system is estimated to be 1780 $/KW. The maintenance cost of this system is 0.01 $/KWh. The investment horizon is 16 years. The interest rate is 20%.

Using the above information, an analysis was conducted in three parts:

- Economic evaluation with considering the uncertainty of electricity, natural gas price and optimal time of implementation.
- Investment valuation considering the uncertainty about future electricity price
- Investment valuation without considering the associated uncertainties

In the first part, it is assumed that the future electricity and natural gas prices are known and there is no uncertainty about them. Project investment starts in the first year of the investment horizon. Benefits of implementing a CHP system are calculated by multiplying the energy price in any given year by the corresponding amount of energy conserved. Annual energy saving benefits resulting from investing in the CHP system should then be discounted by a proper discount rate. The present value of investment is calculated from the summation of discounted benefits of the system over its life. The present value of CHP investment was calculated to be -565,004.

In the second part, the uncertainty about the future energy prices was characterized using a binomial lattice. Using Mont Carlo simulation a random path of electricity prices across the binomial lattice were generated. A distribution of the present value of investment is developed. The cumulative distribution of present value of investment is shown in Figure 13.

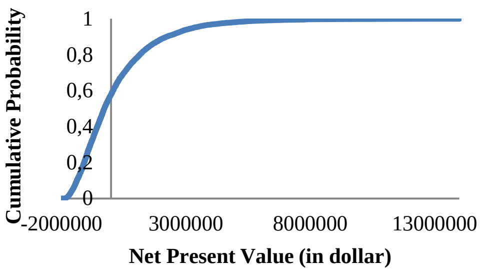

Figure 13: Cumulative probability of NPV with the only uncertainty of electricity price

In the third part, the uncertainty about future electricity prices is characterized as mentioned above. Fives scenarios of future natural gas price are developed *[Ten Different models used in Gas price scenarios: 1. Lift model, 2. CIMS-US (Consolidated Impacts Modeling System) model, 3. US-REGEN (Electric power research institute), 4. Energy 2020 model, 5. Nems (The National Energy Modeling System) model, 6. EPA-IPM(Environmental Protection Agancy)-(Integrated Planning Model), 7. MRN-NEEM (North American Electricity and Environmental Model), 8. US National Markal Model, 9. FACETS model, 10. ADAGE model].* A Monte Carlo was conducted through one scenario was randomly selected randomly in each iteration. The minimum energy price boundary demonstrates the electricity price in each year by which the present value of project equals to zero in that year. So, if electricity price goes becomes less than the minimum energy price boundary in a year, then investment present value get negative in that year. In each iteration, it is checked whether the randomly generated energy price path crosses the minimum energy price boundary. The CHP system installed whenever the energy price path crosses the minimum energy price boundary for the first time. The installation cost of system changes over time in as modeled by the experience curve. In each iteration, the present value investment was calculated. The cumulative distribution of investment value is developed (Figure 14a). Moreover, the probability of implementing the CHP system in any given year over the investment is also developed as shown in Figure 14b.

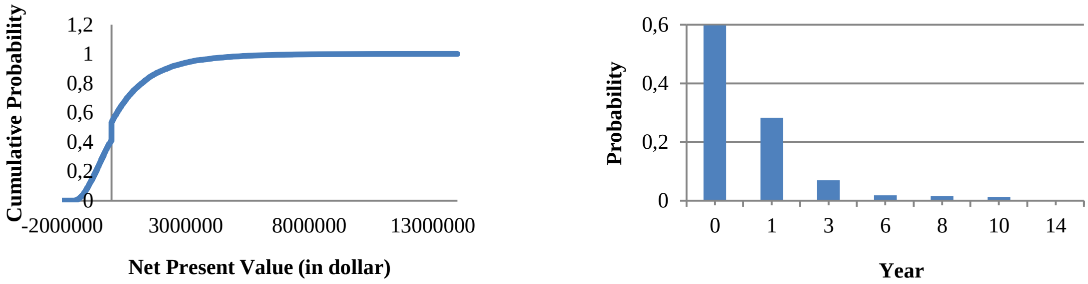

Figure 14: (a) Cumulative probability of NPV in optimum installation year with uncertainty of electricity price, natural gas price and implementation costs(left) (b) probability of implementing the CHP system over the investment horizon (Right)

5. Conclusion

To evaluate investments in CHP system, a proper trade-off analysis should be conducted between energy saving benefits and system costs. The method should have the ability of considering benefit uncertainties such as future electricity prices, natural gas prices and installation costs. Moreover, it should be able to identify the optimum implementation time. In this article, a novel approach for valuation of investment in CHP systems based on the real option theory is presented. This approach identifies the optimum implementation time, based of which the installation cost obtained from an experience curve. The benefits of the system are calculated under uncertainties of electricity and natural gas prices. Utilizing the proposed real options approach can lead to the development of the risk profile of investment in CHP systems. Using this approach, decision makers can have a better understanding of the investment in CHP investments.

Greenhouse gas emission and its contribution to climate change has become a global concern. Increasing the efficiency of energy production and reducing the dependency on fuels are among the main mechanisms suggested in order to reduce the GHG emissions and the global warming effect (IEA 2015). Utilizing CHP systems are among the efficient ways of producing energy. Implementation of CHP systems requires large-scale investments that will be recovered by uncertain energy saving benefits.

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