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Department of Economics

Investment in Enhanced Landfill Mining (ELFM): A Real Option Approach

A case study of Koshe/Repi landfill site (Ethiopia)

Abiy Getachew Sime

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Photo of Koshe/Repi landfill site, Addis Ababa, Ethiopia (www,nelsonelson, 2012).

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Abstract

The marginal socio-economic condition of many people, lack of cooperative culture and cultural aversion towards waste, absence of well-defined enforcement mechanism to effectively coerce the population, restricted public service funding, high rate of population growth and the resulting ever increasing waste production are some of the major challenges faced by most developing countries, including Ethiopia, in an effort to implement effective and efficient municipal solid waste management (MSWM).

Koshe/Repi, an old landfill in Addis Ababa, Ethiopia, is considered to be a huge opportunity in terms of material recovery and energy production. In fact, by adopting Enhanced Landfill Mining (ELFM) as approach for handling the cumulated waste, considerable net economic benefits may be attached to energy production (Waste-to-Energy, WtE) and materials recovery (Waste-to-Material, WtM). In line with this, the thesis produces a preliminary decision making model for Koshe/Repi ELFM project by considering the time evolution of predicted CO_2 emission reduction and landfill gas recovery. To achieve this objective, we take a real option perspective and use the binomial method for assessing the economic profitability of the project. Empirically, the model is supported by data from Addis Ababa city municipality, community development research and Ethiopian electric power corporation (EEPCo).

Results of the model reveals that, the percentage (or share), α, of total revenue from emission reduction to be reimbursed to a private firm, is crucial in attracting investments to Koshe/Repi ELFM project. Moreover, for a specific share value (e.g. 16%), where the net present value (NPV) is negative ($–0.18 million), the low annual volatility of electricity price (15%) is high enough to offset the negative NPV. As a result, the project is worth to invest for share value between 15% and 17% included, even though the NPV is negative. Finally, this study call for further investigation focusing on the estimation of determinant exogenous parameters such as annual volatility, carbon credit, investment and operation costs, salvage value and penalty cost.

Abbreviations

ABM............................Arithmetic Brownian Motion

APV............................Adjusted Present Value

BTU............................British thermal unit

CCX............................Chicago Climate Exchange

CDM............................Clean Development Mechanism

CER............................Certified Emission Reduction

CtC ....Closing the Circle

DCF............................Discounted Cash Flow

DN..............................Do Nothing

DTA............................Decision Tree Analysis

EEPCo.........................Ethiopian Electric Power Corporation

ELFM..........................Enhanced Landfill Mining

EU ETS.......................European Union Emission Trading Scheme

EU-15..........................European Union Member States

EWM..........................Enhanced Waste Management

GBM............................Geometric Brownian Motion

GHG............................Greenhouse Gas

HoA-REC....................Horn of Africa Regional Environmental Center and Network

IRR.............................Internal Rate of Return

IW...............................Industrial Waste

KWH...........................Kilowatt Hour

LFG .... landfill gas

MAD............................ Marketed Asset Disclaimer

MSW .... Municipal Solid Waste

MSWM........................ Municipal Solid Waste Management

MWH........................... Megawatt Hour

NPV .... Net Present Value

RE (t) .... Revenue from Emission Reduction at Time t

ROA .... Return on Asset

SBDA .... Sanitation, Beautification and Parks Development Agency

SMM............................ Sustainable Material Management

SWM .... Solid Waste Management

WEDC .... Water Engineering and Development Center

WtE.............................. Waste-to-Energy

WtM .... Waste-to-Material

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1. Introduction

"Koshe/Repi" is an old landfill in Addis Ababa, Ethiopia, established in 1964. It is located in the south west part of the city about 13km far from the city center, and it covers a total area of 36 hectares. Since establishment it has been serving as the only waste disposal site for households and industrial waste produced in and around the premises of Addis Ababa. The city government of Addis Ababa estimates the amount of accumulated waste to 14.56 million m^3. However, due to scarcity of studies, it is difficult to confirm the exact figure for the accumulated waste composition, volume and weight. Nevertheless, data collected from the ten sub cities of Addis Ababa confirm that Koshe/Repi has been overwhelmed by the amount of waste for many years. For example, only from April 2004 to August 2005, about 494,949 m^3 of waste has been disposed of. To easily visualize this waste amount, it is worth considering the following analogy. 80,000 tons of waste is the amount of waste transported by 1500 lorry movement (Argaw, 2010; SBDA, 2005as cited in Haile *et al*., 2012; www, 2Mercato, 2011).

It is clear that a major criterion employed for Koshe/Repi's site selection during its establishment (about 40 years ago) was distance from the city center. Furthermore, currently there is no environmentally sound management to deal with the accumulated waste and how the waste affects the surrounding air, soil, water and human health (Haile *et al*., 2012). In particular, toxic liquid that drains or leaches from the accumulated waste (landfill leachate) pollutes the surrounding soil, surface and ground water. Above all, the geological nature of the surrounding area facilitates the pollution of ground water (Haile *et al*., 2012; www, leachate, 2012).

Due to high population growth (from 2.1 million in 1994 to 3 million in 2011) and urban expansion (6.75km^2/year) of the city of Addis Ababa, the Koshe/Repi site, which was at the outskirt of the city when established is now overtaken by the city. As a result, the surrounding residents are exposed to air, soil and water pollution that cause health problems. A report from the local health office shows typhoid and malaria as the most common diseases that occur in the area (Mahiteme, 2005). Moreover, the foul odor and unpleasant look creates inconvenience to human well-being (Haile *et al*., 2012; www, addisababacity, 2007; www.csa, 2011). See appendix B for the current condition of Koshe/Repi landfill site.

At the 25th Water Engineering and Development Center (WEDC) conference held in Addis Ababa, Birke (1999) and Geleta (1999) emphasize that the accumulated waste on and around the site have caused human life and material losses. Particularly, the land filling gas (LFG) which burns the waste (auto combustion) and the toxic liquid which contaminates the surface and ground water are the primary causes for the loss of human life and material (which can be recycled). To overcome these problems and in the long run to restore the site, the municipality of Addis Ababa is in the process of closing Koshe/Repi. The cost of the closure is about 30 million birr (1.7 million dollar) and will be carried out in two phases. In the first phase, 19 hectares of the landfill will be closed. While in the second phase, the landfill will be completely closed. Total closure will be undertaken only after the new landfill site (under construction around “Sendafa”, 31km to the east of Addis Ababa) becomes operational (www, addisababacity, 2007).

At a forum with local stakeholders organized by HoA-REC[1] (2011) in partnership with the Addis Ababa city administration, the municipality presented the current envisaged plan for post closure care and monitoring. Among these a park, a recreational center and/or sport facility are the main future plans. For the valorization of the area, a methane capturing system is also among the envisaged alternative solutions where methane will be used to produce electricity. However, the executive director of HoA-REC stresses the eminent need to answer the question about the future fate of Koshe/Repi in the best interest of the community (www, hoarec, 2011).

1.1 Problem Background

At the local stakeholder consultation for the Koshe/Repi landfill gas (hereafter LFG) project, the Addis Ababa city administration (2011) discloses the project activities for electricity generation from the LFG. In addition, panel of experts from the United Nation Development Programs, HoA-REC, United Nations Framework Conventions on Climate Change, and Golden Standard[2] discuss on local communities benefits from the proposed project. These benefits include among others carbon dioxide (CO_2) emission reduction, health improvement, odor elimination and avoidance of fire and gas explosion. Most importantly, the estimated

[1]HoA-REC- Horn of Africa Regional Environment Center and Network

[2] United Nation Development Programs is a regulatory and technical advisor, United Nations Framework Conventions on Climate Change is a regulatory body for carbon credits, Golden Standard is a validator for socio-economic impact of the project and HoA-REC is the project proponent for LFG emission reduction

11,000 MWH[3] per year generated electricity can also be used to meet the annual electricity consumption of 8000 households (www,addisababacity, 2011).

The study predicts a project period of 9 years (2012-2021). It also estimates the fixed cost expenditure to 7.6 million birr and annual operation and maintenance cost to 3.2 million birr. Over the 9-year project lifetime, the total amount of electricity generated is estimated to be 98,684 MWH. Moreover, the average amount of CO_2 emission reduction is 81KtCO_2[4] per each year of the project life time (www, addisababacity, 2011).

1.2 Aim and Delimitation

The broad aim of the thesis is to produce a preliminary decision making model by considering the time evolution of predicted CO_2 emission reduction and landfill gas recovery. The model can be used by private firms to assess the economic profitability of enhanced landfill mining (ELFM) projects of Koshe/Repi, which is a public initiative.

Here, the city administration of Addis Ababa faces two alternatives: either to be paid by a private firm (bid price) who is interested to invest in the ELFM project of Koshe/Repi. In this case, the firm decided to invest in such a project because the project is worth investing and possible revenue from selling of electricity and CO_2 emission reduction offset the cost incurred to construct and run the power generating plant. Or, alternatively the city administration of Addis Ababa pays a private firm to invest in the ELFM project of Koshe/Repi, in which case the firm decided that the ELFM project is not worth investing. However, even in this case, the city administration of Addis Ababa can later reclaim the land for other development programs like a new well managed landfill site, new recycling center etc.

[3]MWH-megawatt hour
[4]81KtCO_2 is equal to 81,000 tone CO_2

Specifically, the research focuses on the waste-to energy (WtE) economic performance determinants of ELFM. Based on the preliminary case study made on Koshe/Repi by the Addis Ababa city administration (2011), this thesis will focus on the following research questions:

- What will be the optimal investment decision, in a situation of new entry, for a private firm interested to invest in the ELFM project of Koshe/Repi?
- On a condition that a private firm decided to invest in the ELFM project of Koshe/Repi and start generating electricity, when will permanent abandonment (exit) be an optimal decision by paying a penalty for breaching the contract?
- Which exogenous parameters are responsible for private firms' decision to invest in the ELFM project of Koshe/Repi?

Delimitation

Although, assessing electricity business in isolation, without considering the revenue from emission reduction, is interesting, it is not discussed here since the business is not commercially attractive.

2. Theoretical Perspective

2.1 Neo Classical Investments Theory

In economics, investment is defined as an immediate incurrence of cost in the expectation of future rewards (Dixit and Pindyck, 1994). Examples include firms that construct plants, merchants who buy products for sale and a person who pursues a vocational education. The majority of investment decisions share three characteristics: irreversibility, uncertainty and choice of timing. First, investment cost may be partially/fully irreversible. This means that "*the initial cost of investment is at least partially sunk*" (Dixit and Pindyck, 1994, p3). Second, the future reward of an investment is usually uncertain. What can be done to better estimate the value of the future reward is to calculate the probabilities of a higher profit and lower profit (loss) for a venture. Third, there is a flexibility to choose the timing of investment decision. An investor can make use of the timing flexibility to postpone the investment decision in order to get more information about the choice of investment timing, which of course can never be completely certain. The interaction of these three characteristics determines the optimal investment decision (Dixit and Pindyck, 1994).

Traditionally, organizations use different quantitative analysis methods to measure the costs and values connected with a project. The typical approach for a project evaluation employs the discounted cash flow (DCF) analysis. One of the measures given by this analysis is net present value (NPV). NPV is calculated as the difference between the present value of net expected cash inflows and cash outflows as shown below:

$$NPV=C_0+\sum_{t=1}^{n}\frac{Ct}{(1+r)^t}$$

Where C_0 is the initial (usually negative) cash flow,

Ct is the project net cash flow at time t,

r is the discount rate (opportunity cost of capital),

n is the number of periods for projected cash flows.

It is obvious that a company's shareholders prefer large dividends for their invested capital. This mean company's shareholders prefer firms to invest in each project which is worth more than it costs. For that reason, to best fulfill their shareholders' interest, companies apply the NPV rule to make investment decisions. In simple terms, the NPV rule can be stated as "*invest until the value of an incremental unit of capital is just equal to its cost*" (Dixit and Pindyck, 1994, p.5). The NPV rule has three features. First, it takes into account the time value of money which means "*a dollar today is worth more than a dollar tomorrow*" (Brealey *et al*., 2008 p. 118). Second, NPV depends on forecasted cash flow and opportunity cost of capital. Hence a manager's taste on a project, companies accounting method, profitability of company's existing or independent project shall not be considered in selecting a profitable project which otherwise leads to inferior decisions. Third, since NPVs are in units of today's dollar, it follows the principle of "*value additivity*". This means NPV of the combined investment of two projects (p1 and p2) is equal to the sum of the NPV of individual projects (i.e. NPV (p1+p2) =NPV (p1) +NPV (p2)). Therefore, a poor project can be easily identified when it comes in combination with the good project (Dixit and Pindyck, 1994, Brealey *et al*., 2008; Yeo and Qiu, 2003).

Instead of calculating the NPVs of projects, companies often compare the rate of return on projects with the return the shareholders might earn by investing in similar projects in a security market. In most cases, this rate of return rule should help to select projects which will increase firms' value. However, since this rule considers firm's average activity, it sometimes leads to sub optimal decisions. For example, successful past investment might act as a hurdle for the new investment (Brealey *et al*., 2008).

Organizations' task of selecting projects with the highest NPV is not always a simple decision. The choice of selecting an appropriate discount rate is extremely difficult for projects characterized by substantial uncertainty. The usual approach to deal with project uncertainties is to develop the project specific risk adjusted discount rate. But even then the NPV approach fails to account for how uncertainty can amplify the value of the project. In fact, the NPV rule assumes either the investment is somehow reversible, or if irreversible, then it is a *now or never* project. That is to say, if the firm is not undertaking the investment now then it will not be able to undertake it in the future. A now or never assumption is not realistic. Based on changing market conditions, it is critical to have management intervention in operational decision making, in order to secure higher return or minimization of losses in a volatile market (Dixit and Pindyck, 1994; Yeo and Qiu, 2003).

2.2 The Value of Managerial Flexibility

Active managers make decisions in response to the current market condition which is characterized by uncertainty, change and competition. Under unfavorable market condition (e.g. lower price than expected, higher material cost than set at the beginning) managers will postpone or defer projects until the market condition improves. They may even abandon a project to limit the down side risk of loss. On the other hand, under favorable market condition (e.g. higher price than expected, lower material cost than set at the beginning) managers may expand the scale of the project to better retain the upside potential for profit. This means, the arrival of new information about price, cost etc. resolves the uncertainty of the market condition and hence "*management may have valuable flexibility to alter its initial operating strategy in order to capitalize on favorable future opportunities or to react so as to mitigate losses*" (Trigeorgis, 1996 p.1). This managerial flexibility introduces asymmetry (skewness) to the probability distribution of NPV (Yeo and Qiu, 2003; Trigeorgis, 1996).

Passive managers on the contrary, have no option to interfere in the project all the way through the project life cycle. One of the motivations to compute active and passive management value is to have an estimate for the value of managerial flexibility. Managerial flexibility can be estimated as the difference in value between active and passive management of the project. The value of managerial flexibility increases with the rise in the uncertainty of the project. This is obvious as active managers are in a better position to capitalize on good fortune and minimize losses during unfavorable future condition. Such managerial flexibility, in particular, can be very valuable and an investment rule which ignores it can be erroneous (Dixit and Pindyck, 1994; Santiago and Bifano, 2005).

As the above two paragraphs make it clear, the NPV rule which says "*invest when the value of a unit of capital is at least as large as its purchase and installation cost*" (Dixit and Pindyck, 1994 p. 6) must be somehow modified. The value of the unit capital must be at least equal to the sum of the purchasing and installation cost and the cost forgone to keep the investment option alive (opportunity cost of investing). Option pricing method can separately calculate this value which can be added to passive NPV (calculated without the consideration of managerial flexibility) to value the project under active management. Hence NPV (active) = NPV (passive) + v, where v is the value of managerial flexibility (Yeo and Qiu, 2003).

The failure to account for the value of managerial flexibility, may explain why the neo classical approach be unsuccessful to give correct values for investment opportunities embedded with real options (Dixit and Pindyck, 1994; Yeo and Qiu, 2003).

2.3 An Overview of Options

There are two types of options: a call option and a put option. *"A call option gives its owner the right to buy stock at a specified exercise or strike price on or before a specified exercise date"* (Brealey *et al*., 2008 p.565). Depending on when to exercise an option, a call option can be a European call or an American call. A European call option can be exercised only on one specific day. However, an American call can be exercised on or at any time before the option expiration day (Brealey *et al*., 2008).

After purchasing a call option, a buyer may or may not exercise the option depending on what take place to the stock price. If the stock price at the end of the option expiry date rises above the exercise price, then exercising the option to acquire the share pays. The value of the call in this case is the market price of the stock minus the exercise price the buyer pays to acquire the share. On the other hand, if the value of the stock immediately before the option expiration date falls below the exercise price, nobody will want to buy the stock at that higher price (exercise price). Hence, the call option at this particular case will be worthless (*ibid*).

While a call option gives the owner the right to *buy* a stock, a put counterpart gives the owner the right to *sell* the share. A condition in which a put option becomes profitable is the opposite of the case where the call option becomes profitable. Therefore, if the stock price immediately before the option expiration date falls below the exercise price, it pays to buy a stock from the market and then sell it using the put option for an exercise price. The value of the put in this case is the difference between the exercise price proceeds of the sale and market price of the share. On the other hand, if the stock price immediately before the option expiration date rises above an exercise price, nobody will want to sell the stock at an exercise price. The put option in this case will be worthless (*ibid*).

The position diagrams in figure 1 below explicitly show the pay offs to the owners of call and put options.

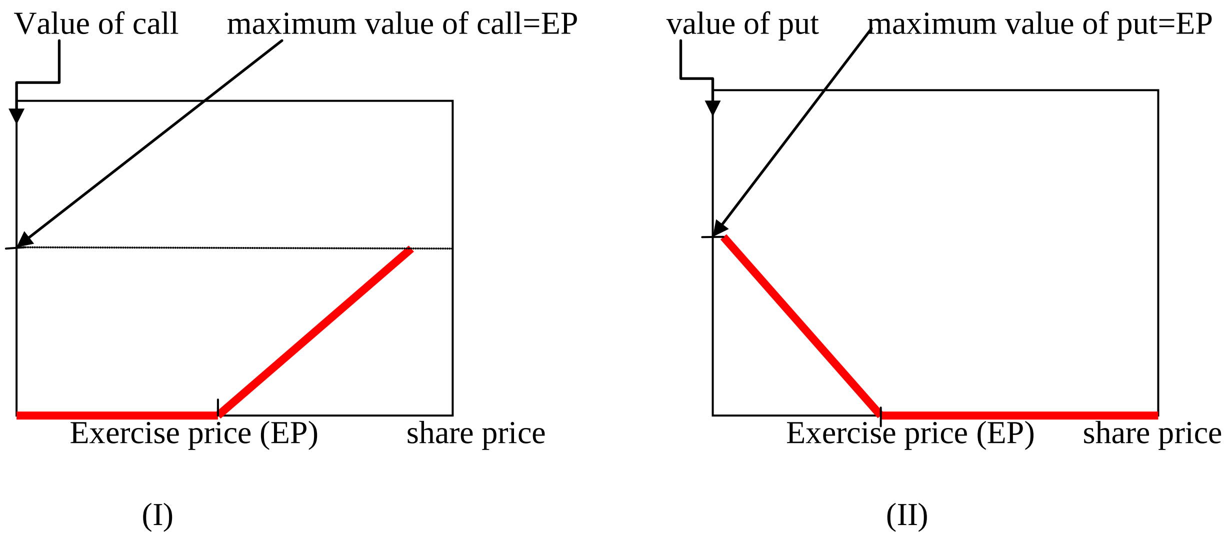

Figure 1 Position diagrams for a call (I) and put (II) options (adapted from Brealey *et al.*, 2008).

2.3.1 Real Options

Copeland and Antikarov *et al.* (2003) define a real option as the right (not the obligation) to make a decision (e.g., expanding, contracting, deferring or abandoning) on a project or an investment at a predetermined cost (exercise price) for a predetermined duration (the life of the option). Therefore, what makes real options "real" is they typically pertain to tangible assets like capital equipment while the financial options counterpart pertain to financial assets like stocks and securities. Here, it is emphasized that every project has an embedded option. CEOs will miss the opportunities associated with real options if they ignore option values during screening of investment opportunities (www, investopedia, 2012).

Like the financial options counterpart, the values of real options are predominantly determined by the following five variables: 1) the underlying risky asset: As its value goes up so does the value of the option. One of the distinct differences between real and financial options is that in real option the real asset operator (management) can raise the value of the underlying asset and hence raise option value. On the other hand, in financial options, the financial option owner cannot shake the value of the underlying asset (e.g. a share of company & stock).

This means both the option writer and the option purchaser cannot affect the rate of return from the company's share. 2) The exercise price or investment cost: With call option this is the amount of money you invest to buy the asset. While in put option this is the amount of money you receive when selling the asset. Therefore, as the exercise price rises, the call value decreases and the put value increases. 3) The option time to expire: As expiration time increases, so does the value of the option. This is because we will have more time to learn about the uncertainty. 4) The volatility of the underlying asset value: In the presence of managerial flexibility, a rise in volatility will increase the value of the option. 5) Risk-free interest rate: An increase in risk-free rate increases the value of the option. The sixth important variable is the cash inflow or outflows, dividends paid by the underlying asset, where the real option analogy is revenue or profit from the underlying asset (typically a project). Consequently, if the cash out flows lost to competitors' increases, then the option value decline since the return on asset (here after ROA) declines. ROA is a profitability ratio which can be calculated as ${(EBIT - tax)}/{average\ total\ asset}$ where EBIT is earning before interest and tax. Even though, ROA indicate the efficiency of management in using assets (typically projects) to generating earnings, it should be noted that a high ROA does not necessarily mean that it is possible to get the same return by buying a similar asset today, nor is necessarily true that a low ROA implies the asset can be better employed elsewhere (Copeland and Antikarov *et al.*, 2003; Brealey *et al*., 2008).

2.3.2 Taxonomy of Real Option

Copeland and Antikarov *et al*. (2003) claim that real options classification is primarily based on the type of flexibility they offer. Hence we have:

1. A deferral option: where the owner of the option has the right to delay the start of the investment (project). It is basically an American call option[5] found in many projects.
2. The option to abandon: where the owner of the option has the right to quit the project by paying some fixed price. It is an American put option.
3. The option to contract: where the owner of the option is able to scale back the operation by selling some part of the project for a fixed price. It is also an American put option.

[5]The basic distinction between an American and European option is that American option can be exercised at any time before expiration while European option is exercised only at expiration (Brealey *et al*., 2008).

4. The option to expand: where the owner of the option is able to scale up the operation following the success of the immediate investment projects. It is an American call option.
5. The option to extend: where the life of a project is extended by paying a fixed price. It is also an American call option.
6. Switching options: these are portfolios of call and put options that allow the owners to switch between two modes (e.g. gas vs. oil, exit vs. reenter, shutdown vs. restart) (Brealey*et al*., 2008).

The following paragraphs discuss some of the most common options by taking the examples given by Schwartz and Trigeorgis (2001) and Kulatilaka (1993).

2.3.2.1 Option to Wait

Assume an oil company having a one year lease to start drilling a land with potential oil reserve. Initiating the project entail an exploration cost. Under favorable market condition (e.g. higher oil price) preliminary exploration study will be followed by road and other infrastructure construction (I_1), which in turn will be followed by the construction of new processing plant (I_2). Extraction of oil will only begin at operating stage. Under this condition management may decide to exercise the option to extract oil. The processing plant may be designed upfront such that if oil price rise than expected, then the rate production can be enhanced (say by x %) with an additional outlay of I_x. On the other hand, under unfavorable market condition (e.g. lower oil price), management may choose to waive any future planned outlays or if the processing plant is designed upfront, management may reduce the operation scale (say by c %) and hence saving the amount of the last outlays by I_c. Management can also sell a portion of the plant and equipment for their salvage or change them to alternative use value. Immediately before the termination of the lease, the value of the option to wait is MAX (V-I_1, 0) where, V is the present value of expected cash flows from completed project. Hence the option to wait is similar to an American call option on V. Early investment means sacrificing the option to wait implying that this option value loss should be included as investment opportunity cost. Therefore, investment is justified only if the cash benefits, V, surpass the initial outlay by a significant amount (Brealey *et al*., 2008; Schwartz and Trigeorgis, 2001). Diagrammatically the option to wait may be represented as follows:

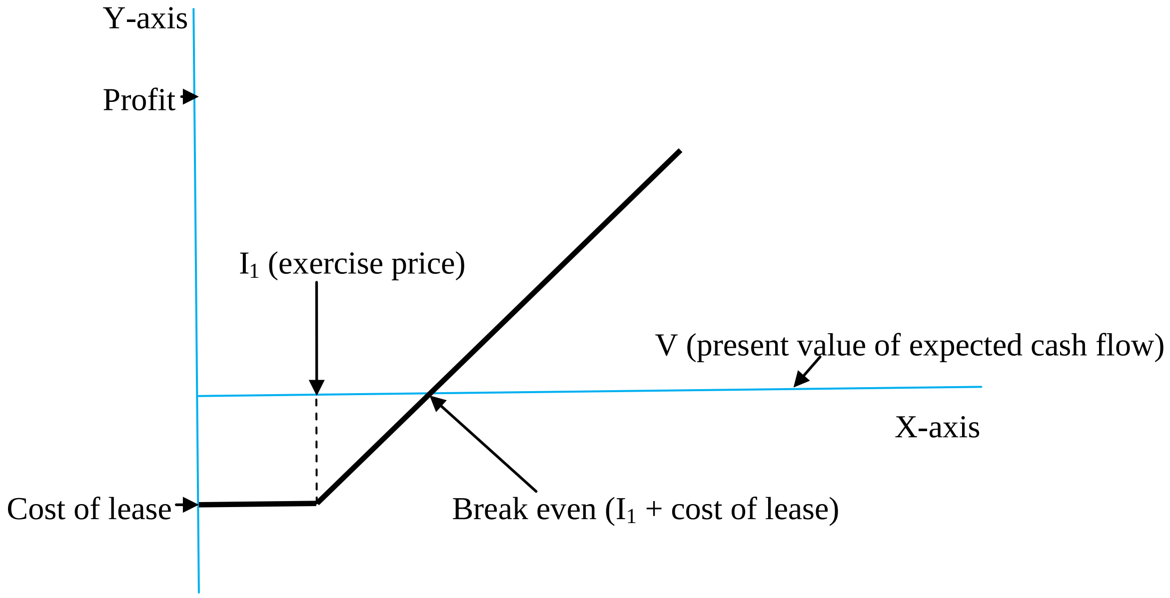

Figure 2 Profit diagram of call option (adapted from Brealey *et al*., 2008).

Here, it should be noted that profit diagrams (like figure 2) deduct the initial cost to acquire the option (cost of lease) from the final payoff, profit, when the option is exercised. Hence, the basic principle of finance, discounting the initial cost by a proper discounting rate to account for the time value of money, is ignored (Brealey *et al*., 2008).

2.3.2.2 The Option to Expand

If oil price turns out to be more favorable than expected, then management may enhance the scale of production by x% by incurring a subsequent cost I_x. This is analogues to a call option to gain an additional x% of the base (initial) project by paying an exercise price of I_x. Therefore, an investment opportunity having an option to expand can be viewed as the sum of a base (initial) project and a call option on upcoming investment i.e. V + MAX (xV – I_x, 0). The option to expand can be of a strategic importance because it allows a firm to exploit on future growth opportunity. For instance, when a firm buys vacant (undeveloped) land or builds a plant in a new location, it is basically installing a growth/expansion option which will be exercised if and when the future market condition (e.g. price and/or cost) turns out to be favorable (Schwartz and Trigeorgis, 2001).

2.3.2.3 The Option to Abandon

If oil price decline unexpectedly or the firms' performance drop, then management have the option to abandon the project permanently to salvage value (and cash salvage value if any value can be recovered) rather than continue incurring losses. This is analogues to American put option on the current value of the project, V, with an exercise price of the salvage value (S) or best alternative use (A), hence, allowing management to receive V + MAX (A - V, 0). Obviously, general-purpose capital asset (asset that can be used in multiple industries) will have a higher salvage (abandonment option) value than a specific-purpose capital asset (asset than can only be used in a specific industry). Moreover, valuable abandonment options are common in capital intensive industries like airlines, railroads and financial services (Brealey *et al.*, 2008; Schwartz and Trigeorgis, 2001). Diagrammatically the option to abandon can be represented as follows:

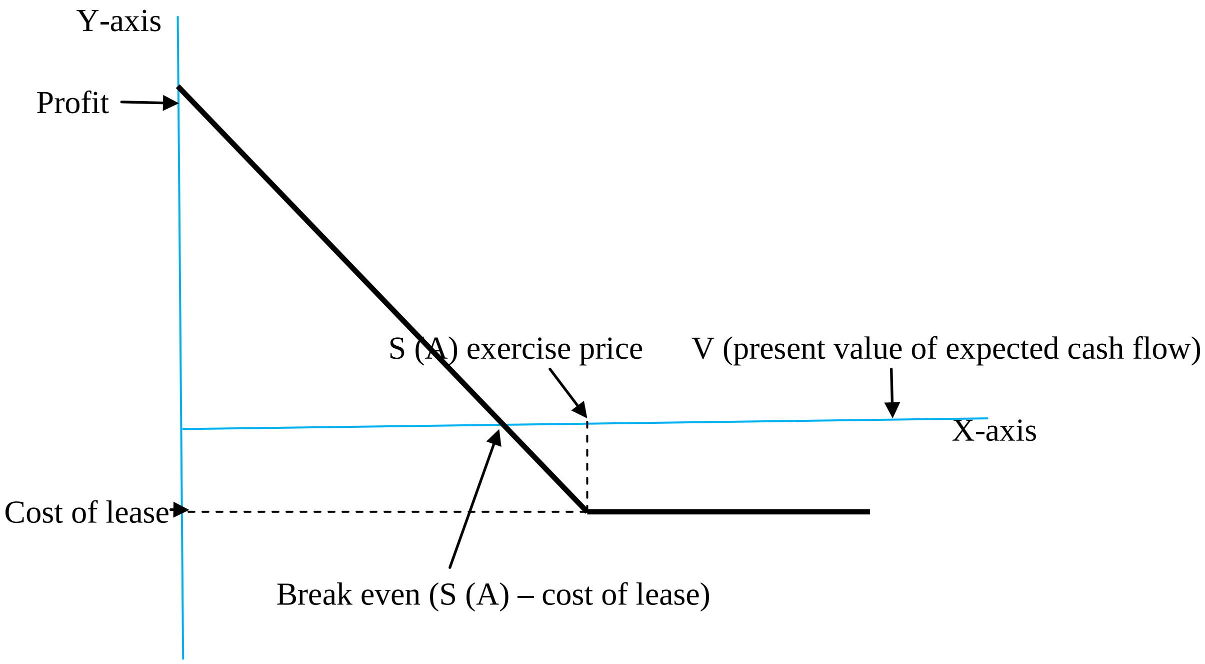

Figure 3 Profit diagram of put option (adapted from Brealey *et al*., 2008).

2.3.2.4 The Option to Contract

If market conditions turns out to be unfavorable (e.g. lower price and/or higher cost than expected), management may choose to operate below capacity or alternatively reduce the scale of operation by c%, thus, saving slice of the planned investment expenses, I_c.

Accordingly, this option of loss mitigation is analogous to an American put option on c% of the base scale project with an exercise price of I_c (potential cost saving) giving value MAX (I_c- cV, 0). Like the option to expand, the option to contract is valuable in new product introduction. It is also used in choosing between technologies and plants having different mix of construction and maintenance cost. By choosing a plant with lower construction and higher maintenance cost, a firm can acquire the option (flexibility) to contract operation by lowering maintenance cost when projects are no longer profitable (Brealey *et al*., 2008; Schwartz and Trigeorgis, 2001).

2.3.2.5 The option to switch

Assume that an oil refinery operation is designed in such a way that it can use different forms of energy inputs (e.g., fuel, gas, electricity) in order to convert crude oil into different outputs (e.g., gasoline, lubricants). Therefore, as inputs or outputs relative price fluctuate over time, the firm acquire a valuable built-in flexibility to shift from the current inputs to the least-priced future inputs or to choose to produce a product mix which is most profitable. Such a flexible technology cost more than the one which provide less or no choice. Therefore, a firm willing to acquire the flexible technology will pay more (positive premium) than the cost of the less or none flexible technology. Generally speaking, process flexibility can be attained not only by having a flexible technology but also by building and maintaining relationship with different suppliers mix and changing the mix as comparative price of each suppliers change. Process flexibility is valuable in electric power, oil, chemicals and crop switching (Schwartz and Trigeorgis, 2001).

Product flexibility permits firms to switch among different (alternative) outputs in response to the market conditions of products. For instance, automobiles, electronics and pharmaceuticals industries are typically characterized by production facilities equipped with product flexibility. In fact, product flexibility is valuable, if and when product differentiation is important and demand is volatile, which are the typical behavior of the above mentioned industries (automobiles, toys, electronics and pharmaceuticals). Hence, it is worthwhile for firms' to acquire the more costly technology which will allow it to have the capacity to change product mix or scale of production in response to the changing market demands. In general, the option to switch is like having a nested options problem each time to be exercised by the firm depending on inputs cost or outputs price which lead to low cost of operation or higher profit (kulatilaka, 1993; Schwartz and Trigeorgis, 2001).

2.3.3 Decision Tree Analysis (DTA)

Smith and Nau (1995 cited in Brandão and Dyer, 2005) discuss how to evaluate real option in discrete time model using decision tree analysis (hereafter DTA). They mention that by using risk free rate to discount the cash flow and making adjustments for risk in the probabilities of each state, DTA can effectively be used to value projects with options. Hence, the problem of estimating the correct risk adjusted discount rate for projects with options is solved.

Real option valuation in continuous time has some practical limitations. The major limitation is market incompleteness and as the result the difficulty of determining a market portfolio having a risk which correlate with the risk of the project. Copeland and Antikarov *et al*. (2003) propose an alternative method in order to overcome this limitation. The method is based on the assumption "*that the present value of the project without options is the best unbiased estimator of the market value of the project*" (Brandao and Dyer, 2005, p. 24). This assumption is called the Marketed Asset Disclaimer (MAD) assumption which makes the project itself as the underlying asset for the replicating portfolio, hence, making the market complete. The other assumption they made is that the variation in project return follow a random walk. Assume that the project did not pay out dividend and the project value at time t and t+1 is represented by v_t and v_{t+1} respectively. Under random walk assumption, ln (v_{t+1}/v_t) is normally distributed with mean $(\mu-\frac{1}{2}\delta^2)$ and variance σ^2. As the time period length close to zero, this stochastic process can best be represented by the Arithmetic Brownian Motion (ABM) as follows: $\ln v = (\mu-\frac{1}{2}\delta^2)dt + \sigma dz$ where dz is the standard wiener process $E[dz] = 0$ and $E[(dz)^2] = dt$ and μ is the expected growth rate (Dixit and Pindyck, 1994). The assumption $\ln(v_{t+1}/v_t)$ is normally distributed implies (v_{t+1}/v_t) is log normally distributed which is modeled by a Geometric Brownian Motion (GBM) stochastic process as follows: $dv=\mu v dt + \sigma v dz$ where μ is the expectation (trend) term and σ is the variation (uncertainty) term. The significance of the assumption, that at any time t, the distribution of the project value is normal, is several uncertainties of a single project can be summed as one single representative uncertainty which will simplify the stochastic modeling process. Moreover, Monte Carlo simulation[6] can be used to obtain the parameters of this process (www, PUC-Rio, 2008; Brandão and Dyer, 2005).

[6]Monte Carlo simulation is a computerized technique used to assess the impact of risk in decision making. Its ultimate goal is to make a better decision in the world of uncertainty. @RISK is the foremost add-in for excel software for making Monte Carlo simulation (www, palisade, 2012).

More importantly, Brandão and Dyer (2005) argue that a discrete time model which uses a binary tree (binary lattice) can approximate this continuous model.

3. Literature Review

3.1 Waste as a Threat and Opportunity

3.1.1 Why is Waste a Problem?

In broad terms, leftovers from manufacturing process or unwanted materials from community or households can be defined as waste or rubbish or garbage or junk based on the type of material or regional terminology (www, fullcycle, 2009). In fact, waste is a human concept. Waste contains (physically) the same material as useful products lacking only value. In natural process production and decomposition are balanced, which in turn means the waste of one process becomes the raw material for another process. In contrast to natural process, human-made system principal economic activities are production and consumption which negatively affect the environment. These economic activities are characterized by massive consumption and return waste that impacts on the environment. This means that, valuable resources are lost when waste products are disposed. Since most resources are finite, human-made systems carelessly reduce the earth's future capacity to supply raw material. The Environmental Protection Agency (EPA) of the United States estimates the annually produced amount of solid waste in the United States to be 11 billion tons (Cunningham *et al.*, 2007). Half of that amount is agricultural waste, which are usually recycled into the soil and, hence, become a useful fertilizer for new crops, and also used to reduce erosion. However, agricultural waste is also a major source for air and water pollutions in the United States (Cunningham *et al.*, 2007; www, fullcycle, 2009; White *et al.*, 1999).

3.1.2 Waste as a Resource

Despite health, safety and environmental concern, waste products also possess huge opportunity. In today's world where resources are limited and energy is scarce, waste is unexploited source for resource recovery and energy production. For instance, in the United States > 90% auto batteries, > 50% steel, > 45% aluminum packaging and > 40% paper and paper board are recycled (EPA, 2003 cited in Cunningham *et al.*, 2007). At the same time, more than 110 waste incinerators in the United States burn about 45,000 tons of waste daily to produce electricity and/or stem (Cunningham *et al.*, 2007).

In general, adopting a closed cycle technique (which combines maximum recycling, valorization of energy form the waste and the subsequent sequester to off-set CO_2 from waste valorization) for waste management that mimics the natural process will contribute to sustainable development through: (i) restoring of natural resources, (ii) reducing environmental stress caused by poor Solid Waste Management (SWM) practices, (iii) promoting public health and avoiding health related economic losses on account of pollution which are caused by poor SWM practices (www, sixthwave, 2012; Jones *et al*., 2010; Zia and Devadas, 2008; White *et al*., 1999).

3.2 Classification of Waste

According to White *et al.* (1999) waste primarily can be classified on the basis of physical state as solid, liquid and gaseous. The solid waste in turn can be further classified by:

- Original use which includes food waste, package waste etc.
- Material type where metals, glass, papers, plastics etc. are included among many others.
- Physical properties which comprises recyclable, compostable and combustible.
- Origin (source) which includes industrial, agricultural, domestic (households), commercial etc.
- Safety level which includes hazardous and non-hazardous solid waste.

The remainder of this thesis focuses on households and commercial waste which together referred to as Municipal Solid Waste (MSW).

3.3 Sustainable Material Management (SMM)

Sustainable Material Management (SMM) is an approach which focuses on attaining sustainable material use whilst preserving the natural resources and reducing negative environmental impacts. SMM takes into account keeping economic efficiency while attempting to achieve social equity[7] (Jones *et al*., 2010).

History of SMM had evolved from end of pipe "do more with less" concept in 1970 to closed loops integrated concept in 2000+.

[7]Social equity is one of the vaguely defined and understood elements of the concept sustainable development. However, in simple terms it can be defined as one of the integral element in creating sustainability. Sustainability will be achieved when economic, environmental and social equity are balanced (Elkington, 1997).

This evolution can be conveniently categorized into 3 broad approaches: reaction, re-designing and re-framing. I, Re-action: here the emphasis is establishing a clean technology which brings eco-efficiency. II, Re-designing: this approach started around 2002 and employ reduction, reuse and recycling to achieve eco-effectiveness. III, Re-framing: this is an integrated approach that uses the system perspectives and incorporates social, geological, physical, economical and institutional implications of the system (Jones *et al*., 2010).

3.4 Waste Management

As Jin *et al*. (2006) stressed, Municipal Solid Waste Management (MSWM) is a challenge for urban areas of both developed and developing countries. However, the fast growing cities of the developing countries, particularly, face a huge challenge in implementing a proper solid waste management (SWM) that deals with the huge amount of waste generated. This is mainly due to the fact that the cities need to accomplish an effective and efficient MSWM that keeps in pace with the requirements of the rapid economic growth, population increase, industrialization, and changed consumption pattern. Hence, it becomes increasingly difficult for the cities of the developing countries to realize such effective and efficient SWM systems. Generally speaking, for cities of both developing and developed countries to be successful in implementing a proper SWM, the cities should address the three key drivers: public health, environment and resource recovery. Where, in public health the focus is on waste collection while in environment the goal is improving waste disposal. In resource recovery, on the other hand, the focus is on closing the loop for materials, i.e. recycling, reuse, and material and energy valorization. Nevertheless, addressing these three technical elements is not sufficient to bring a sustainable SWM system. Accordingly, the cities need to address the 3 key governance strategies: inclusivity, financial stability and sound institutions' policies. Inclusivity refers to the full participation of stakeholders whereas financial stability refers to the provision of cost effective and affordable service (Wilson and Scheinberg, 2010; Seng*et al*., 2010).

According to Passel *et al*. (2010) and Zee *et al*. (2004), the waste management program in most developed countries employ a hierarchical system. Such system, also called Lansink's stepladder, comprises in order of decreasing priority: waste prevention and reduction > recycling or reuse > incineration with energy recovery > land filling. However, due to the complex trade-off between economic, social, and environmental issues the priority order between incineration and land filling is still a debated.

Despite the controversy of priority order, absence of land filling sites and growing environmental concern force some countries to adopt land filling as the last resort. Hence, what once has been a convenient and less costly waste disposal option now becomes costly due to the rise of land price and increasingly demanding construction and maintenance. Faced with these constraints, some countries switch to other waste disposal options. For example, the Netherlands is able to recycle about 64% of its waste leaving the reminder to be incinerated to produce electricity. Hence, a small amount of waste ends up in land filling. Their approach is inspired to Lansink's stepladder: as much as possible avoid waste creation, recover valuable materials, generate electricity and only land filling what is leftover (Cunningham *et al.*, 2007;www, waste-management-world, 2011).

3.5 Waste Management in Developing Countries

Even though, some of the challenges to MSWM are common to both industrialized and developing countries, developing countries, in particular, face a number of different fundamental issues which are shared by most countries of the third world. Hence, awareness of the wider social, economic, and cultural context of the third world countries is needed in order to meet the challenges, which in turn imply that immediate technological solution and long term strategies of MSWM must not be simply imported from industrialized countries without modification. Generally speaking, the two major problems developing countries face with regard to MSWM are insufficient collection and inadequate final disposal. Most cities of the developing countries collect less than 50% of the total waste generated leaving the uncollected waste to usually be flung into the street, bodies of water, vacant lots or burned (Medina, 2007). Even for the collected waste, open dumping is the most common final waste disposal method despite the fact that, open dumps usually pollute water, air, and land. Therefore, these methods of final waste disposal pose significant health risks for humans living nearby the open dumps, as well as it is a threat for the surrounding environment (Thomas-Hope, 1998; Medina, 2007).

The nature and extent of urbanization in developing countries have a major implication on these countries' MSWM. For instance, 30%–50% of the population of the developing countries is urban who produce a high volume of waste, 75% of which is domestic waste (Thomas-Hope, 1998). Furthermore, the evolution of unplanned and spontaneous urbanization, absence of accessible road networks or adequately managed waste disposal systems and sewage make MSWM in developing countries challenging.

On the other hand, as compared to fully industrialized countries, developing countries have a low waste generation rate. For instance, low income countries have an average waste generation rate of 0.4 to 0.6 kg/person/day, while, an average waste generation rate in industrialized countries varies from 0.7 to 1.8 kg/person/day (Zerbock, 2003). Moreover, the waste composition of developing countries is characterized by high density (usually 2-3 times higher than that of industrialized countries), high moisture content (2-3 times higher than that of industrialized countries), high amount of organic content, high amount of dust and dirt (usually arising from street weeping) and on average smaller particle size (than that of industrialized countries) (Zerbock, 2003). These differences should be recognized in terms of the additional problems they pose as well as in terms of the potential opportunities that arises from the waste composition (Medina, 2007).

The dichotomy of opportunities and threats that arise from waste with high organic content is of special interest. Organic waste presents both opportunities and problems. Anaerobic decomposition of organic waste in dumps and landfills produce methane. As a greenhouse gas, methane (CH_4) is 20 times stronger than carbon dioxide (CO_2) which accounts for landfills to contribute to about 11% of greenhouse gas emissions (Medina, 2007). On the other hand, high organic content also presents enormous opportunities in terms of recycling and composting. Recycling allows for saving a huge amount of energy which can be translated into fewer power plants needed, as well as a lesser amount of fossil fuel burned, both of which contribute to a lower amount of greenhouse gas emission. Composting, on the other hand, may be a benefit in reducing a substantial volume of waste for disposal which can also be translated into the ultimate greenhouse gas emission reduction (Medina, 2007).

Due to the high rate of urbanization (as large as 4% in many African countries) and the corresponding increase in demand for service, meeting financial demands of MSWM remains to be a challenge for cities of developing countries (Zerbock, 2003). For example, 20%–40% of municipal revenue is spent on ensuring basic waste management in developing countries (Thomas-Hope, 1998). This is to mean that, municipal tax and fee revenues do not rise as quickly as population and the attempt to increase municipal revenue for waste management, by levying comprehensive taxes, is particularly challenging in developing countries where a high level of urban poverty exists. Hence, the situation implies the need for a social fund proportionate to the level of poverty in urban areas. Therefore, source identification of such finance should be the major policy issue in developing countries.

Nevertheless, “*waste management is by no means solely an economic or technological matter but it raises important questions about equity and governance as well*” (Thomas-Hope, 1998 p. 2). The social aspect of MSWM is further revealed in the population who earn their livelihood from scavenging at garbage collection points and dump sites. “*This is consistent with high levels of informal economic activity that occur in developing countries, especially among the poor*” (Thomas-Hope, 1998 p. 2).

Greater urban concentration and increased waste quantity are not the only problems related with solid waste management in developing countries but also, the amount of waste varieties to be managed and its potential for contamination are equally challenging. Much of industrial, hospital, and transportation waste have a high level of toxicity. Hence, the potential risk to human health, water resources and ecology in general is greatly amplified with these types of waste (Thomas-Hope, 1998).

Many cites of the developing countries are unaware of the degree to which revenues of MSWM are collected and even the true costs of their total MSW operation (Zerbock, 2003). Problems are further compounded when MSW collection revenues are rolled into general account instead of returning to waste-related operation. One of the potential solutions employed by many municipalities is privatization of MSWM operation. Of course, the financial picture becomes clearer with private contracts even though the local government is still held accountable if service quality declines (*ibid*).

All in all, Thomas-Hope (1998) and Couth *et al.* (2010) argue that some of the major challenges when trying to implement an efficient and effective MSWM in most developing countries are:

- The marginal socio-economic condition of many people.
- The lack of cooperative culture and cultural aversion toward waste.
- The absence of well-defined enforcement mechanism to effectively coerce the population to comply with the stringent regulatory framework.
- Restricted public service funding and the lack of qualified technical and human resources.
- Municipal authorities’ low level of awareness towards environmental and public health effects of inadequate waste management.

- The high rate of population growth and the resulting ever increasing waste production and unprecedented pressure on resources.

3.6 An Overview of Waste management in Addis Ababa

Addis Ababa, the capital city of Ethiopia, has a population of 3 million with an area of 540 km^2 (54 000 hectare). The city's decentralized municipal government is organized into 3 hierarchal layers, where the city government is at the top which controls and administers 10 sub cities. Each sub city in turn administers a total of 99 kebeles, the smallest local units for the city administration (Addis Ababa city government, 2010).

The solid waste generation rate of the city of Addis Ababa is 0.4 kg/person/day. Physically, the solid waste is composed of 60% organic (e.g. vegetable, paper and wood), 15% recyclables (e.g. rubber/plastics, metals and glass) and 25% non-combustible stones and other tiny materials. With regard to the source of the solid waste, 70% is from households, 9% is from commercial/retail activities, 5% is from industrial manufacturing, 3% is from hotels and 1% is from hospitals. Despite the fact that, a large proportion of the city's municipality budget is used to collect, transport and dispose solid waste, only 65% of the total waste generated is collected, transported and disposed of. Moreover, the city's municipality is limited to 5% recycling and 5% composting of the total waste generated. The rest of the total waste (25%) is dumped into open sites, rivers and valleys, drainage channels and onto the street. Even for the waste that is properly collected, the final disposal method, dumping into Koshe/Repi, is not at all a sustainable way of waste management (Addis Ababa city government, 2010; Community Development Research, 2011).

The informal material recovery from the waste refuse point, by waste pickers (scavengers), has proven to be economically profitable. Though, scavengers are not involved in such activities because of their concern for waste management but for economic reasons, their activities play a key role in the solid waste management of Addis Ababa (*ibid*).

In general terms, the process of scavenging can be carried out in 3 distinct phases:

- Phase 1: where households separate higher market value materials like papers, plastics, tin, glass, metals, old shoes and clothes which can be sold to street vendors (locally known as "Lewache" and "Korals").

- Phase 2: where scavengers salvage materials of low market value (such as broken glass, metals, plastic bottles, cans, cardboards etc.) from on-site garbage and dust bins.
- Phase 3: where scavengers recover reusable and recyclable materials from the final disposal site, Koshe/Repi (Addis Ababa city government, 2010; Couth and Trois, 2010).

3.7 Key stakeholders in Addis Ababa MSWM and LFG industry

The key stakeholders in the Addis Ababa MSWM and LFG industry can be categorized into:

- Local community: This includes those living in and around Koshe/Repi, scavengers and government and non-governmental institutions located at close proximity to the vicinity of Koshe/Repi.
- Governmental institutions: These include Addis Ababa City Municipality (owner of landfills), Ethiopian Electric Power Corporation, Environmental Protection Authority, Ministry of Works and Urban Development, Ministry of Finance and Economic Development, Ministry of Water and Energy.
- Non-governmental organizations that have an affiliate to sustainability: including Forum for Environment, HoA-REC, and Institute for Sustainable Development etc.
- Consultants: including Swan Management, and Golden Standard etc.
- Financers: These include local banks, the World Bank and African Development Bank (Community Development Research, 2011; HoA-REC, 2012).

3.8 Enhanced Landfill Mining (ELFM)

3.8.1 ELFM Evolution, Definition and Future Market Potential

In response to the need to attain a SMM, a trans-disciplinary consortium was set up in 2008 at Flanders (Belgium): to develop a new approach to waste management and land filling within the larger framework of SMM. The new vision to waste management is called Enhanced Waste Management (EWM) which applies an integrated and sustainable approach to waste management to comply the idea of closing the material loop. In EWM the Lansink's step ladder is even more stressed except land filling as a final solution is avoided.

Land filling will be part of EWM if and only if it is considered as a temporary storage place for future mines of materials. In short, EWM comprises two major pillars: the first pillar which focuses on recycling is an approach to improve recycling and storage in order to increase the re-use rate and the second pillar is the concept of Enhanced Land fill Mining (ELFM) which stresses the idea that the waste dumped to landfill today needs to be mined after limited time (Geysen *et al*., 2009; Jones *et al*., 2010).

The new approach to land filling known as Enhanced Landfill Mining (ELFM) comprises valorization of new and closed landfills into material known as Waste-to-Material (WtM) and energy known as Waste-to-Energy (WtE) with the ratio dependent on the type of waste and contemporary technology for material and energy production. Quaghebeur *et al.* (2010) stress that for waste dominantly composed of stones, metals and glass/ceramics (the major composition of Industrial Waste (IW)), WtM technology seems the best option. On the other hand, for waste primarily composed of textile, paper/cardboard, wood and plastics (the dominant composition of MSW), WtE appears the best alternative (Geysen *et al*., 2009).

ELFM is different from traditional landfill mining. Traditional landfill mining is one of waste treatment options where untreated wastes are deposited for long time. As Geysen *et al.* (2009) argued in traditional landfill mining the goal is limited to the reclamation of methane, land and certain metals such as copper or alumina. It is not a preferred waste treatment option from an environmental perspective due to emissions, low efficiency of energy recovery and overall shifting of risks and burden to the future. ELFM is also different from sustainable landfill where only organic materials are allowed to degrade under moist and aerobic condition. ELFM is part of the big vision of EWM and it takes into account the extended producer responsibility concept. This means that actors' and stakeholders' (i.e. landfill owner, operator and waste producer) responsibility is extended from promoting reuse, recycling and incineration to taking landfill as future mines of materials to be mined after short, medium and long period. Hence, due to the extended responsibility more material ends up in recycling instead of incineration and dumping (Geysen *et al*., 2009; Passel *et al*., 2010; Hellweg *et al*., 2010).

Recently the scale of landfill mining shows enhancement. This is mainly due to the rise in energy price as well as the increase in demand for recyclable materials (e.g. plastics and metals) which make landfill mining projects more profitable.

For instance, Group Machiels, a Belgium based waste management company; recently declare the completion of preparation to start a huge project in 2014. The project comprises of valorization of the area called Houthalen-Helchteren (an old landfill about 50 miles east of Brussels). Group Machiels claims that in the 20 years project life time, 45% of Houthalen-Helchteren content will be recycled while the rest will be converted into electricity. Furthermore, landfill mining projects receive renewable energy credit (credit for emission reduction) which will make investments in such projects even more attractive (Webb, 2010).

3.8.2 ELFM Economic Performance

ELFM economic performance is determined by the following factors: technology which includes waste to material (WtM) and waste to energy (WtE), government regulation in the form of subsides, taxes, allowances and markets which include input and output markets. Even though landfills vary in location, size and content, their economic and environmental performance drivers are quite similar (Passel *et al*., 2010).

Generally speaking, the profitability of mining projects can be assessed by having an insight into their benefits and associated costs. The benefits may be related to efficient operation of landfills and benefits resulting from regained land and recyclables. In contrast, costs are distinguished as capita[8] costs and operational costs. Nevertheless, a more detailed Cost benefit model may be used to establish the performance drivers' economic impacts on ELFM projects (i.e. performance drivers' impact on Internal Rate of Return (IRR) of ELFM projects). IRR is calculated by finding a discount rate which makes NPV zero. After finding the IRR, it's variation in response to variation in uncertain assumption can be tracked using a Monte Carlo sensitivity analysis. The base scenario IRR is taken as 15% (before taxes). Projects with IRR greater than 15% (before taxes) are considered profitable. The result of the model from the case study at Remo9 landfill site shows that WtE efficiency, electricity price, CO_2 price, investment cost of WtE installation, operational cost of energy production and ELFM support are the most important parameters in explaining the variation in IRR. WtE efficiency, electricity price and ELFM support have strong positive relationship with IRR whereas CO_2 price has a strong negative relationship while the rest have small negative

[8]Capita costs are costs associated to site preparation and rental/purchase of equipment for the purpose of reclamation, personal safety or construction or expansion activities (Zee *et al*., 2004).

[9]The Remo landfill site in east Flanders is an old landfill operational since 1970 and currently contains more than 16 million tons of waste with equal percentage of households and industrial wastes (Passel et al., 2010).

contribution to IRR variation. The result of the model is important since it contains both uncertainty of input parameters and their significance (Zee *et al*., 2004; Passel *et al*., 2010).

3.8.3 ELFM Environmental Performance

Landfill mining research up to now has dealt solely with local risks like pollutant emission during excavation process. Though, this approach has been beneficial and essential, it is not sufficient since resource recovery from landfills will create a regional and global scale environmental impact. For instance, 20.3 hectares of landfill might contain as much as 217,680 metric tons of steel and 18,140 metric tons of aluminum (Krook *et al*, 2011). Recycling such considerable amount of steel and aluminum and hence replacing virgin production of these metals will lead to huge amount of energy savings and circumvent many kinds of environmental pollutant (*ibid*).

In ELFM projects, specifically, environmental performance can be assessed by calculating the carbon footprint of the internationally agreed greenhouse gases such as CO_2, methane (CH_4) and nitrous oxide (N_2O) in all activities of a company relating to emission. Here, we will have two scenarios: do nothing (DN) and closing the circle (CtC). In the DN scenario only a limited amount of energy is recovered from CH4. There is no material production and hence no incoming and outgoing of materials. This implies that the greenhouse gas emission of the DN scenario accounts that of the conventional market production methods. On the contrary, in CtC scenario WtE and WtM plants are installed. Therefore emissions during the operation activities are accounted here. Operational emissions are of different category such as: emissions during energy production and non-energy use, emission during freight and passenger transport, emission during material incoming and outgoing, capital asset emissions, emissions from the waste and waste water, and emissions during end of life of product. Citing the Remo landfill site example again, the study reveals that the CtC scenario reduce greenhouse gas emission by about 15% without any particular mitigation with 20% marginal error in calculating both the DN and CtC carbon footprint. More importantly, the result holds true with variation of different parameters like the carbon content, composition and caloric value of waste. In general, to address the environmental performance of landfill mining projects, there is a need to have a research that apply a systems approach (e.g. life cycle assessment), allowing to balance positive and negative impacts occurring in local, regional and global scale (Passel *et al*., 2010; Tielemans and Laevers, 2010; Krook *et al*, 2011).

3.8.4 Challenges in ELFM

The consortium fully acknowledges the difficulties in implementing ELFM. Getting a new landfill site and the permit for construction is now becoming more and more difficult. For example, the double taxation by local authorities for both land filled waste and for the surface occupied by the waste makes land filling more costly than ever. "*landfill mining might also lead to an increased dispersal of unwanted substances such as heavy metals, especially if the applied technologies fail to separate out the dispersed hazardous materials in the landfill*" (Krook *et al*, 2011 p. 518). Another challenge which ELFM projects might face is the technological challenge to separate metallurgical slags (steel slags and stainless steel slags rich in CaO). In fact, having efficient hazardous waste separation technologies are critical since it largely determines the usability of the resulting recyclable (Krook *et al*, 2011; Gerven *et al.* (2010).

In a nut shell, investment cost, WtE electrical efficiency, environmental certification and treatment of carbon dioxide (CO_2) and societal acceptance constitutes a crucial factor in ELFM projects success. Hence, ELFM success depends on technological innovation and the ability to tackle multifaceted socio-economic barrier like government regulation and directives, societal acceptance, economic uncertainty etc. (Geysen *et al*., 2009; Jones *et al*., 2010).

3.9 The Technology of Landfill Gas (LFG) Power Plants

Natural degradation of MSW (anaerobic[10] decomposition of organic materials) generates landfill gas (hereafter LFG). LFG is typically composed of 40-60 % methane (CH_4) with the remaining percentage being mostly carbon dioxide (CO2). In addition, LFG also contains small amounts of nitrogen (N_2), oxygen (O_2), water vapor, and many other contaminants. Once produced, the LFG may migrate off-site and may even cause explosion if a proper gas collection system is not installed in place. By drilling a series of wells into the landfill and connecting each of one with the other by plastic piping system, the accumulated LFG can be collected and used for electricity generation through gas turbines. However, some scholars argue that this approach focuses only on the handling of methane. Thus, it ignores the issue of exactly addressing the toxic substances in the LFG.

[10]The breaking down of organic substances into smaller compounds by microorganisms can happen with the presence of oxygen (aerobic) or without the presence of oxygen (anaerobic) (Wikipedia).

They emphasize that regardless of the ultimate use of the LFG, it should be filtered out first to remove the toxic substances (www, energy, 2012; Ewall, M., 2012). See appendix C, D, E and F for sample gas extraction well and for the gas collection network of Koshe/Repi LFG project.

The collected gas, which is mostly saturated with water, result in low British thermal unit (BTU)[11] LFG after passing through the dewatering process. Later, the dry, low BTU, LFG can be used in piston engines, a heat engine that converts gas under pressure into rotating motion by using one or more of reciprocating pistons, to generate electricity. In terms of composition, the dry LFG is typically 57% methane (CH_4), 42% carbon dioxide (CO_2), 0,5% nitrogen (N_2), and 0,2% oxygen (O_2) and it can be processed into a high BTU LFG which is more efficient in generating electricity than the low BTU LFG counterpart (www, energy, 2012).

In addition to producing electricity, the technology concurrently reduces greenhouse gas emission (under the assumption that the technology also embraces a system which removes the toxic components of LFG). This is done in two ways: first, by capturing and destroying methane (CH_4), which otherwise would enter into the atmosphere. Second, by displacing carbon dioxide (CO_2) which otherwise will be generated by burning fossil fuel at conventional power plants (www, EPA, 2012).

To estimate the value of environmental and energy benefits of LFG power plants, let’s take an example of LFG power plant which typically produces 3 megawatt of electricity. The annual environmental benefit from this power plant is equivalent to any one of the following:

- Reduction of annual greenhouse gas emission from 24,800 passenger vehicles.
- Reduction of carbon dioxide (CO_2) emission from burning 14.2 million gallon of gasoline.
- Reduction of emission by planting 27,000 acres of forest.

And the energy benefit is equivalent to the powering of 1770 homes (www, EPA, 2012).

3.10 A Glimpse of Carbon Trading

The carbon trading concept came after the Kyoto protocol. In December 1997, some 180

[11]British thermal unit (BTU) is a traditional energy unit. 1 BTU, which is equivalent to 1055 joules, is the energy needed to raise the temp of 1 pound (0.454 kg) water from 39^{o}F to 40^{o}F (Wikipedia).

countries signed the Kyoto protocol in Kyoto japan.

The protocol demands the 38 industrialized countries to diminish their greenhouse gas emissions by 5.2% between the years 2008 to 2012 as compared to the 1991 level (www, investopedia, 2007; Rinaudo *et al,* 2008). This target seems to be already achieved by the European Union member states (EU-15), though, the emission performance among them remain to be mixed. This is to mean that the majority of the member states have an outstanding performance, while, very few are still away from their Kyoto targets (www, europeanenvironmentagency, 2011).

The concept of carbon trading is very similar to commodity market. Carbon is given economic value, which allows countries (companies) to trade it. Hence, a country (a company) buying carbon is buying the right to burn it, whilst, a country (a company) selling it is giving up the right to burn it. The better a country (a company) can store carbon, the higher value that a country (a company) will charge for it (www, investopedia, 2007).

Carbon trading is of two types: cap and trade and carbon offset. In cap and trade form the cap component is supposed to be a governmental or intergovernmental body that will set a legal limit on the amount of permissible pollution at a given time of period. While, the trade component give companies a space in addressing emission reduction commitment. In theory, companies exceeding their reduction commitment may sell the spare to those who have failed to do so cost effectively. Nevertheless, in practice, the industrial lobbying efforts and difficulties in measurement which granted private firms with the cap and trade scheme beyond and above their need to cover the existing level of emission, has made the scheme so far unsuccessful. In carbon offset on the other hand, rather than cutting emission at the source, institutions, companies, governments and individuals finance emission-saving projects outside of the place where emission takes place. However, even in theory carbon offset is not really emission reduction scheme as it is often presented. It simply moves reduction to a place where it is cheap to make (Gilbertson and Reyes, 2009). Summarizing the above facts, *"Carbon trading is a market mechanism allowing those most efficient at reducing emissions to do so and trade their "carbon credits" with those who cannot reduce emissions as cost effectively*" (Rinaudo *et al,* 2008 p. 49).

In the actual global market place for integrating voluntary emission reductions with cap and trade and carbon offset, carbon credit is assigned a monetary value. For instance, in Chicago climate exchange (CCX), one of the world's first market place for trading of carbon emission, one metric ton of carbon dioxide (CO_2), which is equivalent to one carbon credit, is about 2$ as of November 2007. On the other hand, offset providers sell one carbon credit at about 12$. Other greenhouse gases have given value based on a standard multiple of carbon dioxide (CO_2). For example, methane (CH_4) is about 20 times the value of carbon dioxide (CO_2). In contrast to the CCX, the European Union emission trading scheme (EU ETS) currently sets 30$ per carbon credit, which will be valid until the end of 2012 (Wagner, 2007).

The Kyoto protocol introduces a mechanism (clean development mechanism) by which developed countries can support project with less than business as usual carbon emission in developing countries (carbon offset). Nevertheless, projects in developing countries to generate carbon revenue, they should satisfy both the additionality and leakage requirement of the clean development mechanism (CDM). Additionality of CDM embraces two important concepts. First, CDM projects are expected to add environmental benefits since these projects greenhouse gas emissions is lower than the base line scenario (a situation without the project). Second, CDM project will not be viable and hence not commercially attractive had it not been for the revenue from the carbon trading. "*This additionality is generated in projects such as capturing methane from an urban landfill and flaring it" (*Analytical *et al*., 2008*).*Leakage on the other hand, refers to emission outside the project boundary but caused by the project. For instance, assume a forest project is established on pasture lands and as a result farmers who previously used the pasture lands for grazing shift to another area in search of grazing land and clear the forest in that area. The emission connected to the cleared forest is considered as a leakage to the project and will be taken into account in the carbon credit trading (Analytical *et al*., 2008; Rinaudo *et al,* 2008).

In short, the carbon market may be explained as the buying and selling of GHG (greenhouse gas) emission allowances and emission reduction credits in order for a country (a company) to meet its GHG emission commitment. The price of CER (certified emission reduction), which is certified under the Kyoto protocol's CDM, fluctuate widely and it is loosely correlated with traditional macro-economic factors. While, the increase in the output of traditional energy sources stimulate the demand for CERs, the main determinant of CERs price at the macro level are political and administrative processes responsible for the implementation of global climate change treaties. At the micro level on the other hand, CERs price is sensitive to the risk term which the buyer and seller allocate to the project. Even though CERs are not a standardized product, the commoditization of its market is likely to advance in the future as the amount issued and availability of tradable CERs increases (Hodes and Kamel, 2007).

It is acknowledged that recycling and composting, higher up in the Lansink's stepladder than disposal, provide a higher emission reduction and hence a higher CDM income than collection of landfill gas for energy use (e.g. generating electricity). This is because, instead of recovering 50% of the total landfill gas and use it to produce electricity, recycling and composting prevent landfill gas from being generated in the first place. Moreover, reuse and recycling offset emission due to the manufacturing of new material from virgin sources (Couth and Trois, 2010).

4. Method

4.1 Choice of Case

Ary *et al.* (2009) in the book called "*Introduction to Research in Education*" define case study as a type of qualitative research type that focuses on a particular unit, which may be a single individual, group, organization, project or program and the goal is to have a detailed understanding of that entity (case). Further, Stake (1995) in the book called "*The Art of case study research*" classify case study as intrinsic and instrumental. It is intrinsic if the case is pre-selected (given) and we are interested to learn about it. On the other hand, it is instrumental if we are interested to learn something other than this particular case and hence case selection criteria are employed. The case in this study falls in the intrinsic category where the case is given and no case selection criteria are employed.

4.2 Types of Data Collection

Broadly, research can be categorized into quantitative and qualitative. Quantitative research employs objective measurement for numeric data gathering. These data (which may be collected by different tools like questionnaires and surveys) are analyzed using different statistical or mathematical methods to study the cause and effect relationship. In contrast to quantitative research, in qualitative research we use narrative description and interpretation to examine a phenomenon in rich detail. More importantly, the researcher in qualitative research takes the role of primary data collector. Data in qualitative research may be collected by interviews (in-depth, structured or unstructured), focus groups, narratives, participant observation or content analysis. Here, it should be noted that the primary goal of qualitative research is to acquire the holistic picture and hence the focus is on the depth of understanding rather than a numerical analysis of data. In contrast, quantitative research focuses on counting, classifying and construction of model to better explain what is observed. Therefore, qualitative research is ideal for the earlier phase of a project while quantitative research is highly recommended in the later part of the project in order for the researcher to have a clear picture of what to expect from the conducted research (www, experiment-resources, 2012; www, employee-communication, 2010).

With regard to the approach, qualitative research is subjective in a sense that the researcher, in trying to understand human behavior and the reason behind such behavior, is subjectively immersed in the issue under study. Quantitative research on the other hand, is objective in a sense that the researcher is objectively separated from the subject under study. This is to say that in quantitative research, what is required to answer the inquiry is only precise measurements and analysis (*ibid*).

In this thesis, both qualitative and quantitative research methods are used to generate input for real option model. Quantitative data for the proposed ELFM project of Koshe/Repi include revenue from emission reduction, operation and maintenance cost, waste to energy (WtE) potential and investment and operational cost. These data are obtained from "*Koshe/Repi landfill gas project*", a preliminary case study done by Addis Ababa city administration (2011), and "*Ethiopia solid waste and landfill [country profile and action plan]*", a report produced by community development research (2011). Furthermore, data for electricity price, risk free rate and risk adjusted discount rate are obtained from Ethiopian electric power corporation (EEPCo), the sole company responsible for the generation, transmission, distribution and sale of electricity in Ethiopia.

Qualitative data about the case are obtained from a personal visit to the site and from published materials which include articles and local stake holders' consultation papers. Moreover, websites of governmental and non-governmental organizations, who are in one way or another affiliated to the Koshe/Repi landfill site, are also assessed to acquire additional qualitative information.

4.3 Choice of Technology

Tolis *et al*. (2010) assert that the recent innovative technology for energy recovery from Municipal Solid Waste (MSW) may address the challenge of solid waste management and reduce impacts from energy production (the two key contributors of climate change and global warming). Therefore, the Waste to Energy (WtE) technology is chosen in this thesis due to the following two major factors:

1. To stress the potential of waste as alternative source of energy for the city of Addis Ababa. This will permit to hedge against decreases in the energy provision from hydropower plants which are challenged by several factors such as scarcity of finance, exceptional climate variability which induces uncertain water supply etc.
2. Since the technology embraces Sustainable Material Management (SMM), it reduces the waste stock and hence the greenhouse gas emission at Koshe/Repi landfill site.

It is emphasized that optimal decision in WtE technology includes not only selection of suitable technology but also optimization of investing time based on volatile financial condition, fuel and electricity price and CO2 allowances (Tolis *et al.*, 2010; Block and Strzepek, 2011).

4.4 Real Option Approach

This study adopts a real option approach to the analysis of the economic profitability of ELFM project for Koshe/Repi valorization. A firm's investment expenditure is irreversible (sunk cost) because of two major reasons. The first reason is the industry/firm specific nature of firm's capital. This means the firm's capital cannot be used profitably by another firm in the same or different industry. For example, most firms invest in specially tailored marketing or advertising investments which are designed to reach the most desired customers or target market. The second reason is government regulation or firm's arrangement. Example includes the capital control nature of the firm which limits investors to sell or reallocate their funds (Pindyck, 1991). Notwithstanding the importance of specific firm's arrangement, investment in Koshe/Repi ELFM project is mostly irreversible. This is because once a firm is engaged in the project; there is limited opportunity to recover the investment cost by reselling firm's asset (Mahiteme, 2005).

Irreversible investments are sensitive to different kinds of risks. Particularly, uncertainty over future product price, operating cost, interest rate, investments cost and timing are the major risks for irreversible investments. However, despite a risky nature, an irreversible investment also presents an opportunity for a firm. A firm wanting to undertake an irreversible investment holds a call option on financial asset. This in turn means a firm will have a right (not obligation) for some specified time period, to pay an exercise (strike) price in return for an asset (e.g. market securities, commodities). Since the future value of the underlying asset is volatile, the firm may exercise or kill the option to invest depending on the underlying asset value at maturity. The firm will exercise the option (invest) and have positive net payoff if the price of asset rise above the exercise (strike) price and will not invest (kill the option) if it falls below the exercise (strike) price.

In the no investment case, it will lose only what it spent to acquire the option. In the case of real option, the underlying asset is a real asset (e.g. projects) rather than financial asset (Brandao and Dyer, 2005; Pindyck, 1991).

Due to a possible profit potential of a project, a firm[12]may enters in an auction to construct a plant which generates electricity. Under this condition, it may hold both a call and put options depending on the contract agreed with the regulator. Assume the contract offered by the regulator allow the winning firm to wait for some time before starting to construct the plant and if the firm fails to start constructing the plant by the end of the given time, then the regulator cancel the contract and confiscated the project. Moreover, if the winning firm abandons the project after starting to generate electricity for any reason(s) before the time agreed on the contract, then the regulator forces the firm to pay a penalty for breaching the contract. Here, the firm has a call option, once got the concession, during the allowable waiting time. It will exercise the option (invest to construct the plant) if the value of option (revenue from selling of electricity) at the end of the option expiry date (end of allowable waiting time) is greater than the exercise price (investment cost to construct the plant). On the other hand, the firm holds a put option once it decided to invest and construct the electricity generating plant. In this case, the exercise price of the put option is the penalty cost for breaching the contract (abandonment) and the firm will only abandon the project if the future expected value of the project is lower than the penalty cost (Bastian-Pinto, Brandão, Gomes, Dalbem and Igrejas, 2012).

Traditional net present value (NPV) rule which assumes an expected cash flow ignores any project flexibility. This means once the management of the firm decided to commits to a project, future decisions taken then after will not affect project’s outcome.

[12]In this case it is assumed that a firm (an investor) perceives the flexibility in the contract for future energy generation, such as the option to defer project start date or even to permanently abandon a project as an opportunity to capture a higher expected return or minimize losses (Bastian-Pinto, Brandão, Gomes, Dalbem and Igrejas, 2012).

However, typical projects give management an opportunity to expand operation when market conditions become favorable or abandon a project when it is performing poorly. In addition management may have the opportunity to defer investments, temporarily suspend operations, switch inputs or outputs, adjust scale of operation or resume operation which allow management to affect the projects future cash flow in a way to improve returns and reduce losses (i.e. allow enhancing projects value) (Brandao and Dyer, 2005).

In the case of complete market (hypothetical), it is possible to find a portfolio of securities that replicate projects expected cash flow in up and down states of all future times. However in the case of incomplete market (real case), there will permanently be a difference between the cash flow of the project and replicating portfolio (projects in natural resources are exception to this). To sum up, the failure to take into account project flexibility and the assumption of fixed discount rate makes traditional NPV method inadequate for option valuation (Brandao and Dyer, 2005).

A firm's investment in ELFM is a sunk /irreversible cost. This is mainly because of the industry specific nature of the capital of the firm. The implication of this is the suitability of real option approach in valuation of investments in ELFM. In this thesis, in particular, the binomial method for valuing options is used. Binomial method is widely preferred amongst market professionals because of its ease of implementation and its versatility in applying to both simple and complex options (Pindyck, 1991).

4.5 Software

In this thesis Microsoft excel 2007 and @RISK 6 are used. With integrated features which enables users to easily store, organize and analyze numeric data, Microsoft excel simplifies most of the calculations done in this thesis. In particular, the cash flow analysis for the Koshe/Repi ELFM project and the scenario analysis for the determinant exogenous parameters are easily done by using this software. In addition @RISK 6, a software which is integrated in Microsoft excel and used to analyze risk and decision making under uncertainty, is used to identify the most important input(s) which will affect the output of the model. Besides, the drift of the future projection of electricity price is modeled using @RISK 6 in GBM.

5. The Empirical Results

5.1 Generic Investment Contract Setting

For a firm interested to invest in the ELFM project of Koshe/Repi, the contract offered by Addis Ababa city administration may demand the immediate commencement of the construction of the power generating plant in year 0. This means, the contract has no flexibility regarding the project start date. However, the contract still has flexibility in a sense that the firm could abandon the project at any time during the agreed project life time (9 years). Nevertheless, abandoning the project will cost the firm to pay a penalty (-$\boldsymbol{\rho}$) for breaching the contract.

The revenue from carbon credit should be divided between the firm and the municipality. This is mainly due to the fact that clean development mechanism (CDM) projects, including landfill mining, will not be commercially attractive had it not been for the revenue from emission reduction. Therefore, the contract is assumed to fix the share, α, of revenue from emission reduction to be paid to the firm. Hence, the share to the Addis Ababa city administration is (1-α).

A firm (an investor) in such a condition holds a put option on the future value of the project. It will continue its operation (generating and sale of electricity) as long as the expected future value of the project (t+1) discounted by the risk free rate is greater than the sum of the penalty cost for breaching the contract (-$\boldsymbol{\rho}$) and the revenue from salvage value. The sum of the penalty cost (-$\boldsymbol{\rho}$) and salvage value is the exercise price of the put option, while, the sum of the future revenue from emission reduction and electricity is the volatile market value of the project. In each year of the project life time, the firm either exercise or kill the put option depending on whether the future expected value is less than or greater than the exercise price respectively. The value of the penalty cost (-$\boldsymbol{\rho}$) at a particular year is assumed to be 1% of that year's revenue from emission reduction reimbursed to the firm. This means, the total revenue of the municipality will be increased by the amount of penalty ($\boldsymbol{\rho}$) for the year the firm abandon the project. Later in the analysis and discussion chapter, the effect of different value of $\boldsymbol{\rho}$ in a private firm optimal decision is studied.

5.2 The Present Value of the ELFM Project of Koshe/Repi

The initial step in a real option analysis is to assess whether there are options attached to the underlying asset, the ELFM project of Koshe/Repi. If there is no option attached to it, the valuation of the project is usually done by discounted cash flow (DCF) analysis. The ELFM project of Koshe/Repi is expected to generate 11,000 MWH of electricity per year (www, addisababacity, 2011). The average selling price of electricity in Ethiopia is 0.06 US $/KWH (Embassy of Japan, 2008). Therefore, yearly revenue from electricity selling is: 11,000,000 KW * 0.06 $/KW= 0.66 $ (in million). Yearly revenue from carbon dioxide (CO_2) emission reduction is collected from community development research (2011) and shown in table 1 below. See appendix A for Methane generation potential of Koshe/Repi landfill.

Table 1 Carbon credit for Koshe/Repi ELFM project

year	0	1	2	3	4	5	6	7	8	9
carbon credit in million $	2,379	2,1838	2,0252	1,8666	1,7202	1,5982	1,4762	1,3542	1,2444	1,098

(Community development research, 2011).

The yearly fixed cost of the project (operation and maintenance) is forecasted to be: 0.32 $ (in million). The investment required is forecasted to be 3$ (in million) for landfill closure and 0.76$ (in million) for gas extraction (www, addisababacity, 2011).

Table 2 below shows the cash flows forecast for the entire life time of the ELFM project of Koshe/Repi. The present value of revenue from electricity is calculated by discounting cash flows at a risk adjusted discount rate of 10% (EEPCo, 2007). Fixed cost and revenue from emission reduction are discounted at risk-free rate of 5% (www, grandmillenniumdam, 2011).

The break even value of α is calculated as follows:

$$PV(elec) + \alpha * PV(emission) - PV(fixed\ cost) - Investement\ cost = 0$$

$$3.801 + \alpha * 12.84 - 2.275 - 3.76 = 0$$

$$\alpha = \frac{2.234}{12.84} \approx 17.4\%$$

Therefore, a basic discounted cash flow (DCF) analysis would reveal that for any $\alpha > 17.4\%$, the Koshe/Repi landfill mining project is profitable. This is to mean that, for α value lower than 17.4%, a private firm will not invest, since the NPV of the project is negative. However, the optimal investment decision is likely to be changed if we take into account the abandonment option attached to the ELFM project of Koshe/Repi.

Table 2 Net present value (NPV) of the ELFM project of Koshe/Repi for α=16%

year	0	1	2	3	4	5	6	7	8	9
rev from electrcity		0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66	0,66
present value@10%	3,801	0,6	0,545455	0,4958678	0,450788881	0,40980807	0,3725528	0,33868	0,307895	0,2799
rev from emssion reduction		2,38	2,18	2,03	1,87	1,72	1,6	1,48	1,35	1,24
present value with 16% share to the private firm @ 5%	2,055	0,3627	0,316372	0,2805745	0,24615258	0,2156264	0,1910311	0,16829	0,146197	0,12789
fixed cost		0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32	0,32
present value at 5%	2,275	0,3048	0,290249	0,276428	0,263264792	0,25072837	0,2387889	0,22742	0,216589	0,20627
NPV	-0,179									

Nevertheless, an important question regarding which input(s) (rev from electricity, rev from emission reduction or fixed cost) highly affect the output (NPV) remains unanswered. This question is swiftly answered using sensitivity graphs developed by @RISK 6 software (see appendix G). As can be seen from the graphs (appendix G), revenue from electricity is the most important factor in altering the mean NPV, while, revenue from emission reduction is the least important factor in affecting mean NPV. The implication of this result is that, the project NPV is highly dependent on the amount of revenue from electricity and the value of fixed cost rather than the amount of revenue from emission reduction.

5.3 The General Binomial Method

In this section the model is run at α=16%. Moreover, the volatility of the future selling price of electricity is assumed to be 15%, where price follows Geometric Brownian Motion (GBM).

Later in the analysis and discussion chapter, the effect of different values of α and volatility on the project value is discussed. See appendix H for the drift of future electricity price projection.

Since a future stock price, selling price of electricity, can take limitless value, a binomial method gives a more realistic measure for option's value if one is working with a large number of sub periods. However, the most important question remains unanswered. How to calculate the ups and down change in stock value? Fortunately, there is a simple formula that relates the volatility of the stock returns to the up and down change of future stock price, as shown below:

1 + upside change = u = $e^{\delta\sqrt{h}}$

1 + downside change = d = $1/_{u}$

Where,

e = base for natural logarithm = 2,718,

$\boldsymbol{\delta}$ = the volatility of the stock return (continuously compounded),

h = interval (in fraction of year) (Brealey *et al.*, 2008).

Using the above formula for the up and down change, the value for u= $2.718^{0.15}$ =116% and the value for d = $\frac{1}{1.16}$=86%.

5.4 Calculating the Risk-Neutral Probabilities

The up (p) and down (1 – p) probability in the world where investors are assumed indifferent to risk can be easily calculated from the revenue binomial tree (figure 4) of the ELFM project of Koshe/Repi as follows:

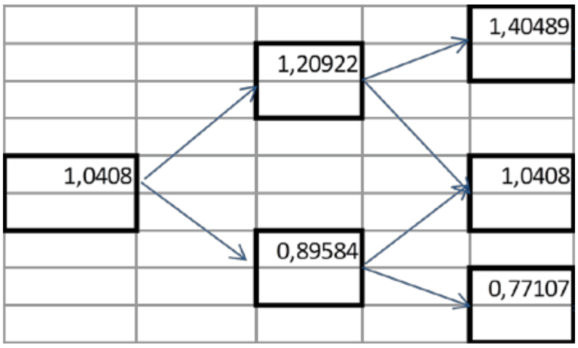

Figure 4 Sample revenue binomial tree for Koshe/Repi ELFM project.

$\frac{1.21p+0.89(1-p)}{0.95} - 1 = 0.05$, Which gives, p = 0.31 and 1– p = 0.69.

The cash flow of the ELFM project of Koshe/Repi is shown below (figure 5). The top number in the box is the cash flow and the lower number is end–of–period present value in millions dollar.

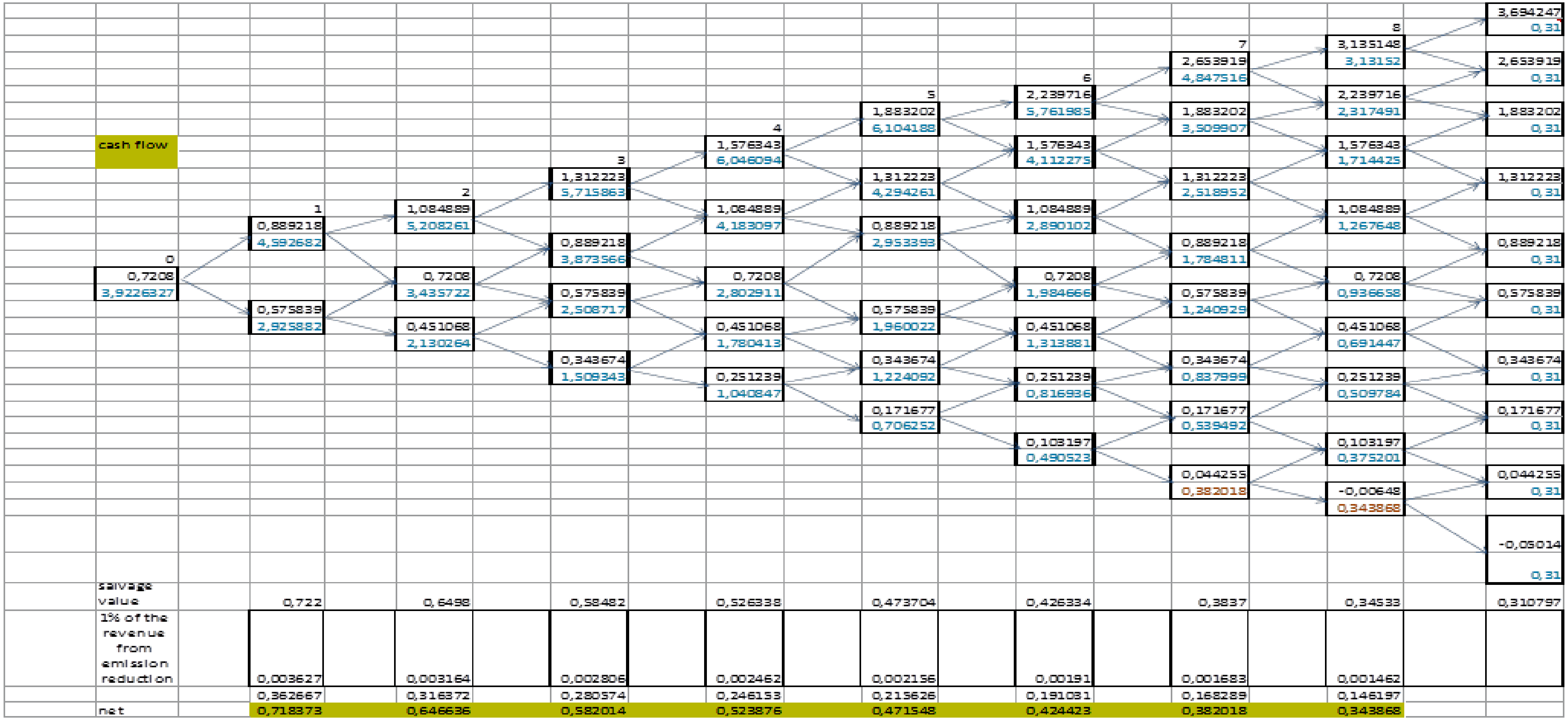

Figure 5 binomial tree for Koshe/Repi ELFM.

5.5 Koshe/Repi ELFM Project Value and Optimal Abandonment

Koshe/Repi ELFM project value in binomial tree is calculated by starting at the far right side of figure 5 (Year 9) and work backward to the present. A private firm involved in the ELFM project of Koshe/Repi will surely abandon in year 9, when the landfill is exhausted. Hence, we enter ending salvage value ($0.31 million), assuming 5% depreciation[13], as the end- of-year value in year 9.

Stepping back to year 8, assume that the private firm ends up in the best possible scenario, where the cash flow is $3.13 million, in that year. If the private firm does not abandon, then the upside payoff is 3.69 + 0.31 = $4 million and the down side payoff is 2.65 + 0.31 =$2.96 million. The present value by using the risk-free rate of 5% (www, grandmillenniumdam, 2011) is

$$PV= \frac{(4*0.31)+(2.96*0.69)}{1.05} = \$3.13 \text{ million.}$$

Now, the private firm has to either exercise the put option or kill it. Since the future expected project value ($3.13) is higher than the exercise price, sum of $-\boldsymbol{\rho}$ and salvage value ($0.34), the private firm will not exercise the put option. Hence, the PV of $3.13 million is entered as the end-of-year value at the lower end of the top node for year 8. The values in other nodes of year 8 can be filled by the same procedure. Nevertheless, at some point the private firm faces a situation where it is better to bail out than to continue. This occurs when the cash flow drops to –$0.006 million. This is the case because the present value of continuing is only:

$$PV=\frac{0.31*(0.04+0.31)+0.69*(-0.05+0.31)}{1.05} = \$0.27 \text{ million}$$

The payoff if the firm chooses to abandon is $0.34 million (the sum of penalty payment and salvage value). Hence this value is entered as end-of-year value for the node in year 8 having cash flow equal to –$0.006 million. Then, the same exercise is repeated for year 7, then year 6, then year 5, and so on until year 0, checking at each node of each year whether to abandon. Accordingly, the private firm should abandon the ELFM project of Koshe/Repi if the cash flow drops to $0.04 million in year 7, and to $–0.006 million in year 8.

[13] Later in the analysis and discussion chapter, the effect of different values of depreciation rate on a firm's abandonment choice is discussed.

By solving backward through the binomial tree, the present value of Koshe/Repi ELFM project is found to be \$3.92 million and the net present value (NPV) worth \$3.92 – 3.76 = \$0,16 million. If there were no abandonment option, the Koshe/Repi ELFM project discounted cash flow (DCF) valuation would be –\$0.18 million. Hence, the value of the option to abandon is \$0.16 + 0.18 = \$0.34 million.

The adjusted present value (APV), the present value which takes into account the abandonment option value, can be calculated by the formula:

APV = NPV with no abandonment + abandonment option value

= – 0.18 + 0.34 = **+\$0.16** million

6. Analysis and Discussion

In this chapter a sensitivity analysis of volatility ($\boldsymbol{\delta}$), share, α, of revenue from emission reduction to be paid to a private firm, penalty ($\boldsymbol{\rho}$) and salvage value is discussed. Moreover, the research questions will be explicitly answered.

6.1 Scenario Analysis

- **Impact of different values of $\boldsymbol{\delta}$ on a project value at a constant α=16% and $\boldsymbol{\rho}$=1%.**

Table 3 and the corresponding graph (figure 6) below shows the effect, on a project value, of an increase in the values of volatility. The last column in table 3 display the percent increase in APV with respect to APV value at $\boldsymbol{\delta}$=15%. It is trivial that an increase in volatility of the future electricity price means greater fluctuation of electricity price in either direction. Since the firm holds a put option on the ELFM project of Koshe/Repi, it has an advantage of continuing the operation, hence realizing the profit, if the electricity price goes up or abandons the project, hence minimize the loss, if electricity price goes down in each year of the project life time.

Table 3 Relationship between increase in volatility and APV

$\boldsymbol{\delta}$ in %	APV in million $	% increase in APV in million $
15	0,162632675	0
20	0,17502114	0,076175
25	0,196828826	0,210266
30	0,229105848	0,408732

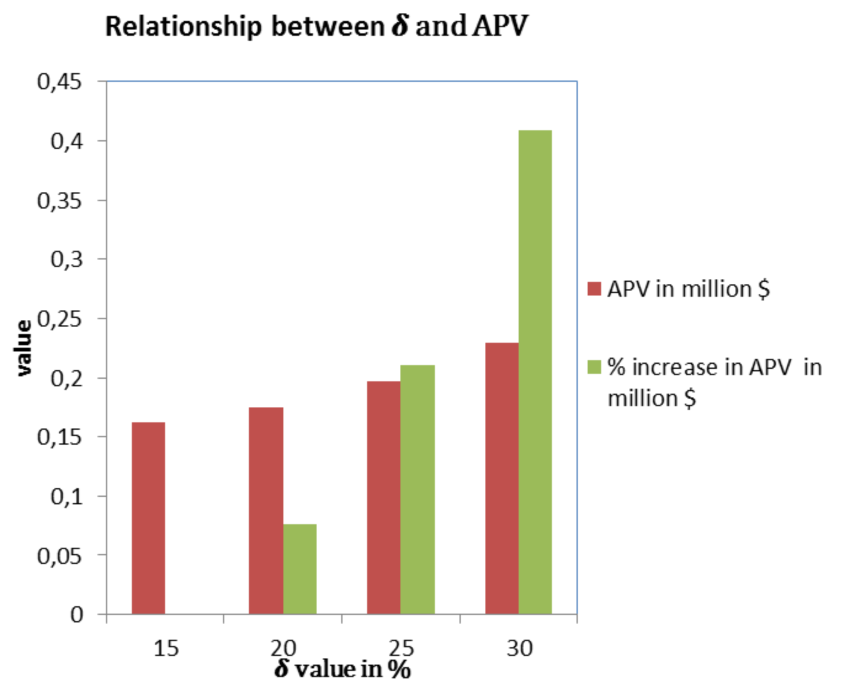

Figure 6 Relationship between volatility and APV.

- **Impact of different values of α on a project value at a constant $\boldsymbol{\delta}$=15% and $\boldsymbol{\rho}$=1%.**

Using the discounted cash flow (DCF) analysis, it is estimated that the percentage (or share), α, of total revenue from emission reduction to be paid to a private firm must be greater than 17.4% for Koshe/Repi ELFM project to be worth to invest. However, a private firm can accept share value as low as 15% (table 4 and the corresponding figure 7) due to the put option attached to the project. This act by the private firm will increase the total revenue of Addis Ababa city municipality by about 2.4% (17.4%–15%).

Table 4 NPV and APV values for Koshe/Repi ELFM project for $\boldsymbol{\delta}$=15% and $\boldsymbol{\rho}$=1%

α in %	NPV in million $	APV in million $
14	-0,4355971	-0,1099807
15	-0,3071721	0,026325989
16	-0,178747	0,162632675
17	-0,050322	0,298939362
18	0,078103	0,435246049
19	0,206528	0,571552736

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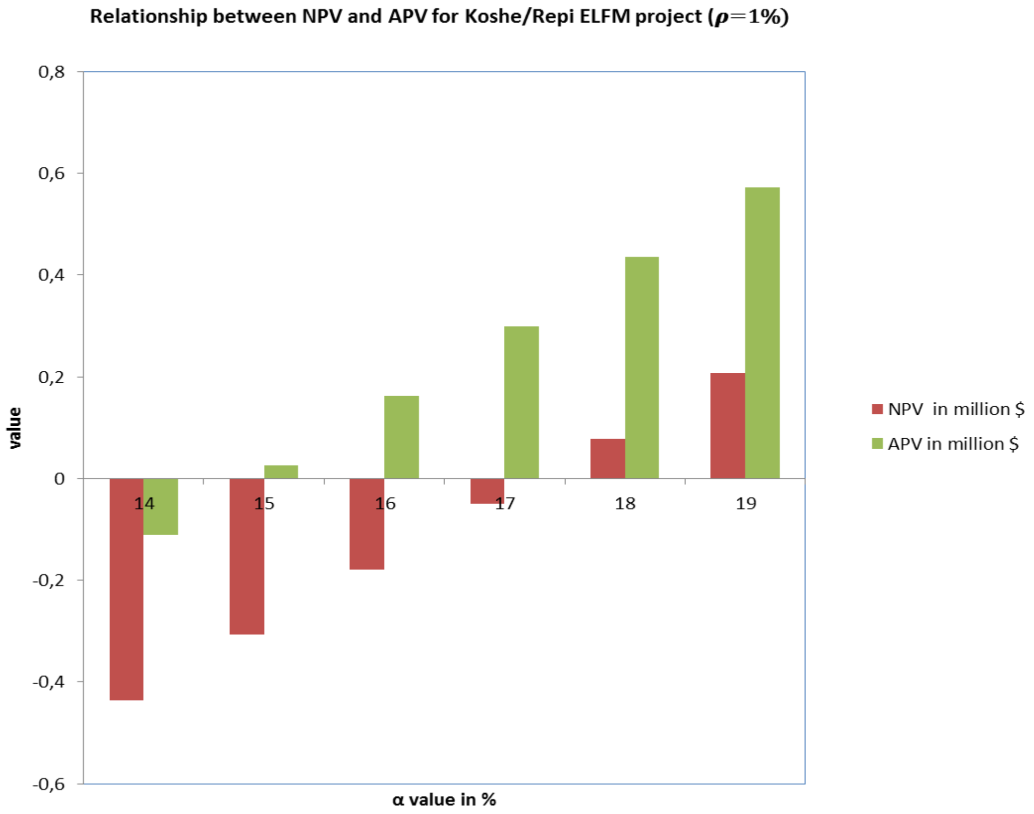

Figure 7 Relationship between NPV and APV for Koshe/Repi ELFM project.

Figure 7 reveals that though the NPV is negative, a small range of α values (15% to17% inclusive) will make private firm's investement, in the ELFM project of Koshe/Repi, profitable, under a real option approach.

- **Impact of different value of $\boldsymbol{\rho}$ and salvage value on abandoment choice at a constant α=16% and $\boldsymbol{\delta}$=15%.**

As can be seen from table 5 and the related graph (figure 8) Addis Ababa city administration has little control, by altering$\boldsymbol{\rho}$ value, over a private firm's abandoment choice at a fixed value of α =16% and $\boldsymbol{\delta}$=15%. Since the exercise price of the put option is the sum of (–$\boldsymbol{\rho}$) and salvage value, keeping salvage value constant, an increase in $\boldsymbol{\rho}$ has an impact of moving the exercise price to the left (lower value). It seems as if the line joininig the maximum value of the put and exercise price, in the put option position diagram, is slightly rotated inward by the hinge at the maximum value of put. Likewise, a very large increse in $\boldsymbol{\rho}$ (as large as 30%) is desirable to significantly shift the exercise price and hence somehow limit the firm not to abondon the project.

Morover, the corresponding decrease in option value is not significant as the penality (**ρ**) and salvage value are responsible for the private firm abandoment choice.

Table 5 Relationship between **ρ**, APV and no of abandonment nodes (constant α=16% and **δ**= 15%)

ρ	number of abandoment nodes	APV in million $
1%	2	3,922632675
2%	2	3,922545061
5%	2	3,922282219
10%	2	3,921844148
15%	2	3,921406077
30%	1	3,920204398

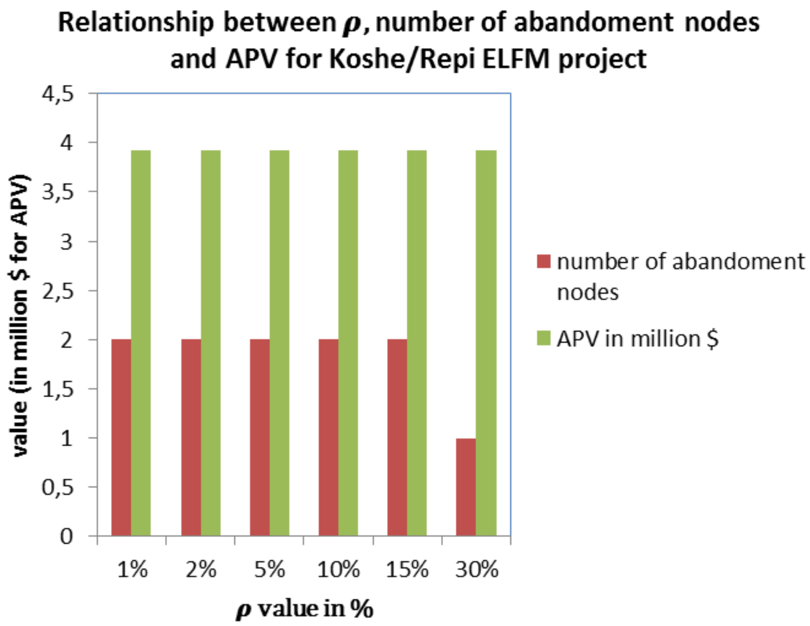

Figure 8 Relationship between **ρ**, number of abandoment nodes and APV

On the other hand, the amount of salvage value has insignificat impact on a private firm's optimal abandoment choice as can be seen in table 6 below. In fact, the probability that a private firm abandon the project (1-p=0.69) is independet of penality (**ρ**) and slavage value. This stressed the argument made that by changing penality(**ρ**) and salavage value the firms optimal abandoment choicewill not be affected.

Table 6 Relationship between salvage value and number of abandoment nodes (constant α=16% and $\boldsymbol{\delta}$= 15%)

depreciation rate in %	number of abandoment nodes
5	2
10	2
15	2
20	2

- **Explicit answers to the research questions**

Research question 1: What will be the optimal investment decision, in a situation of new entry, for a private firm interested to invest in the ELFM project of Koshe/Repi?

A private firm will invest in Koshe/Repi ELFM project for share value, α, between 15% and 17% included, even though the NPV is negative.

Research question 2: On a condition that a private firm decided to invest in the ELFM project of Koshe/Repi and start generating electricity, when will permanent abandonment (exit) be an optimal decision by paying a penalty for breaching the contract?

A private firm should abandon the ELFM project of Koshe/Repi if the cash flow drops to $0.04 million in year 7, and to $–0.006 million in year 8 (α=16%) .

Research question 3: Which exogenous parameters are responsible for private firms' decision to invest in the ELFM project of Koshe/Repi?

Volatilty of electricity price ($\boldsymbol{\delta}$), share, α, of emssion reduction paid to a private firm and investment and operation costs are highly responsible for private firms' decision to invest in ELFM project of Koshe/Repi. However, Penality ($\boldsymbol{\rho}$) and salvage value has little significance on firms' optimal abndoment choice.

7. Conclusion

In this thesis a private firm investment decision in the ELFM project of Kosh/Repi is studied. A real option approach is employed to estimate the project value, option value and optimal abandonment timing. Data are collected from the preliminary study by Addis Ababa city administration (2011), a report by community development research (2011) and from Ethiopian electric power corporation (EEPCo). According to the model, developed in this thesis, if the percentage (or share), α, of total revenue from emission reduction to be reimbursed to a private firm is less than 15%, then the proposed project is not profitable for private firms to invest in. On the other hand, if the share is raised to 16%, the project is profitable with adjusted preset value (APV) of **+$0.16** million. Hence, for a private firm to invest in the ELFM project of Koshe/Repi, the share should be large enough (α >=15%) to offset the probable negative cash flows from operation.

The ELFM project of Koshe/Repi emphasizes the need for Addis Ababa city administration to offer an attractive terms in the contract settings. This can be done by raising the share, α, value to the level where a private firm will be willing to invest in the project. This act in one hand will lower the municipality revenue from the project; while, on the other hand will benefit the municipality by making the project commercial attractive. Under a limited funding sources, for valorizing Koshe/Repi, the municipality obviously has to adjust the share, α, in such a way that it will attract private firms to the project (i.e. α >=15%).

The city municipality might raise the amount of penalty ($\boldsymbol{\rho}$) in an attempt to limit a firm's optimal abandonment choice. This act on one hand will lower the flexibility of the project and hence, will limit a private firm's interest to invest on the project. While, on the other hand it will compensate the municipality of the lost revenue from emission reduction if the firm abandons the project. For instance, should the firm abandons the project at time t, the municipality may set a penalty ($\boldsymbol{\rho}$) equivalent to the sum of the subsequent years (9-t) revenue from emission reduction. This is calculated by the formula $(1-\alpha)\sum_{t=t}^{9} \text{RE}\ (\text{t})$, where RE (t) is revenue from emission reduction at time t.

Nevertheless, the amount of penalty cost (-$\boldsymbol{\rho}$) and salvage value have insignificant impact on the firm's optimal abandonment choice. This in turn means that, once Addis Ababa city municipality has able to attract a private firm to the project, there is less probability that the firm will abandon the project sometime during the project life time.

Finally, this study call for further investigation focusing on the estimation of determinant exogenous parameters such as annual volatility, carbon credit, investment and operation costs, salvage value and penalty cost.

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Appendix A Methane Generation Potential of Koshe/Repi Landfill

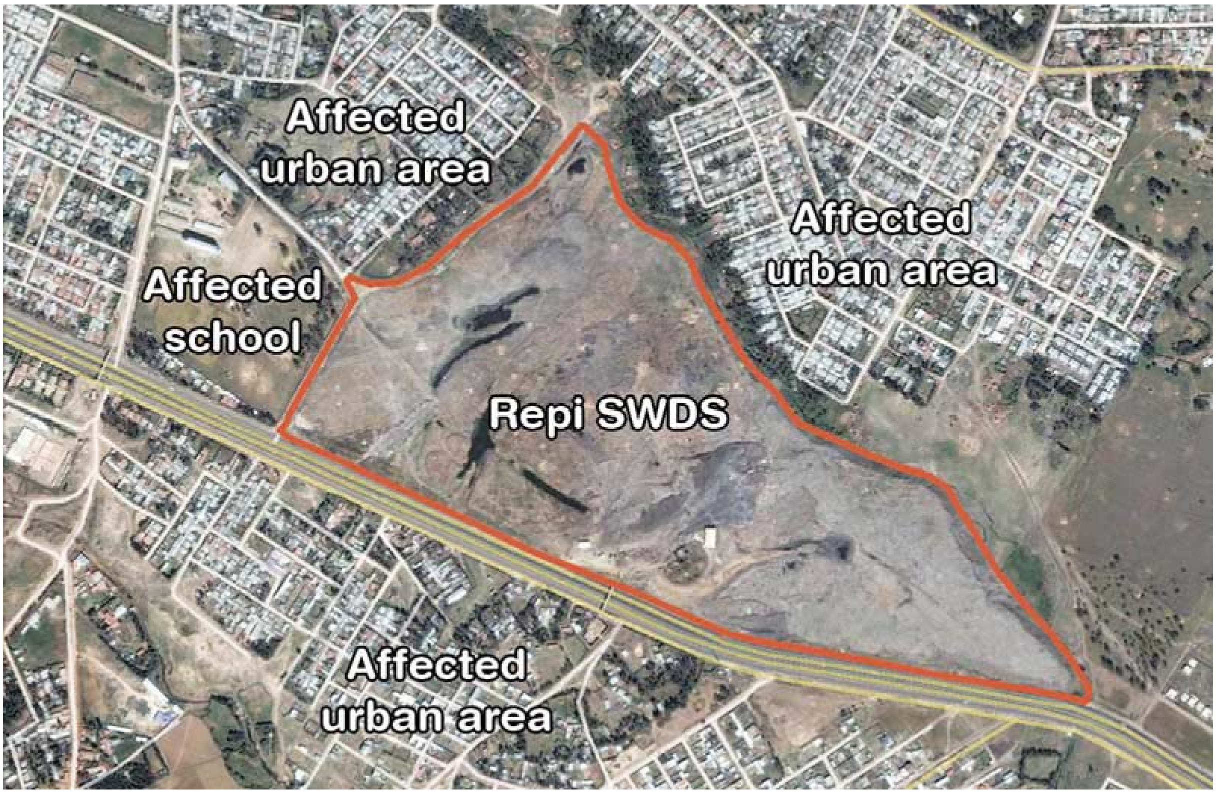
Year	Time(year)	[14]LFG(m3)	LFG(m3), 50% to be harvested	Methane destroyed(t)	[15]ER tCO2e	Carbon credit(EURO)
2012	1	41230125	20615063	9276.778	194812.34	1948123
2013	2	38060202	19030101	8563.546	179834.46	1798345
2014	3	35133995	17566998	7905.149	166008.13	1660081
2015	4	32432765	16216383	7297.372	153244.82	1532448
2016	5	29939216	14969608	6736.324	141462.79	1414628
2017	6	27637379	13818690	6218.41	130586.62	1305866
2018	7	25512517	12756258	5740.316	120546.64	1205466
2019	8	23551021	11775511	5298.98	111278.57	1112786
2020	9	21740333	10870166	4891.575	102723.07	1027231

Community Development Research (2011).

[14]Landfill gas in meter cube
[15] Emission reduction in tone of carbon dioxide

Appendix B Current Condition Of Koshe/Repi

"*Area around the Repi Landfill has become populated since its construction in 1968, leading to inhabitants being affected by the pollution*" (www, nelsonelson, 2012).



Repi SWDS-Repi sold waste disposal site.

Nels, 2012. Repi landfill. [Online] available at:

http://www.nelsonelson.com/wiki/index.php?title=Repi_Landfill

[Accessed September 1, 2012].

Appendix C Horizontal well in Koshe/Repi landfill site

Nels, 2012. Repi landfill. [Online] available at:

http://www.nelsonelson.com/wiki/index.php?title=Repi_Landfill

[Accessed September 1, 2012].

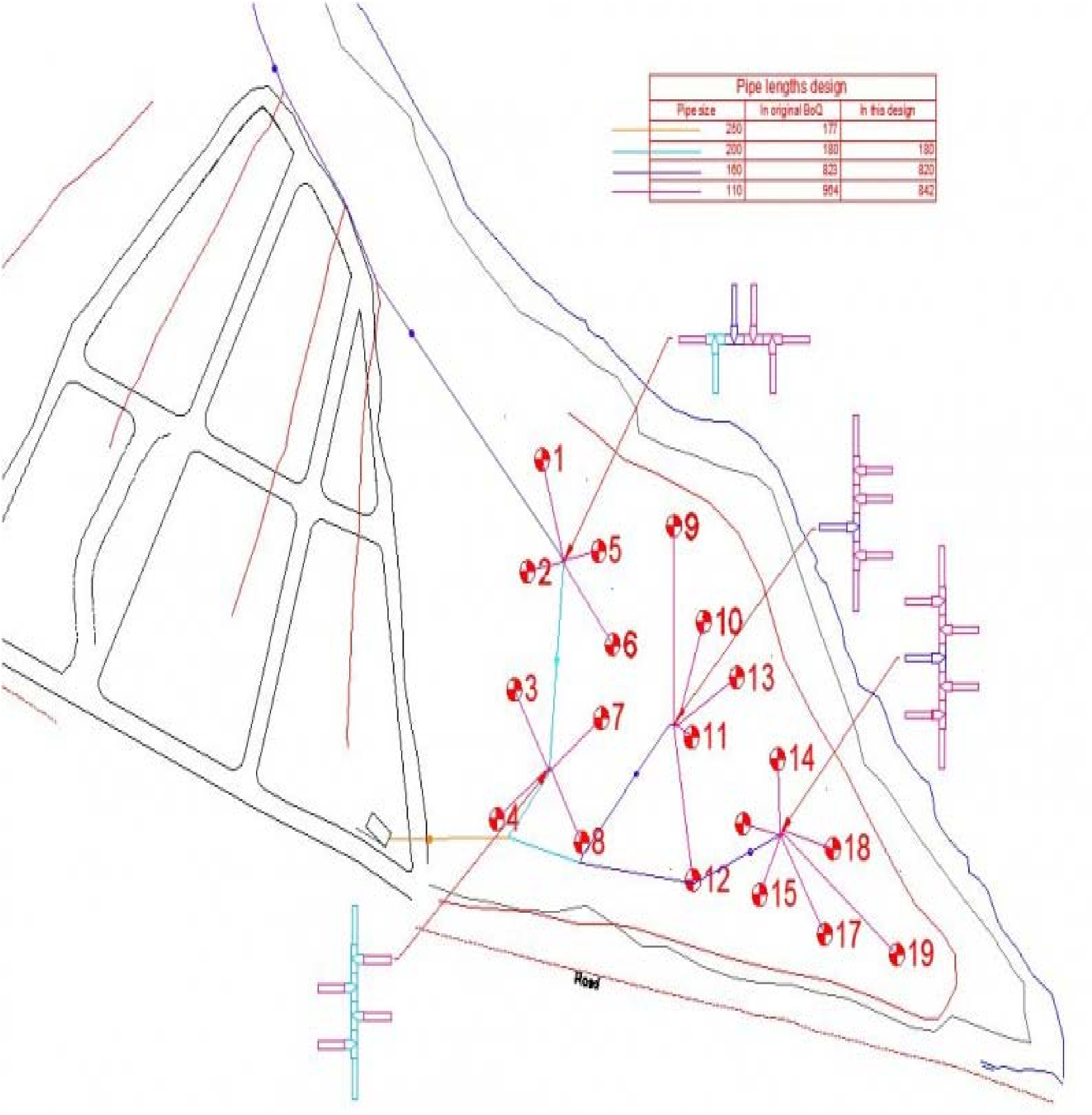
Appendix D Sample gas extraction well (vertical)

Nels, 2012. Repi landfill. [Online] available at:

http://www.nelsonelson.com/wiki/index.php?title=Repi_Landfill

[Accessed September 1, 2012].

Appendix E Koshe/Repi gas collection network



Nels, 2012. Repi landfill. [Online] available at:

http://www.nelsonelson.com/wiki/index.php?title=Repi_Landfill

[Accessed September 1, 2012].

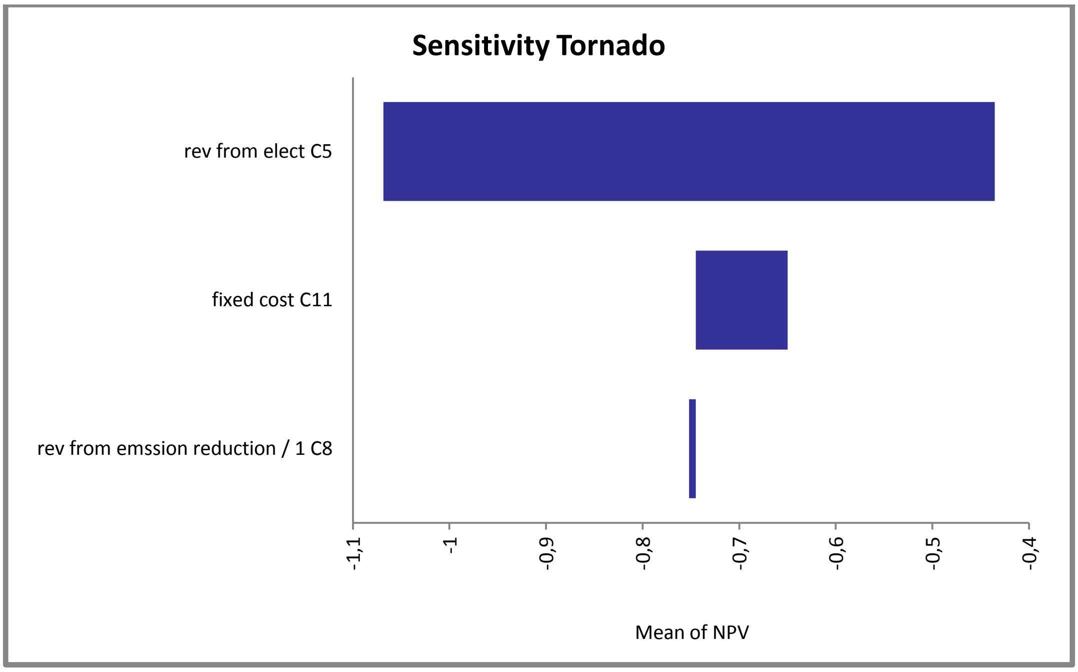
Appendix F Sample gas extraction well #3

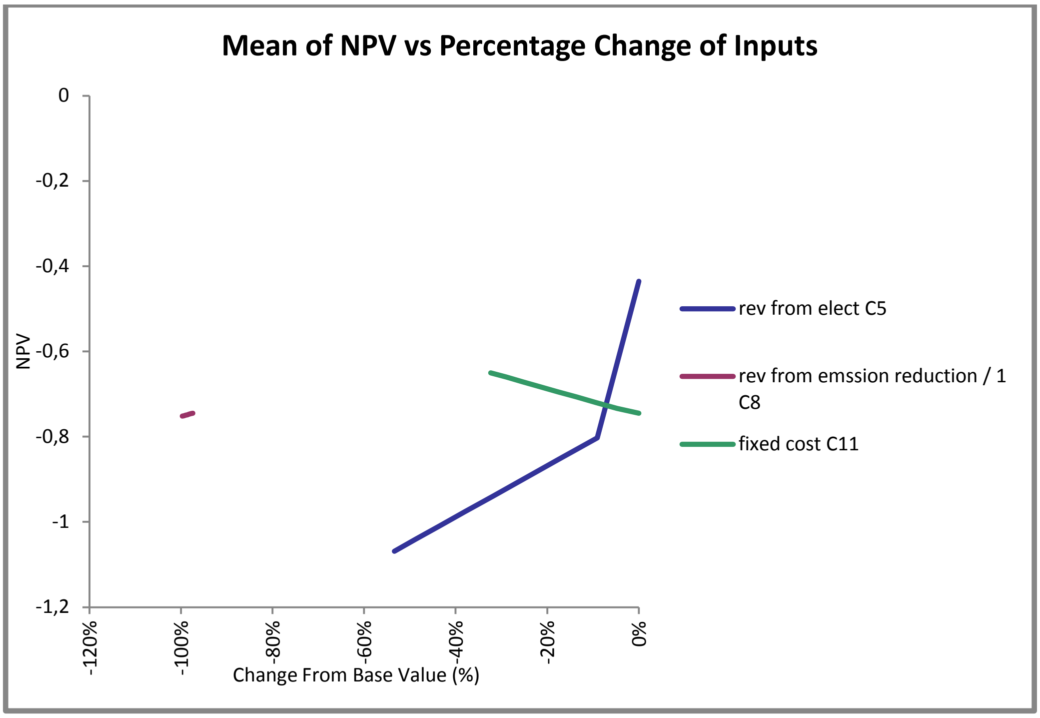
Nels, 2012. Repi landfill. [Online] available at:

http://www.nelsonelson.com/wiki/index.php?title=Repi_Landfill

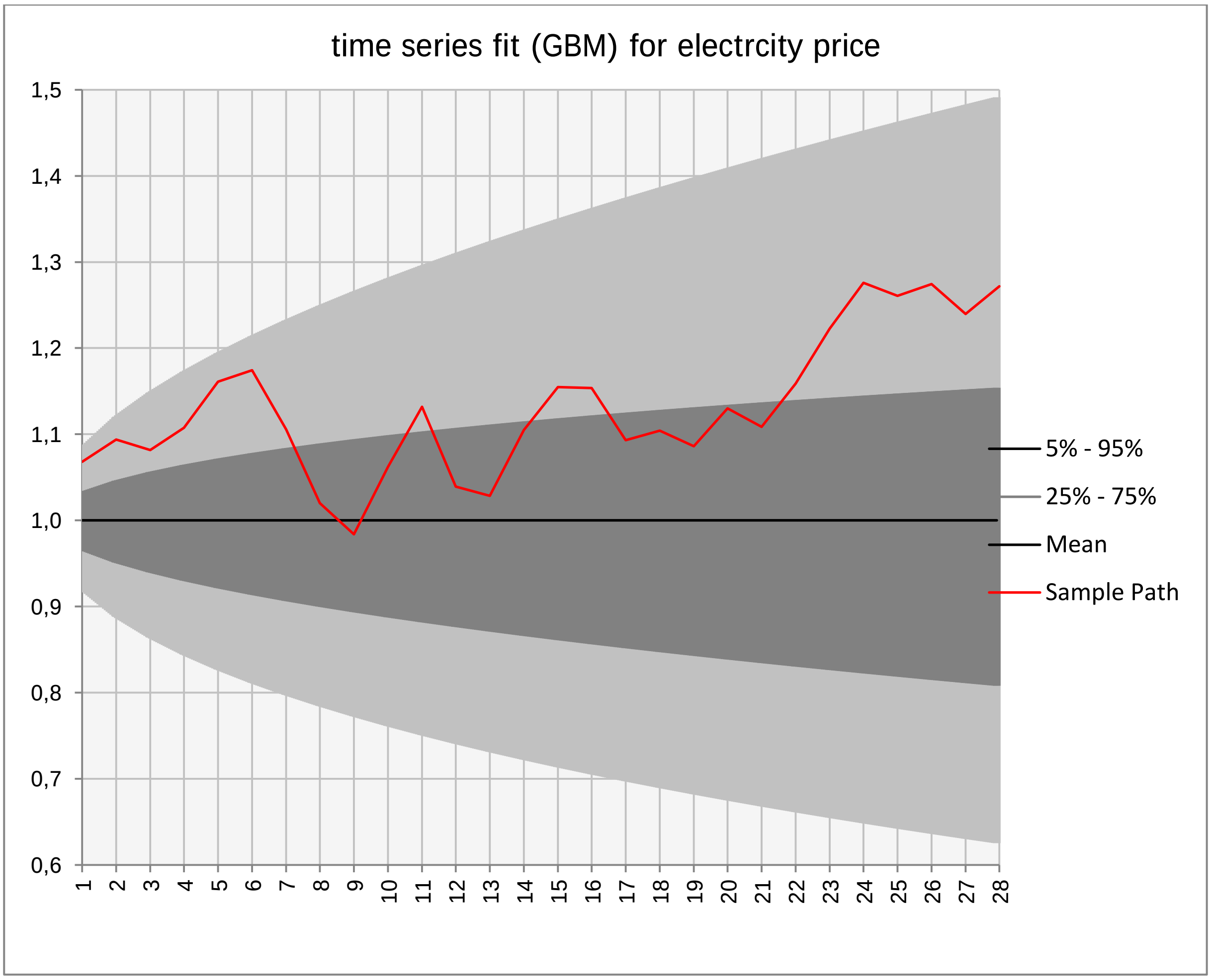
[Accessed September 1, 2012].

Appendix G Sensitivity graphs





Appendix H Time series fit (GBM) for electricity price



Vertical axis: electricity price (in Ethiopian Birr) per KWH (kilo watt hour)

Horizontal axis: time (in year)

NB: Most of the time, electricity price varies from the mean by a small amount (darker region). It is only rarely that electricity price varies in significant amount from the mean (light region).