Risky Business: A Real Options Valuation for Biopower Investments in sub-Saharan Africa

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Abstract

Adequate electricity supply in many African countries remains unaffordable, inaccessible and unreliable and this paper therefore seeks to assess the value of public-private partnerships in closing this gap. The standard binomial lattice model is extended to include the risk of government failure, as a key determinant of project value and partnership success in developing countries and ultimately guides the investment decision and timing by prospective investors. The results suggest that projects which would ordinarily be executed using traditional valuation methods and the standard binomial model, are significantly affected by the inclusion of government risk as a constant factor of uncertainty and consequently heightens the risk of investing in developing countries. The objective is to highlight imperatives for potential investors, in relation to costs, benefits, and inherent uncertainties surrounding biopower and related renewable energy investments, for enhanced energy access, economic and sustainable development of the region.

Keywords

Real Options Valuation; Biopower; Africa; Waste; Energy

1. Introduction

An estimated 80% of African households continue to rely on traditional biomass as a key energy resource, with attributable energy use currently estimated at 50%(Maishanu, Sambo and Garba, 2019)(van Zyl-Bulitta et al., 2019). The efficient use of waste generated in municipalities is therefore in focus, as Africa is experiencing unprecedented population growth, with predictions of 1.3 billion additions by 2050. This translates to an extra 3.5 million people a month, or 80 more people every minute(UN Environment, 2015) and makes Africa the single largest contributor to future global population estimates.

An expanding middle class and related increase in per capita consumption, urbanisation rates and population growth becomes especially troubling when considered in light of inadequate infrastructure to handle the associated increase in solid waste. The cost of providing sound waste management services appears burdensome and poses a challenge to authorities with limited resources and competing priorities. This cues the imperative for strategic partnerships in waste valorisation schemes and especially decentralised waste to energy(WtE) projects.

Decentralised energy systems have gained traction due to existing centralised models in most developing countries being subpar, difficult to finance and entailing costly operation and maintenance routines with rapidly deteriorating equipment. Distributed grids on the other hand, are largely dependent on public-private partnerships(UNEP (2018). Africa Waste Management Outlook. and United Nations Environment Programme, Nairobi, 2018) due to modern technology employed and are governed by the elements of cost, performance efficiency in terms of energy production or recovery and community acceptance due to perceived economic and environmental impact.

An additional consideration of equal importance is the risk element in energy system selection, investment and deployment. A valid distinction between uncertainty and risk is expressed by Mun(Mun, 2006), who asserts that uncertainty varies from risk, as it is resolved through the passage of time, events, and action. Risk however, is usually the outcome of uncertainty and will often remain constant over time. Uncertainty may also increase as time passes and is often confused or used interchangeably with risk. The objective of this paper therefore is to test the element of government failure risk, as a factor that ultimately influences investment decisions. Government failure is defined based on substantive knowledge to include elements of expropriation disputes and attempts, ethnic and political instabilities, policy overturns, insurgency and usurpation of authority and an overall lack or absence of cooperation from the authorities. This risk is deemed constant and empirically modelled in a binomial lattice to ultimately determine the value of investment partnerships with government and adequate system selection in bridging energy access deficits prevalent across the region.

2. Literature Review and Justification

The real options framework remains a dominant assessment tool in investment appraisal, due to its value-add to capital decisions affecting the bottom line and the provision of strategic business options for projects riddled with uncertainty and characteristic to developing countries. It also gives the investor the right, but not the obligation to invest in and pursue value-adding technology and strategy; and equally assumes that the investor is both logical and competent and seeks to maximise wealth and minimise the risk of losses.

The traditional discounted cash flow (DCF) valuation method falters in the presence of uncertainty, due to its deterministic approach which potentially and grossly underestimates the intrinsic value of a project. The application of the real options analysis (ROA) is based on the existence of a financial model-usually derived from the DCF method. It also requires the presence of uncertainties which affect active project decisions and the outcome of the financial model(Mun, 2006). The ROA aids in understanding a project's true strategic value, where traditional valuation methods make certain projects appear ill-advised due to high implementation costs and no apparent payback timeline for the future(C., 2006). In addition, the ROA provides a justification for the project's existence and execution and is therefore a valuable extension of the traditional DCF method.

Burke(Burke, 2012) states the characteristics required in an investment scenario for the ROA to be beneficial. First, uncertainty in the future must exist and therefore impacts the outcome of the investment decision. A degree of irreversibility must also apply, such that part of the initial investment will be lost should the investor reconsider the investment or project. Lastly, where the timing of the investment is flexible, the investor has the option to wait as more information becomes available, before making the investment.

ROA has been applied and assessed in diverse contexts across literature. It has been used in assessing the characteristics of renewable energy(RE) investments and its diverse applications (Liu, Zhang and Zhao, 2019), including the development of a policy benefit model to analyse China's biomass power production investments(Wang, Cai and Dai, 2014). Kumbaroğlu et al.(Kumbaroğlu, Madlener and Demirel, 2008) developed a policy planning model using ROA, to determine the impact of uncertainty and technical change on the diffusion of emerging RE technologies; while Locatelli(Locatelli, Mancini and Lotti, 2020) applied a systematic simulation of scenarios based on defined thresholds and investment parameters, to assess investment appraisal methods based on real options,. Agaton(Agaton et al., 2020) developed an investment model to analyse the economic feasibility of waste-to-energy(WtE) projects in developing countries using ROA and suggests that based on energy production and investment costs, incineration or direct combustion is the best technology option for WtE projects, followed by gasification and pyrolysis.

Kim et al(Kim, Park and Kim, 2017) applied the ROA to a case study hydropower project using a compound options model. The authors assessed RE projects using estimates for uncertainties that affect project profits and economic feasibility. The ROA was conducted with the objective of yielding an option value to determine project feasibility. The emphasis was on high volatility and the associated risk of investing in developing countries.

This paper extends Kim's work to the sub-Saharan African(SSA) RE and WtE scene, using a simple options model to build or defer the projects in question. The stochastic variables defined in past literature are duly acknowledged, however, a definitive constant in the global south is the investment and business risk often determined by the political stability or otherwise of the target region. This has previously been defined in the context of government failure risk, and the authors suggest that it is the key determinant of strategic optionality and overall project feasibility.

3. Materials, Methods and Assumptions

3.1 Research Questions

What is the justification, cost and benefits of investing in a decentralised biopower plant, considering the risk of government failure and other investor cost considerations? How does this impact the overall decision to invest, abandon or continue in partnership with government?

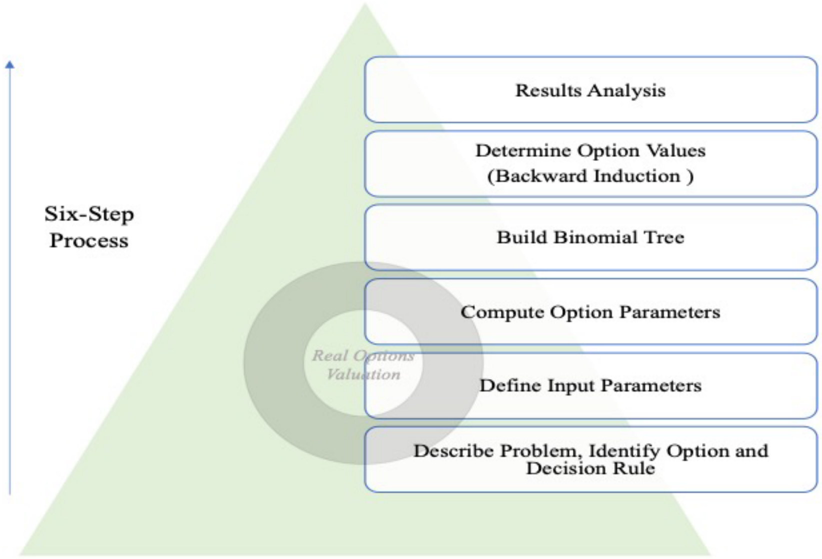
3.2 Theoretical Assumptions and Project Scenario

The literature guides the selection of two irreversible options for investment based on direct combustion and downdraft gasifier technologies in the project scenarios. A decision is considered irreversible once the investment has been made(Balietti, Chesney and Vargas, 2018). The downdraft gasifier is also considered the most suitable option for decentralised heat and power generation, because the syngas obtained from it contains minimal amounts of tar and particulates(Akhator, Obanor and Sadjere, 2019). In this scenario, the agreement to invest in partnership with government (PPP) is considered irreversible, and abandoning the project will bear a related cost element.
The ROA is used to determine not only project feasibility, but the optimal investment timeline. It provides flexibility to postpone an investment until part of the underlying uncertainty is resolved and offers estimates related to the optimal investment time. The investment decisions are regarded as independent and exclusive(C., 2006) and government risk is deemed to occur at any time within the projected 5-year horizon.

The project scenarios are based on a company X faced with decisions to build either a US$100million WtE plant based on direct combustion technology(C) or a down draft gasification(G) plant costing US$200million (due to emission concerns leveraged against the popular combustion process). The uncertainty surrounding the investment and project success, leads company X into a public-private partnership(PPP) agreement with the government; and subsequently hedges the risk of losing its entire investment by providing an initial US$10million (for project C) and US$20million (for project G), to cover due diligence, licensing and commitment fees to the government. In exchange, the government provides pioneer status and subsidies for tax obligations, premium land allocation for siting the plant and other support schemes, which would secure a profitable return on investment.

Kodukala and Papudesu(C., 2006) propose a six-step process for determining real options, using the Binomial Lattice method. This is illustrated in Figure.1 below.

Figure. 1 Six-Step Process for Real Options Valuation



A DCF analysis on projected cash flows for both projects is carried out and the Net Present Values (NPVs) of the future cash flows are subsequently determined. An important point here, is that the traditional DCF approach assumes single decision pathways with fixed outcomes and can therefore be deemed a distinct case of ROA, where uncertainty and volatility equal zero(C., 2006).

3.3 Decision Tree Analysis(DTA)

A Decision Tree Analysis (DTA) is also integrated in the project scenario, as decision trees are considered effective tools in the valuation of projects that involve contingent decisions(C., 2006). Decision trees are strategic road maps, depicting alternative decisions, related costs and possible outcomes, including the probability and payoff of outcomes(C., 2006). The probabilities used in the DTA are subjective and imperative to the valuation process. The The existence of private and market risks to the investor justifies the DTA in this scenario, as it is able to factor in private uncertainty in addition to the ROA; thereby providing a unitary framework for valuation of projects that exhibit elements of private and market risks simultaneously(C., 2006).

The DTA in the project scenario is used to determine a build or no build decision for the plants, as a precursor to the ROA. This step may be applied in an investment decision making process, to determine the initial feasibility of the project within defined parameters. It may also be integrated subsequent to the ROA, to illustrate the decision pathways and subsequent course of action, derived from the option values.

3.4 Binomial Lattice and Volatility Factor

The “cone of uncertainty” is explained through the idea of increasing levels of uncertainty over time, even though the risk remains unchanged. The binomial lattice approximates the “simulation of stochastic processes” and the width of the lattice expands, as uncertainty increases(Mun, 2006). Therefore, higher uncertainty levels will result in higher option values and higher time steps or increments used in the binomial model, will increase the chances of deriving more accurate option values(Mun, 2006)(C., 2006).
Heteroskedasticity, which refers to the volatility factor, is also assumed to change over time. Volatility represents the inherent uncertainty associated with the cash flows comprising the underlying asset value. The Logarithmic Cash Flow Returns Method (Table 1) is applied to derive the volatility factor (σ) in the options model. This represents the volatility of the rates of return, which is measured as the standard deviation of the natural logarithm of cash flow returns(C., 2006).
The volatility factor is the square root of (total of squares of deviation/n – 1), where n is the number of values. The return(R_t) is derived using equation 1:

$$R_t = S_t / S_t - 1 \qquad (1)$$

The binomial model is illustrated by the binomial tree (Figures 4-5), with So being the initial or underlying asset value. In the first time step (year 1), the value either goes up or down, and this pattern continues for subsequent time steps, up to the terminal time step (year 5). The up and down movements are represented by the factors u and d, where u is >1 and d is <1 (C., 2006) and it is assumed that:

$$d = 1/u \qquad (2)$$

These factors will be impacted by the volatility of the underlying asset. The first time step of the binomial tree has two nodes, showing the possible asset values ($S_o u$, $S_o d$)(Figures.4 -5) as the time period ends. The terminal nodes at the end of the binomial tree represent the range of possible asset values at the end of the option life (year 5).

Risk-neutral probabilities are also applied within the binomial model by adjusting the cash flows and discounting at the specified risk-free rate. The risk free rate is derived using the difference in the current rates of inflation and government bond yield. The binomial lattice representing the underlying asset value is subsequently modelled below (Equation. 5). It is from this model, that the option values are subsequently derived.

The up and down factors, u and d, are functions of the volatility of the investment or underlying asset and are expressed below:

$$d = 1/u \qquad (2)$$

$$u = \exp(\sigma\sqrt{\delta t}) \qquad (3)$$

The risk-neutral probability is derived as follows:

$$q = (e^{rt} - d)/\ u - d \qquad (4)$$

and the option values are derived using the backward induction method, to build the binomial tree accordingly:

$$C = e^{-rt}\ [qCu + (1 - q)Cd] \qquad (5)$$

r represents the risk-free interest rate and Cu and Cd are the option values associated with up and down movements along the lattice structure;

$$C = e^{-rt}\ [qCu + (1-q)Cd] * (1-Pf) - Pf * CPf \qquad (6)$$

represents the extension to the standard binomial model, by incorporating the element of government failure risk; where Pf is the probability of failure risk and CPf is the associated cost of failure, which relates to the initial investment made to facilitate the PPP agreement (i.e. US$10million(C) and US$20million(G)).

3.5 Limitations

The challenges with cohesive data and accurate information related to project parameters, are the key considerations in the use of experimental or theoretical investment scenarios and the benchmark assumptions have been loosely based around active WtE projects across the sub-Saharan African region.

4. Results and Analysis

4.1 Decision Tree

The project NPV is calculated using the expected value (EV) method (Tables 1 and 2). The EV is simply the product of the probability of the event occurring and the outcome, which is expressed in terms of cash flow value(C., 2006). The project's expected NPV is calculated based on this payoff, by incorporating contingent decisions at various decision nodes in the future. This is where DTA adds value, because the DCF method assumes a fixed path and does not account for the investor's contingent decisions.

The premise of the DTA here is based on the project scenario, where the investor assesses the respective projects on a preliminary basis. The outcome of the DTA based on the probabilities defined, show that the PPP route is the most viable option for the investment, even with a 35% chance of success(Figures. 2-3). The pay-offs are derived as follows: if the project fails, then the loss is equal to the initial amount invested, being the US$10million or US$20million for each project. If the project breaks-even, the total investment sum of US$100million or US$200 million is recouped. Where the projects are expected to yield a profit, the pay-off based on the estimated probabilities would be US$250million or US$300million for projects C and G. The expected NPVs are therefore positive for the PPP nodes and the project is expected to proceed successfully to yield NPVs of US$53million and US$6million respectively. However, a definitive investment decision would be premature based on this outcome, as both projects yield positive NPVs. In order to make a distinction between the exact time to invest and the project to execute, abandon or defer based on available funds and projected success, further analysis is required.

Figure 2. Combustion Project (DTA)

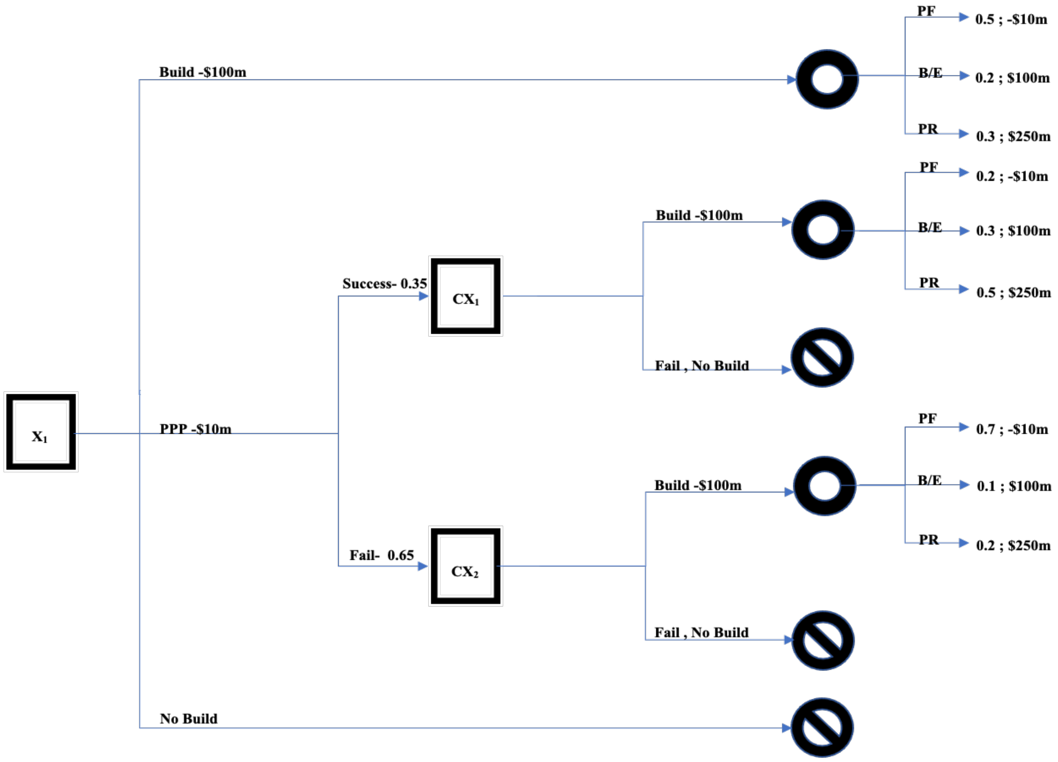


Table 1. Combustion Project (DTA) Expected NPV

DECISION POINT	ALTERNATIVES	EXPECTED NPV CALCULATIONS	EXPECTED NPV ($m)	DECISION
CX1	**BUILD**	0.2 *(-10) + 0.3 * 100 + 0.5 * 250 - 100	**53**	**BUILD**
	NO BUILD	0	**0**	
CX2	**BUILD**	0.7*(-10) + 0.1 * 100 + 0.2 * 250 - 100	**-47**	**NO BUILD**
	NO BUILD	0	**0**	
X1	**BUILD**	0.5*(-10) + 0.2 * 100 + 0.3 * 250 - 100	**-10**	
	PPP	0.35 *53 + 0.65 *0 - 10	**8.55**	**PPP**
	NO BUILD	0	**0**	

Figure 3. Gasification Project (DTA)

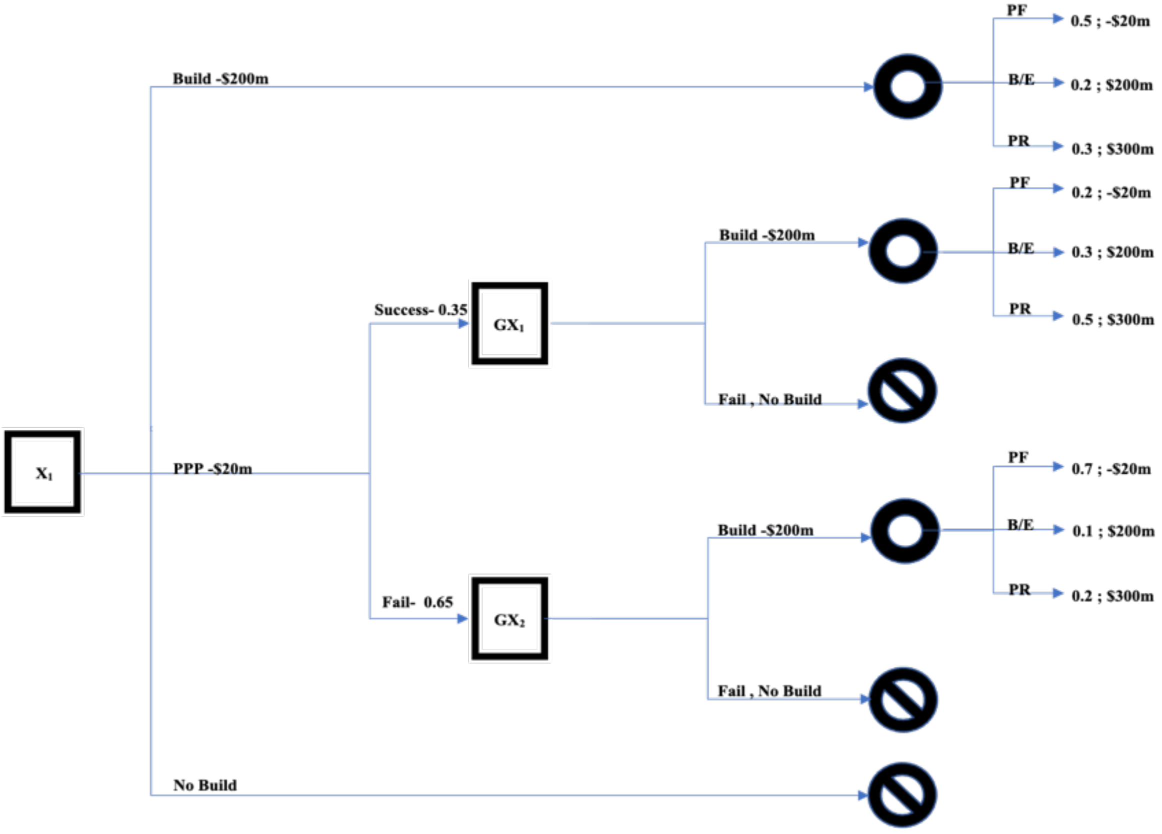
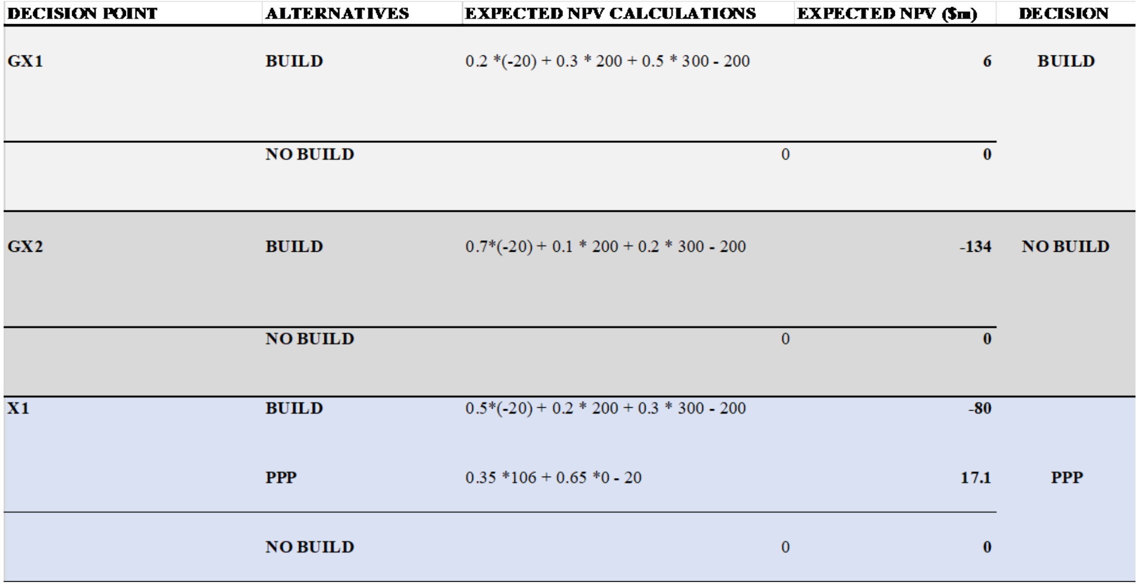


Table 2. Gasification Project (DTA) Expected NPV

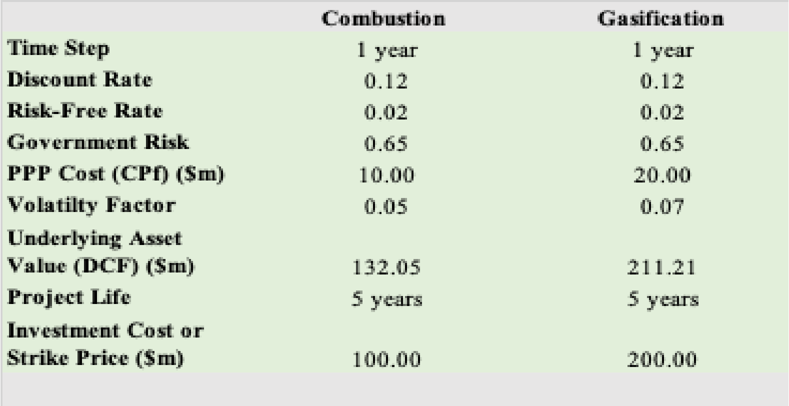


DECISION POINT	ALTERNATIVES	EXPECTED NPV CALCULATIONS	EXPECTED NPV ($m)	DECISION
GX1	BUILD	0.2 *(-20) + 0.3 * 200 + 0.5 * 300 - 200	6	BUILD
	NO BUILD	0	0	
GX2	BUILD	0.7*(-20) + 0.1 * 200 + 0.2 * 300 - 200	-134	NO BUILD
	NO BUILD	0	0	
X1	BUILD	0.5*(-20) + 0.2 * 200 + 0.3 * 300 - 200	-80	
	PPP	0.35 *106 + 0.65 *0 - 20	17.1	PPP
	NO BUILD	0	0	

4.2 Binomial Lattice Model

The projects were evaluated using the six-step process illustrated in Figure.1 and the input parameters to determine the build or wait option are listed in Table 3 below.

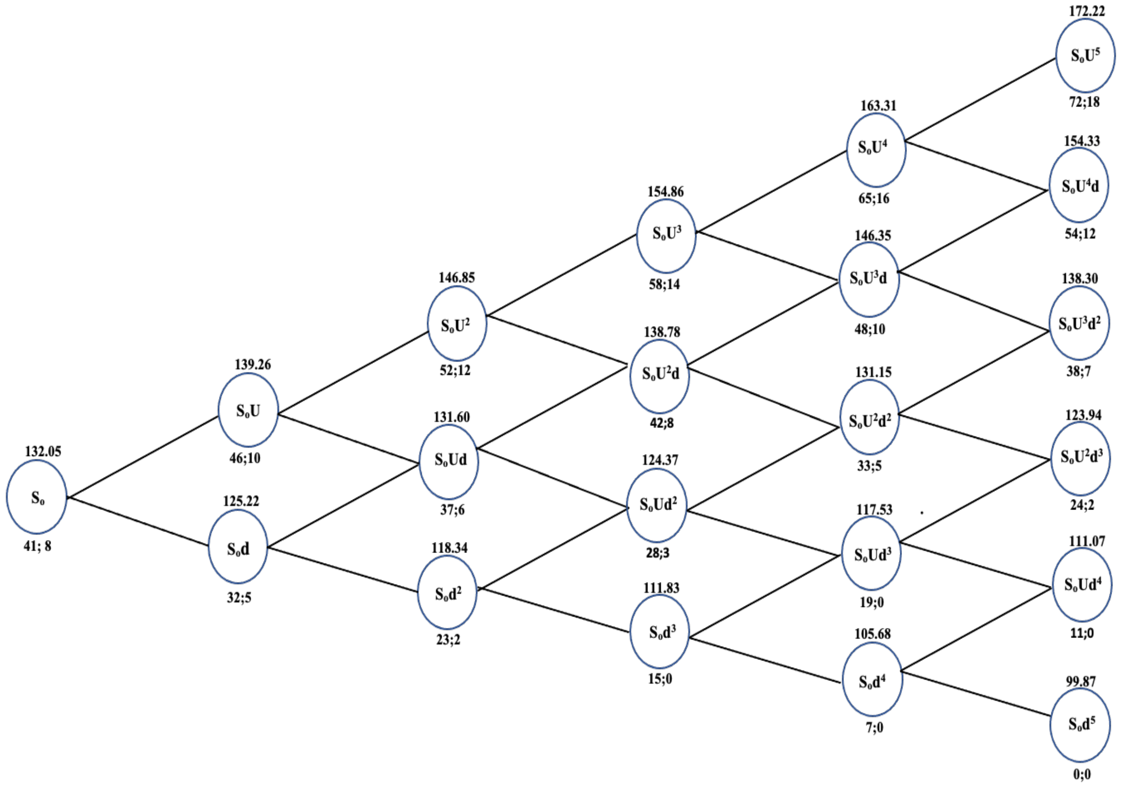
Table 3. Input Parameters



	Combustion	Gasification
Time Step	1 year	1 year
Discount Rate	0.12	0.12
Risk-Free Rate	0.02	0.02
Government Risk	0.65	0.65
PPP Cost (CPf) ($m)	10.00	20.00
Volatilty Factor	0.05	0.07
Underlying Asset Value (DCF) ($m)	132.05	211.21
Project Life	5 years	5 years
Investment Cost or Strike Price ($m)	100.00	200.00

The option parameters are mediates to the final option value calculations and are derived from the input parameters. The up movement (u), down movement (d), and risk-neutral probabilities (q) were estimated at 1.055, 0.948 and 0.677 for project C and 1.073, 0.932, and 0.627, respectively for project G, using Equations.(2)–(4). The option values were computed using Equations.(5) and (6), yielding values for the standard model and the model with the inclusion of government failure risk. The asset values at the varying time steps are also calculated and expressed within the binomial tree. The investor is expected to make distinct investment decisions at each node of the binomial lattice tree (Figures. 4 and 5). The decision is influenced by the option values and the difference between the asset value and investment cost. In Figure. 4, where the asset value (top number) exceeds the investment cost at node S_ou^5, the expected asset value is US$172.22 million, for a proposed investment cost of US$100 million, this results in a net asset value or profit of US$72million. Therefore, the decision at this node will be to invest or build the plant. However, where the constant risk of government failure is considered, the option value changes from US$72million to US$18million (bottom numbers separated by ;). This is still a positive position and the plant would be deemed a worthwhile investment.

Figure.4 Option Values including Government Risk -Combustion

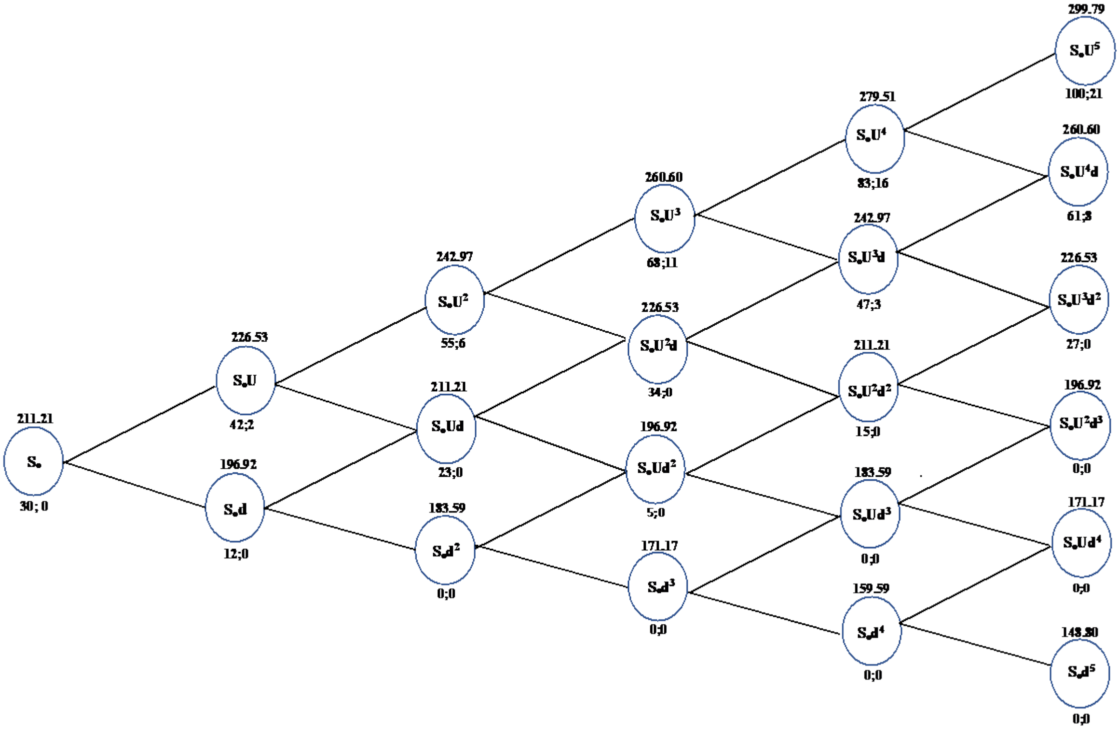


In contrast, moving to the intermediate nodes, at node S_od^4, the expected asset value for keeping the option open is US$105.68million, which yields a profit of approximately US$6million. The option value or strategic net present value at this node however, is US$7million which indicates that there is some value in waiting to execute the project as a higher payoff is expected. The corresponding value with the inclusion of the government risk factor, yields an option value of US$0 at the same node. This may be interpreted as the project having no perceivable value or is unfeasible at that time step due to active government related risk and related uncertainties. If the investor deems the project risk as being too high, for instance, in reality that particular time (i.e. 4 years from year zero) may be related to an impending political election year, which may produce a different and possibly hostile government. Based on this outcome, the plant construction and entire project and PPP arrangement would either be rescinded or deferred to a time where the uncertainty is expected to have passed. This interpretation assumes that investors are rational, competent and responsive to market movements and general information which affects their bottom line. The cost of the decision to rescind the PPP agreement and abandon the project, would translate to a forfeiture of the initial investment of US$10million for the PPP arrangement and represents the irreversibility element earlier described. This decision making process is repeated until time 0, corresponding to node S_o. The option value at that node is US$41million which is higher than the net asset value. The corresponding option value adjusted for government risk, yields an option value of US$8million which is less than the US$10million initial investment. At this point, the investor may decide to defer executing the project, to allow the uncertainty resolve. In this scenario, the option value is highest value at year 5, which suggests that it would be advisable to wait and invest at that time, due to the expected pay-off.

The binomial method offers transparency by showing the project values in the future for expected payoffs and the relevant decision pathways open to competent and rational investors. The premise is based on allowing the future uncertainty pass, thus enabling beneficial decisions by comparing the expected payoff with the investment cost, at a given time step.

The value of the ROA when considered alongside the NPVof US$32.05million, would yield a real options premium of US$8.95million. However, the inclusion and adjustment for the government risk or failure, narrows the options in terms of the optimal time to invest and build the plant; as it is only at the nodes where the option value and risk-adjusted option values exceed the net asset value, will the project be executed or deferred in hopes of higher payoffs. A similar process is repeated for the values in Fig. 5 and the outcome yields an option premium of US$18.70million from an NPV of US$11.21million. However, the risk adjusted ROA value yields US$0million at node S_o, indicating an unfavourable investment time to build the plant and the only other feasible time along the lattice tree, would be at the single terminal node $S_o u^5$; where all the values are favourable and exceeding the net asset value and initial project cost of US$20million.

Figure.5 Option Values including Government Risk -Gasification



However, the outcomes do not alter the DCF-NPV decisions to invest in the respective projects, but simply guide the investor on the optimal time to build or invest, considering inherent uncertainties and risk. It therefore provides an investment strategy, such that, though a project may appear favourable for execution, the ROA provides the optimal timeline to do so. The inclusion of the government risk factor, pushes this optimal investment timing decision further into the future, to allow the timing, events or other uncertainty-related actions pass. Empirically, tariffs and energy production have been identified as the catalysts for RE project profitability(Kim, Park and Kim, 2017), based on the outcome of numerous Monte Carlo simulations and sensitivity analyses. The authors consider these variable factors which can be resolved within reasonable ambits of the investor's ability, system selection or appropriate negotiations with the authorities. However, the risk of government failure is out of investors' control and will constantly hover over a given venture, holding the potential to completely reverse or overturn related agreements or progress made regarding the investment.

This argument is clearly illustrated, where the project has been given a go-decision based on favourable option values derived from the standard model and optimal time to invest has been determined and adhered to. The plant construction has commenced and the relevant processes are set in motion, however, ethnic violence or sudden disturbance around the plant's vicinity such as insurgent activity which becomes protracted, will automatically void all perceived and or expected benefits from the project. In practice, however, a rational investor is expected to protect all investments and assets legally and equally assumes conscientious authorities acting with integrity, to provide necessary support and compensation where feasible.

It is also pertinent to note that the project scenarios assume zero leakage, i.e. the deferral or wait option does not create a loss in value or erosion by competition. The option to wait or defer a project is applicable and beneficial for projects where the investor possesses "proprietary technology or exclusive ownership rights and the barriers to entry are high"(C., 2006). Therefore, the project that yields the most value for the investor at any given time, in light of the risk of government failure, is the option to build the combustion plant. The company may however, exercise caution and stage the project in phases; thus providing investment outlays in tranches, to minimise losses and hedge risks.

From the above analysis, it is evident that the combustion plant is the favourable option, as the government risk-adjusted option value still yields a real options premium; and the option to invest is observed favourably across a larger horizon, based on the defined time steps. The gasification project is only practical for investment at the terminal node and will require a larger investment. In spite of the significant payoff at this node and the superior or preferred gasification technology, the investment outlay would be considered an irrational decision based on the scenario.

Favourable NPVs are a result of payoffs that exceed project investment and corresponds to the strike price in the ROA. Where the expected payoff is greater than the investment cost, a rational decision would be to invest at that time or forfeit the project entirely.

5. Discussion

The advent of covid-19 and the related economic challenges and resource constraints have triggered a strategic divestment of foreign interests within the sub-Saharan African business scene. For example, the South African retail giant Shoprite, announced the conclusion of its divestment from the Nigerian market after 15years of operation and closed the last of its Kenyan stores in February 2021 . This is one of many examples, and the challenge for most SSA governments already grappling with political wrangling, public health crises, currency devaluation, insecurity threats, ethnic conflict, limited economic resources and infrastructure deficits- remains how to attract and retain foreign capital in this case, to the RE scene. This is pertinent to funding and closing energy access and poverty gaps, often requiring technical and financial capacities beyond the ability of these authorities.

The validity of the analysis caried out in this paper, is in its relevance and replicability for actual projects under consideration by potential investors, wary of the afore-mentioned risks in the focal region.

It is also pertinent to state that in spite of the option premium yielded by project C, this outcome is largely attributable to the project parameters defined for the investment scenario. Direct combustion, although a popular method for energy recovery is not without its criticisms. Issues with significant pollution generated from the process, with considerably low efficiency estimates in the region of 5-15% and conversion rates of less than 25% of material energy in municipal solid wastes to "marketed electricity", makes the technology option expensive and the least efficient energy recovery method(Akhator, Obanor and Sadjere, 2019)(GAIA, 2018). Modern applications however, appear to have overcome some of these challenges, as seen with the Ethiopian Reppie facility which has adopted a modern back-end flue-gas treatment technology, that reduces the sulphur dioxide (SO2), nitrogen oxides (NOx), dioxins and heavy metals produced by the plant during the incineration process. The plant operates in cognisance of the European Union's (EU) strict emission limits and residues from the process are duly recycled or safely discarded(Cambridge Industries Limited Profile, 2017).

Gasification entails the conversion of "combustible solids into gaseous fuel mixtures with minimal quantities of char and condensable compounds"(Sobamowo and Ojolo, 2018). The advantage of the biomass gasification system compared to conventional combustion technology, is the reduction in Green House Gas (GHG) emissions. Biomass gasification systems have been observed as having 2-times the effectiveness in reducing GHG emissions(Sobamowo and Ojolo, 2018), over other RE resource recovery technologies. In addition, the unit cost of electricity for energy generation using this system, is considerably lower than other comparable technologies and it is therefore considered suitable for Village Energy Security Programmes (VESP) and Remote Village Electrification (RVE) schemes(Sobamowo and Ojolo, 2018).

The implementation of bioenergy resources for biopower, using decentralised models or distributed grids requires more focused attention, as the popularity of solar energy and hydropower currently overshadows its potential benefits and relevance. Biopower is considered firm power i.e. it does not require back-up generation or battery storage unlike other RE sources and is derived from a homogenous source which is readily and freely available. The challenges however, relate to the logistics of waste transfer from landfills to plant site, separation and sorting mechanisms and preferred conversion technology based on applicable ISOs and Clean Development Mechanism (CDM) protocols.

6. Conclusion

The key objectives of this study were to estimate the risk of government failure, identified as a constant factor in developing countries, determine the optimal investment timeline and the preferred project based on direct combustion or biomass gasification systems. The study also provided a justification for the extension of the standard binomial model, estimated the economic cost and highlighted the benefits of investing in a decentralised biopower plant. It also highlighted the overall impact of the decision to invest, abandon or defer the project, on the potential investor's bottom line.

The real options valuation using the six-step process was applied to determine a strategic investment roadmap for two distinct project scenarios. The scenarios were based on investment decisions involving two competing renewable energy resource recovery technologies, to determine the optimal timeline for investment in a sub-Saharan African country. The region is characteristically considered to be volatile and investments are largely exposed to heightened uncertainty and risks. The simple wait option model of the ROA framework, grants flexibility to investors to build or defer projects to a future time where the uncertainty may have passed. The decision makers determine the optimal or appropriate investment strategy at defined time steps, bearing in mind prevalent or existing private and market uncertainties. It is evident that the framework and the analysis successfully resolved the research objectives of this study and therefore solidifies the superiority of the ROA in investment appraisals, with the valid model extension for developing countries and contexts.

References

Agaton, C. B. et al. (2020) 'Economic analysis of waste-to-energy investment in the Philippines: A real options approach', Applied Energy. Elsevier, 275(April), p. 115265. doi: 10.1016/j.apenergy.2020.115265.
Akhator, P. E., Obanor, A. I. and Sadjere, E. G. (2019) 'Design and development of a small-scale biomass downdraft gasifier', Nigerian Journal of Technology, 38(4), p. 922. doi: 10.4314/njt.v38i4.15.
Balietti, A., Chesney, M. and Vargas, C. (2018) 'Long-Term Investment Choices for Quinoa Farmers in Puno, Peru: A Real Options Case Study', SSRN Electronic Journal, pp. 1–47. doi: 10.2139/ssrn.3175262.
Burke, N. (2012) 'A REAL OPTIONS VALUATION OF RENEWABLE ENERGY PROJECTS (Thesis format: Monograph) Graduate Program in Applied Mathematics'.
C., K. P. & P. (2006) Project Valuation using Real Options. J. Ross Publishing, Inc. ISBN 1-932159-43-6 Printed.
Cambridge Industries Limited Profile, G. P. (2017) 'Africa ' s First Facility', Reppie Waste to Energy Facility, (Cil), pp. 7–10.
GAIA (2018) 'Waste-To-Energy Has No Place in Africa the Trouble With Trash Burning ':, pp. 1–5.
Kim, K., Park, H. and Kim, H. (2017) 'Real options analysis for renewable energy investment decisions in developing countries', Renewable and Sustainable Energy Reviews. Elsevier, 75(October 2015), pp. 918–926. doi: 10.1016/j.rser.2016.11.073.
Kumbaroğlu, G., Madlener, R. and Demirel, M. (2008) 'A real options evaluation model for the diffusion prospects of new renewable power generation technologies', Energy Economics, 30(4), pp. 1882–1908. doi: 10.1016/j.eneco.2006.10.009.
Liu, L., Zhang, M. and Zhao, Z. (2019) 'The application of real option to renewable energy investment: A review', Energy Procedia. Elsevier B.V., 158, pp. 3494–3499. doi: 10.1016/j.egypro.2019.01.921.
Locatelli, G., Mancini, M. and Lotti, G. (2020) 'A simple-to-implement real options method for the energy sector', Energy. Elsevier Ltd, 197, p. 117226. doi: 10.1016/j.energy.2020.117226.
Maishanu, S. M., Sambo, A. S. and Garba, M. M. (2019) Sustainable bioenergy development in africa: Issues, challenges, and the way forward, Sustainable Bioenergy: Advances and Impacts. Elsevier Inc. doi: 10.1016/B978-0-12-817654-2.00003-4.
Mun, J. (2006) Real options analysis Tools and Techniques for Valuing Strategic Investments and Decisions Second Edition, Real Options Analysis. John Wiley & Sons, Inc., Hoboken, New Jersey. Published.
Sobamowo, G. M. and Ojolo, S. J. (2018) 'Techno-Economic Analysis of Biomass Energy Utilization through Gasification Technology for Sustainable Energy Production and Economic Development in Nigeria', Journal of Energy, 2018, pp. 1–16. doi: 10.1155/2018/4860252.

UN Environment (2015) 'Energy Profile Rwanda', (Table 1), pp. 2013–2016. Available at: https://wedocs.unep.org/bitstream/handle/20.500.11822/20519/Energy_profile_Rwanda.pdf?sequence=1&amp%3BisAllowed=.
UNEP (2018). Africa Waste Management Outlook. and United Nations Environment Programme, Nairobi, K. (2018) Waste Management Waste Management, Group.
Wang, X., Cai, Y. and Dai, C. (2014) 'Evaluating China's biomass power production investment based on a policy benefit real options model', Energy. Elsevier Ltd, 73, pp. 751–761. doi: 10.1016/j.energy.2014.06.080.
van Zyl-Bulitta, V. H. et al. (2019) 'A compass to guide through the myriad of sustainable energy transition options across the global North-South divide', Energy. Elsevier Ltd, 181, pp. 307–320. doi: 10.1016/j.energy.2019.05.111.

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