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A real options approach to investment timing decisions in utility-scale renewable energy in Ghana

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ABSTRACT

Private capital is required to urgently complement government's efforts to meet initial capital outlay in renewable energy investments. However, minimising the downside risks for a given return in such a venture presents valuation challenges, including the timing of such investments. Investment timing is therefore relevant to consider when making investments in utility-scale renewable energy technologies which require high initial capital.

This study assesses the value of investment delay in renewable energy projects using real options analysis. A model that combines binomial trees and Monte Carlo simulations are used to evaluate the optimal investment timing of the first cycle of Ghana's Renewable Energy Master Plan. The model incorporates multiple dimensions of uncertainties related to market, economic and technological factors to determine the value of delaying utility-scale renewable energy investments.

The results show value in delaying investments until uncertainties are reduced and maximum benefit is obtained. Also, high system capacities and favourable renewable energy policies that border on attractive feed-in tariffs are required to drive private investment in utility-scale renewable energy.

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1. Introduction

Ghana showed renewed interest in renewable energy as it passed a legal framework (Renewable Energy Act (Act 832)) that seeks to boost renewable energy penetration in the country. Specifically, the government of Ghana seeks to increase its share of renewable capacity from its current level (less than 1%) to 10% by 2030. Therefore, the ministry responsible for energy (Ministry of Energy) has drafted a Renewable Energy Master Plan that serves as a guide to achieving the set targets for renewable energy penetration. The plan estimates an investment of about $5.8 billion, out of which at least 80% must be sourced from private investors. The business and regulatory environment must therefore promote growth in the sector to gain investor confidence.

The primary objective of investors, in general, is to maximise the payoff from their investment [1]. Beyond maximising these payoffs, investors seek to minimise their exposure to downside risks that can occur with such investments. In renewable energy investments, these risks cannot be downplayed. Generally, the risks associated with the renewable energy market are in the form of conflicting government policies [2,3], market factors [4], economic factors [5], technological factors [6] and climatic factors [38]. In the face of uncertainties, it may be of more excellent value to delay investments in renewable energy systems to gather more information or significantly curtail uncertainties before investments are made. The flexibility in timing investments presents additional value to the investor. Further, it reduces potential losses that may arise with immediate investment without adequate knowledge of the market's level of uncertainties. While the option to delay investment may provide extra value to the investor, it is essential to note that delays in investment pose risks such as competitor's entry into the market and forgone cash inflows. Therefore, obtaining the optimal time for investment is important in an environment riddled with uncertainties.

Therefore, renewable energy investors must value their investments by thoroughly considering factors beyond the cost of investment. These include the price of electricity, the favourability

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of policies, the availability of materials for the production of renewable energy technologies, and the availability of resources for research and development of improved technologies.

Traditional means of valuation, primarily Discounted Cash Flow (DCF) models such as the net present value (NPV), is widely used to account to value capital investments. Advanced DCF methods account for strategic flexibility through the use of scenarios and decision tree alternatives. However, these methods do not accurately account for the valuation of flexibility inherent in the investment. DCF analysis applies the same discount rate in the valuation of projects without accounting for reductions in systematic risks arising from flexible projects [7,8]. Further, DCF models are not suitable for the valuation of long term investments where the determination of future cash flows occur with higher uncertainties. DCF analysis generally does not account for the qualitative benefits that characterise strategic investments, thereby undervaluing the investment's potential [8–10].

Real options provide the holder with the right to decide to invest in a real asset. It provides an approach to include flexibilities in the valuation and planning of investments in real assets such as renewable energy technologies [11]. The value of such investment can be broken down into two parts; the tangible value that is created from the assets in place and the intangible value that arises from the flexibilities inherent to take advantage of future opportunities. It provides an approach to estimate the intrinsic value of an investment accurately. There has been an appreciable amount of research that has applied various variations of real options techniques towards energy investments. However, studies that have used real options analysis in valuing investment timing are generally scant, especially within the context of a developing country.

The focus of this study is two-fold. First, the study seeks to determine the value of delaying renewable energy investments in an uncertain environment. Second, the study aims to provide an optimal time for a large scale renewable energy investment project outlined in Ghana's Renewable Energy Master Plan. This study also contributes to the literature on the option to delay. It also presents an approach for determining the cost of delaying investments with unequal cashflows. The study is presented in five sections. Section two introduces the concept of real options valuation, while section three presents the real options model that assesses the option to delay. Section four presents the results, while the last section presents the conclusions made in the study.

2. Investment decisions and real options valuation

Investors prefer options that provide the maximum value. Value creation can vary in different forms, ranging from increased cash flows, cost savings, environmental sustainability, and goodwill. The income approach to investment valuation examines the discounted cash flow stream of investments at a discount rate adjusted for risk [9]. The uncertain future could either provide a positive or a negative outlook to the investor. Capital intensive projects are mostly complex with varying interdependencies, and as such, the estimation of cash flows is less predictable [9]. In addition to tangible cash flows, investments have intrinsic values, resulting in advantageous strategic positions. The value of such positions must be accounted for in investment appraisals. Therefore, investment decisions must be made with the utmost level of strategic flexibility in such an uncertain environment.

The option to defer the execution of a project in real options analysis provides the investor with the option to delay investments until the project is more profitable. An investment with a negative expected NPV, considered unprofitable, may hold value when future business and economic conditions are favourable. On the other hand, increasing uncertainties pose risks to investment even with a positive NPV [12]. Thus, the delay option allows the investor to better understand the uncertainties inherent in the generation of future cash flows through the acquisition of new information. Other investment decisions include switch options, enter and exit options, and interaction options that involve a convolution of multiple investment options. Real options models and DCF models are not mutually exclusive as the former has the DCF as its basis. Thus, it does not entirely play down the importance of DCF methods but builds on it.

Over the past decade, extant studies have been conducted using Real Options Analysis (ROA) as an analytical tool in meeting various research objectives in renewable energy investments. Kumbaroglu, Madlener & Demirel [13] analysed the impact of uncertainty and technical change of renewable energy technologies. The study outlined the impact of uncertainty and changes in technologies on renewable energy diffusion in Turkey using a real options approach to dynamic programming. Their primary sources of uncertainty included electricity prices and demand uncertainty. Lee & Shih [14] presented a model that integrates cost efficiency on renewable energy power generation by evaluating the value provided by renewable energy technologies in the face of uncertainties in fossil fuel prices. Using a binomial lattice structure, the authors presented an optimal policy framework for RE development.

Heinrich et al. [15] analysed investment decisions of electricity producers to invest in renewable and non-renewable energy markets under price uncertainty in Germany. Using real options analysis, the study found that uncertainties in environmental conditions affect the load profiles of renewable energy technologies, which increases the inertia of investors to invest in RE technologies. Kim et al. [6] developed a real options framework to assess investments in a hydropower project in Indonesia. Project volatility was identified using a three case scenario model that reflected uncertainties in tariffs, energy production costs, carbon emissions trading costs and operation and maintenance costs.

In the Philippines, Agaton & Karl [16] evaluated the attractiveness of renewable energy investments. In addition, the study considered the environmental consequences of using fossil fuel sources as substitutes for renewable energy investment generation. The study results show that investment value exists in renewable energy, especially under uncertainties in oil prices. Li et al. [17] also utilised real options and a stochastic dynamic programming model to identify an optimal feed-in tariff for wind power investments in China by considering uncertainties in the intermittency of renewable energy technologies.

Other studies have also involved the use of real options to identify the value of delaying investments. For instance, Martínez-Ceseña & Mutale [18] proposed a methodology for renewable energy generation projects using a combination of mathematical programming and real options analysis. The objective was to determine the investment timing and design that can maximise the profits of such renewable energy projects by considering uncertainties in electricity prices and environmental policies.

MacDougall [19] analysed the value of delaying investments in a 10 MW array of in-stream tidal energy conversion devices by considering uncertainties in electricity prices. The research highlighted three main factors that impact the option value of renewable energy investments: the inherent volatility, the opportunity cost of waiting, and the time to expiry of the option. The authors further concluded that government policies related to renewable energy development are essential for reducing uncertainties related to its development. Finally, Nunes, de Lima, Davison, and Leite [20] assessed the value of switching and delaying renewable energy investments in Brazil. The research considered uncertainties in solar and wind power irradiation and electricity prices.

Most of these studies have considered uncertainties in electricity prices and fossil fuel prices. Beyond uncertainties in tariffs, this study examines investment timing while considering other sources of uncertainty. These sources include demand, exchange rate volatilities, adjustments in renewable energy purchase obligations, and capacity factors of renewable energy. In this case, the study examines investment decisions under market, technical, regulatory and economic uncertainties.

3. Real options modelling: Assessing the option to delay

The option to wait or delay investment for a specific time is essential because of the volatility of cash flows. There is the possibility that investments with negative net present values can yield positive net present values when the investment is delayed. Consider a project that has a lifetime T and is initiated at time t. The value of the project (V_t) is determined by calculating the difference between the present value of the cash flows (Π_t) and the investment cost at time t (I_t), as explained in equation (1):

$$V_t = \Pi_t - I_t \tag{1}$$

The decision to invest or not to invest depends on the sign of V_t, implying that the firm obtains a negative payoff for $\Pi_t < I_t$ and a positive cash flow for $\Pi_t > I_t$. For any period the investor does not invest in the project, there is no cost of investment incurred. This creates an implicit call option with the project as the underlying asset, a strike price of I_t and the value of asset Π_t. The payoff of such an option with investment costs and revenues is provided in equation (2):

$$V = Max(\Pi_t - I_t, 0) \tag{2}$$

The value of a plain vanilla European call option which is exercised only at maturity, can be determined using the Black and Scholes (BS) formula. The BS formula provides a closed-form solution for the value of the option. However, real options are similar to American options since they can be exercised any time it is in the money. This study, therefore, relies on the use of numerical methods in the determination of option value.

Several numerical methods exist for the valuation of American options, including the finite difference approaches (both explicit and implicit), binomial lattice approach, the trinomial lattice approach and the quadratic approximation methods. In evaluating these numerical methods, Zhao [21] concluded that the binomial is the best approach for option evaluation in efficiency and accuracy. Therefore, this study applies the binomial lattice approach to the valuation of the implicit call option.

The option value using the binomial option pricing model is determined by evaluating the upward (u) and downward (d) movements of the value of the project at any point in time, the risk-neutral probability (q) of an upward movement in the value of the project, volatility (σ) and the period of expiry of the option (t). Equation (3a) presents the expression for determining the value of an option which is determined by calculating the expected payoff of the option, discounted at the risk-free rate.

$$V = e^{-rt}(qV_u + (1-q)V_d) \tag{3a}$$

The upward and downward movements represent the change in the value of the project after Δt period. The expression for the movements depend on the volatility (determined by σ). If σ is zero, the upward and downward movements are equal, and the binomial lattice becomes a straight line. The risk-neutral probability (q) provides also depends on the risk-free rate and the value of upward and downward movements. Equations (3a), (3b) and (3c) give expressions on the upward and downward movements and the risk-neutral probability, respectively;

$$u = e^{\sigma\sqrt{\Delta t}} \tag{3b}$$

$$d = e^{-\sigma\sqrt{\Delta t}} \tag{3c}$$

$$q = \frac{e^{rt} - d}{u - d} \tag{3d}$$

4. Case study – Ghana's Renewable Energy Master Plan

The Renewable Energy Master Plan (REMP) is a 12-year master plan with the objective of *"providing investment focused framework for the promotion and development of the country's rich renewable energy resources for sustainable growth, contribute to improved social life and reduce adverse climate change effects"* [22,23]. The government of Ghana has thus identified renewable energy as a double-edged strategy to reduce harmful CO_2 emissions while meeting global environmental targets and increasing the overall energy supply mix in Ghana. The overall target of the plan is to increase the portion of renewable energy to 1363 MW by 2030. The 12-year plan is estimated to cost about \$5.6 billion, with at least 80% of the investment cost being borne by private investors. This highlights the need for an enabling environment for profit generation to boost investor confidence. Fig. 1 provides details of renewable energy development projects under the master plan.

This study focuses on analysing the first of three cycles of the project, which aims to expand utility-scale renewable energy generation by 130 MW by the end of 2020 (the timeline for achieving the target has delayed). The geographical location of Ghana provides good exposure to solar radiations, which is ideal for solar power generation. The country receives average solar irradiation of about 4 to 6kwh/m^2/day with an annual sunshine duration between 1800 and 3000 h.

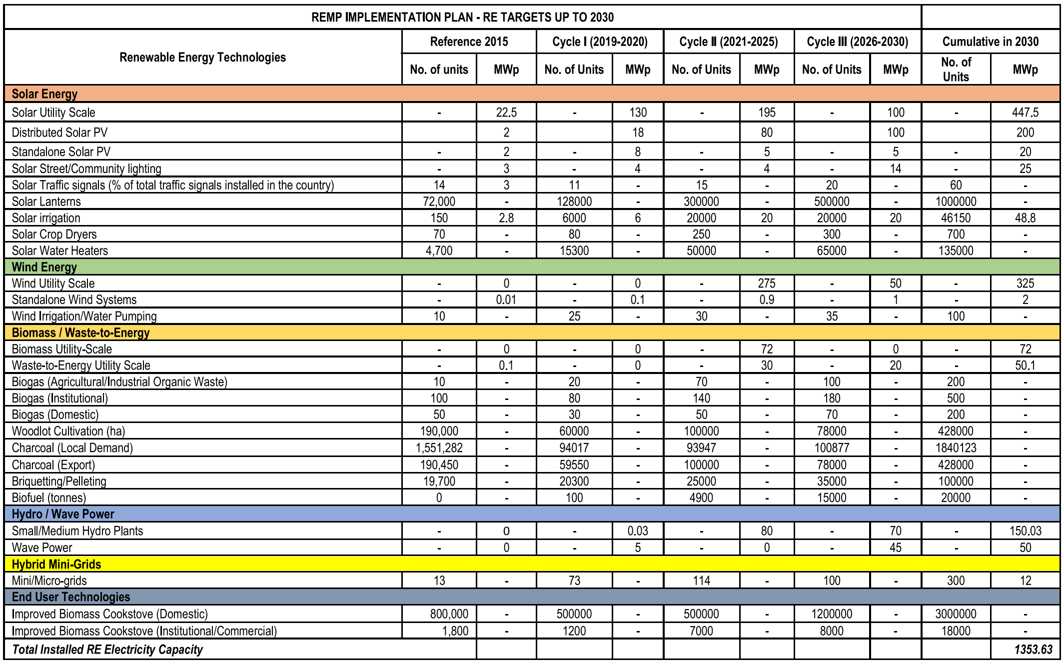
In 2019, Ghana's peak energy demand on the transmission grid was about 2,800 MW, with an installed capacity of about 4,900 MW. The major source of the country's installed capacity is thermal energy generation. An additional utility-scale solar energy capacity may thus pose a threat to increasing the excess unutilised generating capacity. However, this can be advantageous for the country, as renewable energy sources can reduce the costs of fuel and replace liquid fuel-powered thermal plants. Ghana also has the potential to export power to other neighbouring countries. Albeit, this requires other factors such as the competitiveness of power and the extent of demand for power from the different countries.

Essentially, the appropriate investments and timing of investment can yield the best possible returns for the country. This study examines the value of delaying investments in the first cycle of Ghana's REMP and provides an optional timing that maximises profits in a utility-scale renewable energy project. The following subsections provide details of the variables used in the option valuation model and the case study.

4.1. Inputs for valuation

4.1.1. The value of the underlying asset

The valuation of options is based on the price of an underlying asset. For most financial options, the underlying asset is the value of a stock at any point in time t. In this study, the underlying asset is the utility-scale renewable energy project with a capacity of 130 MW. Generally, solar PVs have a useful life between 25 to 40



REMP IMPLEMENTATION PLAN - RE TARGETS UP TO 2030										
Renewable Energy Technologies	**Reference 2015**		**Cycle I (2019-2020)**		**Cycle II (2021-2025)**		**Cycle III (2026-2030)**		**Cumulative in 2030**	
	No. of units	**MWp**	**No. of Units**	**MWp**	**No. of Units**	**MWp**	**No. of Units**	**MWp**	**No. of Units**	**MWp**
Solar Energy										
Solar Utility Scale	-	22.5	-	130	-	195	-	100	-	447.5
Distributed Solar PV		2		18		80		100		200
Standalone Solar PV	-	2	-	8	-	5	-	5	-	20
Solar Street/Community lighting	-	3	-	4	-	4	-	14	-	25
Solar Traffic signals (% of total traffic signals installed in the country)	14	3	11	-	15	-	20	-	60	-
Solar Lanterns	72,000	-	128000	-	300000	-	500000	-	1000000	-
Solar irrigation	150	2.8	6000	6	20000	20	20000	20	46150	48.8
Solar Crop Dryers	70	-	80	-	250	-	300	-	700	-
Solar Water Heaters	4,700	-	15300	-	50000	-	65000	-	135000	-
Wind Energy										
Wind Utility Scale	-	0	-	0	-	275	-	50	-	325
Standalone Wind Systems	-	0.01	-	0.1	-	0.9	-	1	-	2
Wind Irrigation/Water Pumping	10	-	25	-	30	-	35	-	100	-
Biomass / Waste-to-Energy										
Biomass Utility-Scale	-	0	-	0	-	72	-	0	-	72
Waste-to-Energy Utility Scale	-	0.1	-	0	-	30	-	20	-	50.1
Biogas (Agricultural/Industrial Organic Waste)	10	-	20	-	70	-	100	-	200	-
Biogas (Institutional)	100	-	80	-	140	-	180	-	500	-
Biogas (Domestic)	50	-	30	-	50	-	70	-	200	-
Woodlot Cultivation (ha)	190,000	-	60000	-	100000	-	78000	-	428000	-
Charcoal (Local Demand)	1,551,282	-	94017	-	93947	-	100877	-	1840123	-
Charcoal (Export)	190,450	-	59550	-	100000	-	78000	-	428000	-
Briquetting/Pelleting	19,700	-	20300	-	25000	-	35000	-	100000	-
Biofuel (tonnes)	0	-	100	-	4900	-	15000	-	20000	-
Hydro / Wave Power										
Small/Medium Hydro Plants	-	0	-	0.03	-	80	-	70	-	150.03
Wave Power	-	0	-	5	-	0	-	45	-	50
Hybrid Mini-Grids										
Mini/Micro-grids	13	-	73	-	114	-	100	-	300	12
End User Technologies										
Improved Biomass Cookstove (Domestic)	800,000	-	500000	-	500000	-	1200000	-	3000000	-
Improved Biomass Cookstove (Institutional/Commercial)	1,800	-	1200	-	7000	-	8000	-	18000	-
Total Installed RE Electricity Capacity										***1353.63***

Fig. 1. REMP implementation plan.

years [24]. Therefore, the value of the underlying asset is the present value of the future cash flows with an assumed lifespan of 25 years. Equation (4) expresses the present value of the total cash inflows from the project after T years. The yearly cash flows (PV_i) is discounted at a continuously compounded rate of r.

$$\Pi = \sum_{t=1}^{T} PV_t e^{-rt} \qquad 4$$

At every point in time, the cash inflow comprises cash inflows from power generation determined by the feed-in tariffs and the quantity of energy generated, as outlined in equations (5) and (6). The quantity of energy generated in a year is a function of the total installed capacity (130MW) of the solar PV, the system availability of the PV (CAPA) and the number of hours in the year.

$$PV_t = QE_t.FIT_t \qquad 5$$

$$QE_t = 130MW \times CAPA \times 8760\ hours \qquad 6$$

4.1.2. *Exercise value*

The exercise value is the cost of making the initial investment. The exercise value, also known as the strike price, is the present value of the total costs. The total cost is expressed as the sum of the investment cost (I_t) and the present value of the yearly operation and maintenance costs (O_t), also discounted at a continuously compounded rate r.

$$TC = I_t + \sum_{t=1}^{T} O_t e^{-rt} \qquad 7$$

4.1.3. *Cost of delay*

Notwithstanding the potential value in delaying investments, some costs can be incurred for every period an investment is delayed. First, there is a cost to hold the option, which is determined by the value of the premium. Second, every time an investment is delayed, there is a corresponding loss in potential cash inflow if the option was exercised on time. In addition, the entry of competitors can reduce the value of delay, especially in a competitive environment, where a company has no special advantages over its competitors. The cost of delay can be estimated by determining the leakage [19], expressed as a discount rate. MacDougal [19] determined the annual leakage rate for unequal cash flows as $\frac{1}{t}$ expressed as a percentage, where t is the lifespan of the project. However, this approach does not consider the potential cash flows generated by the project for each period the investment is delayed. Therefore, this study presents another method for determining the leakage rate for unequal project cash flows.

A delay of the project for n years indicates forgone cashflows for the period of delay. For each period the investment is delayed, the investor forgoes an amount C_i. Thus, for n years, the present value of forgone cash inflows (K) is expressed in equation (8). To obtain an annualised cash flow forgone for the investor, the equivalent annual annuity (A) is calculated from the present value of the forgone cashflows as expressed in equation (9).

$$K = \sum_{n=1}^{N} C_n e^{-rn} \qquad 8$$

$$A = \frac{rK}{1-(1+r)^{-n}} \qquad 9$$

The leakage is represented as the ratio of the equivalent annual annuity to the present value of cash flows, given that investment was not delayed over the project's lifetime as given in equation (10).

$$\partial = \frac{A}{\Pi} \qquad 10$$

4.1.4. Scenario analysis of project costs and revenues

The first cycle of the renewable energy master plan seeks to increase the total installed capacity of renewable energy by 130 MW by installing utility-scale solar systems. Determining the present values of costs is based on two key factors: investment cost and operation & maintenance costs. Operation and maintenance costs involve costs for preventive maintenance, repairs of solar panels, plant control and other expenses for the commercial management of the solar plant [25]. These cost components are affected either directly or indirectly by fluctuations in exchange rates and inflation rates. Therefore, the scenario analysis for the cost components is majorly based on changes in the exchange rate values between the Ghanaian Cedi (GHS) and the US dollar.

According to the Renewable Energy Master Plan, the 130 MW project requires a capital cost of $169 million, equivalent to about GHS 912.6 million in2019.[1] However, the International Renewable Energy Agency [26] statistics indicate that average capital costs for utility-scale solar PVs in the African market are likely to be about $1.2 to $2 (GHS 6.48 7 − GHS 10.6) per Watt of installed capacity. These costs culminate in total capital costs between GHS 842.4 million ($156 million) to GHS 1.406 billion ($260.37 million), with an average of GHS 1.123 billion ($227.7 million). This study uses these different investment costs as scenarios.

Operation and Maintenance (O&M) costs are estimated to be about $30 (GHS 162) per kW (IRENA, 2019). O&M costs have witnessed declines globally due to increased economies of scale, technology maturity, rising learning curves, and lower capital costs [25]. However, given that parts of the O&M costs include administrative costs and the need to import peripherals, they are affected by changes in inflation and exchange rates. Therefore, this study offsets the decline in global O&M costs for solar PVs with the changes in inflation and exchange rates.

From October 2018 to November 2019, Ghana's central bank recorded a continuous depreciation of its currency against the dollar with a maximum depreciation of about 10% and a minimum depreciation of about 5.18% [27]. Ghana's current inflation rate is approximately 9%. Within the past decade, inflation rates range between a minimum of 7% and a maximum of 17.4% (IMF, 2020). A three case scenario for each of these rates, which identifies the base case, best-case and worst-case scenarios for the inflation and exchange rates, were generated. Table 1 presents the summary of the scenarios for the estimation of the costs.

Feed-in tariffs (FITs) form the main component of revenues generated from renewable energy. According to the Renewable Energy Act 2011 (Act 832), FITs are guaranteed for ten years and subsequently subject to review every two years. The last review of FITs by the industry regulator saw FITs for solar PVs increase to GHS 0.5978 (11 US cents) per kWh of energy produced [28]. The upward or downward adjustment of the FIT depends on the price differential between the electricity from renewable sources and that generated from other non-renewable sources. Scenarios for FITs in this study are based on the ten-year review of the tariffs. Beyond the value of the FIT, this study highlights two important factors that can impact total revenue: the solar plant's capacity factor and the purchase obligations of the solar plant. In the best case, the capacity factor of 30% is given, and in the worst case, a capacity factor of 16.5% was used to determine project revenue. The summary of cases is as presented in Table 2.

The Renewable Energy Act 2011 (Act 832) [32] for Ghana ensures that power distribution companies and bulk suppliers purchase a specified percentage of the total purchase of electricity from renewable energy sources. A governance environment that provides favourable conditions for renewable energy to thrive can increase purchase obligations such that the maximum capacity of power generated from renewable sources will be utilised. However, as highlighted in earlier sections of this study, other political factors can reduce the level of purchase obligations, which can minimise the amount of power produced. Therefore, this study expresses the purchase obligation as a percentage of the total quantity of energy produced. In Table 2, a three case scenario is also presented, which describe possible purchase obligations by the government of Ghana. The best-case scenario presents the situation where the government of Ghana allows a 100% purchase obligation. The second scenario (base case) allows a purchase obligation of 80%, while the worst-case scenario allows for a purchase obligation of 60%.

4.1.5. Determination of project volatility

An assessment of the scenarios under projected costs and revenues yielded 36 scenarios each for projected costs and revenues, based on the possible combinations of each scenario for the various costs and revenue components. Under these scenarios, the net present values of the project were calculated for costs and revenues, with an assumed lifespan of 25 years [29]. The distribution of these values under costs and revenues were fairly normally distributed, as shown in Fig. 2. In determining the volatilities in project costs and revenues, a Monte Carlo simulation of 1000 samples of revenues and costs according to the normal distribution was done for both costs and revenues. The overall project volatility was expressed in terms of the volatilities in revenues (σ_R^2) and volatilities in costs (σ_C^2). Given that the revenues and costs are dependent on the quantities of energy generated, it is assumed that these two variables are dependent, with a non-zero correlation coefficient. Therefore, the variance of the profits is expressed as the variance of the difference between the cost and revenues (See Equation (11)).

Table 2
Revenue scenarios for Ghana's RE project.

Revenue component	Cases			
	Best case	Base case 1	Base case 2	Worst case
FIT adjustments (%)	20	10		0
Purchase obligation (%)	100	80		60
Capacity factor (%)	30	25	20	15

Table 1
Cost scenarios for Ghana's RE project.

Cost component	**Cases**			
	African Minimum	**African Maximum**	**African Average**	**Ghana Average**
Installation costs (GHS million)	842.4	1406	1123	912.6
	Best Case	**Base case**	**Worst case**	
Inflation rates (%)	5	9.2	17.4	
Exchange depreciation rate (%)	0	5	10	

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[1] Throughout this study, we use the 2020 average Cedi-Dollar exchange rate: $1 is equivalent to 5.4 Ghana Cedis (GHS).

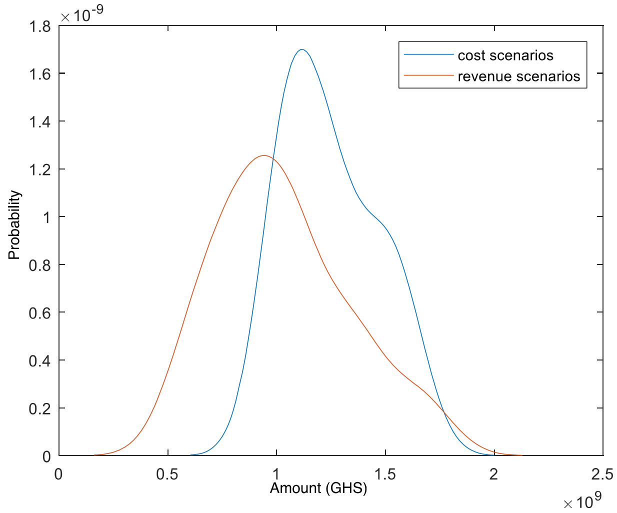

Fig. 2. Probability distribution of costs and revenues.

$$\sigma = \sqrt{\sigma_R^2 + \sigma_C^2 - 2Cov_{RC}} \qquad 11$$

4.2. Results

4.2.1. Option valuation of the base model

Analysis of static present values for project costs and revenues show that the total present value for the cost is about GHS 1.246 billion ($230.7 million), and that of revenues is about GHS 1.03 billion ($190.7 million), resulting in a negative net present value for the project. This shows that the main driver of revenues, which is the feed-in tariff, may not be substantial enough to cause investors to break even. However, given the negative net present value and the project volatilities, there is an opportunity to analyse the value of waiting or delaying investments. Table 3 presents the input parameters for the real options valuation. The average annual cost of delay, expressed as a percentage, was estimated to be 12.7%. The risk-free discount rate was expressed as 12%, and the overall project volatility was estimated to be about 47%. The subsequent analyses present the analysis of the delay option using the static NPV calculated as a baseline.

Using the binomial lattice option valuation model with 300-time steps, the real option was evaluated to examine the value of investment delay. Option values for 50 different values of t ranging between 0 and 25 with a half year time interval were generated. For each of the values of t, the option value was determined. Fig. 3 presents the results of using the parameters in Table 3 above to determine the option value. Fig. 3 shows that the value of the option increases for increasing values of t. The behaviour of the option indicates a diminishing marginal utility property as the rate of increase reduces for increasing values of t.

Table 3
Input parameters for real option valuation.

Variable	Base Case
Costs and revenues	
PV of costs	GHS 1246 million ($230.7 million)
Standard deviation of cost	GHS 207 million ($38.33 million)
Average PV of revenues	GHS 1029 million ($190.7 million),
Standard deviation of revenues	GHS 302 million ($55.93 million)
Rates	
Average annual cost of delay	12.7%
Risk-free interest rate	12%
Volatility estimates	47.3%

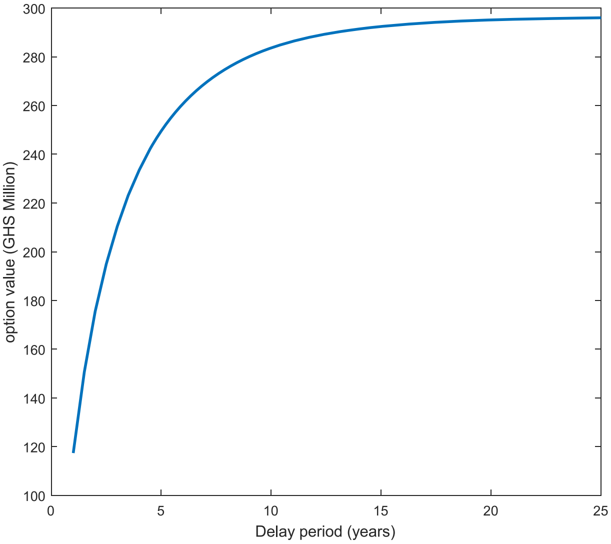

Fig. 3. Option values for different values of t.

Thus, although there is an incentive for the project to be delayed, it is not advisable to delay investment over its lifetime. The stopping criterion for the solution to this model is described by examining the rate of increase in the option value for each half-year the project delayed. Graphically the stopping value of t can be determined from the elbow of the graph shown in Fig. 3. Mathematically, the stopping criteria for successive values of the option follow the ratio shown in equation (12).

$$\ln\left(\frac{V_{(i+1)}}{V_{(i)}}\right) \times 100\% < \varepsilon \qquad 12$$

Table 4 provides optimal investment trigger periods for varying degrees of ε of 5%, 2% and 1%. For each value of ε, the trigger period and the average option value are determined from the binomial lattice model. Investment trigger points range between four to eight and a half years, given the different values of ε.

4.2.2. Sensitivity analysis

The option valuation model consists of three main parameters — the volatility, the risk-free rate and the leakage rate. The sensitivity analysis is done to examine changes in option value and investment trigger points given changes in the parameters of the sensitivity model. For each of the parameters, the sensitivity analysis was carried out based on six main scenarios: (1) when the value of the parameter is zero, (2) when there is a 50% reduction in the base value, (3) when there is a 20% reduction in the base value, (4) when there is a 20% increment in the base value, (5) when there is a 50% increment in the base value, and (6) when there is 100% increment in the base value.

Increasing volatility increases the option value. In the analysis of project costs and revenues, volatilities in revenues outweighed that of costs. This shows the upside potential of the project, which results from increasing FITs, increases in capacity factors and increases in purchase obligations. There is no change in costs and revenues at zero volatility throughout the time steps, resulting in the same negative NPV across the lattice. Given the options available, the optimal decision is to forgo investment entirely, resulting in a zero value. As the volatility increases, the optimal investment

Table 4
Investment trigger points and average option values.

Value of ε	5%	2%	1%
Option value (million)	GHS 233.55 ($43.3)	GHS 265.31 ($49.1)	GHS 277.87 ($51.5)
An investment trigger point (years)	4.0	6.5	8.5

time increases from four and a half years to six years (See Fig. 4).

In the second case, increasing leakage rates reduces the option value. The option value is highest at a zero leakage rate, even compared to the other sensitivity values. Thus, where there is little or no ‘punishment’ to delaying investments, the investor is allowed to postpone investment for a more extended period. At a zero leakage rate, the project's intrinsic value is estimated to be about GHS 770 million ($142.6 million), with an optimal trigger period of about eight and a half years. A 100% increase in the base value of the leakage rate lowers the average option value to about GHS 137 million ($25.37 million), for which the optimal trigger period is about four years (See Fig. 5).

The third case presents changes in the discount rate. Increasing values of the discount rate cause a corresponding increase in the option value. Option values range between GHS 187 million ($34.6 million) to GHS 358 million ($66.3 million), given various scenarios corresponding to changes in the discount rate. Investment trigger periods for these values lie in the range between five to five and a half years (See Fig. 6). The summary of sensitivity analysis is provided in Table 5.

The sensitivity of the option value to input parameters is assessed by examining the coefficient of variation for each of the input parameters (MacDougal, 2015). An input parameter with a higher coefficient of variation shows a higher sensitivity parameter to option values. As shown in Fig. 7, volatility and leakage rates are most sensitive to option values. It is seen that changes in these figures impact largely on the option values.

5. Discussions and conclusions

This study aimed at determining the value of delay for utility-scale renewable energy investments using real options analysis. Real options approaches have the advantage of capturing the flexibilities and uncertainties that are inherent in investment decisions. The results of the study show the importance of delays for utility-scale renewable energy investment. Delaying investments in an uncertain environment provides intrinsic managerial flexibilities through the real option valuation, which would be non-existent if the investment is carried out at time zero. By delaying, investors obtain new and valuable information that can help minimise uncertainties in the project [2,30]. In addition, investment delays can help to improve levels of technology maturity, which provide reductions in technology risks [2]. In the case of Ghana, the importance of delay in triggering investment is highlighted in all scenarios within the sensitivity analysis, with delay times ranging between 4 and 8 years.

In consonance with MacDougal [19]; the study shows that volatility and leakage rates are the dominant drivers in the investment timing decisions to be made by investors in renewable energy markets. Although increased volatility in project revenues drive option values, the increase in value is offset by further delay,

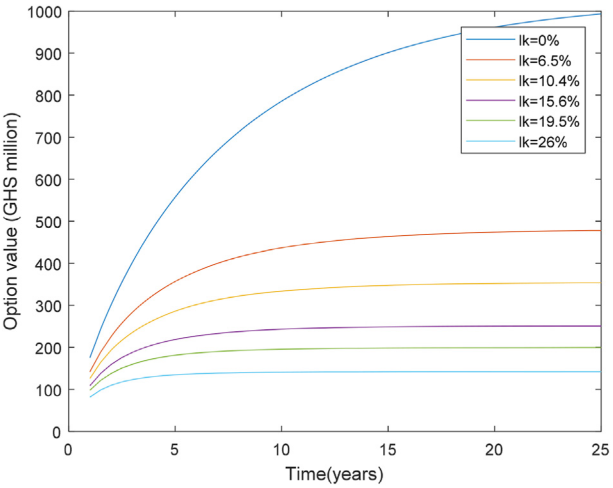

Fig. 5. Sensitivity analysis for changes in leakage rate.

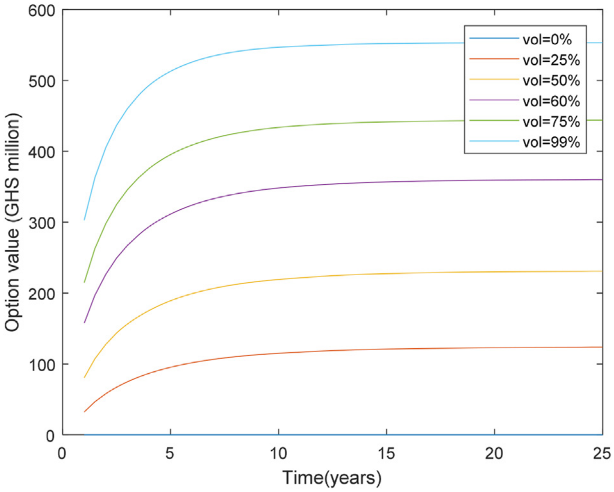

Fig. 4. Sensitivity analysis for changes in volatility.

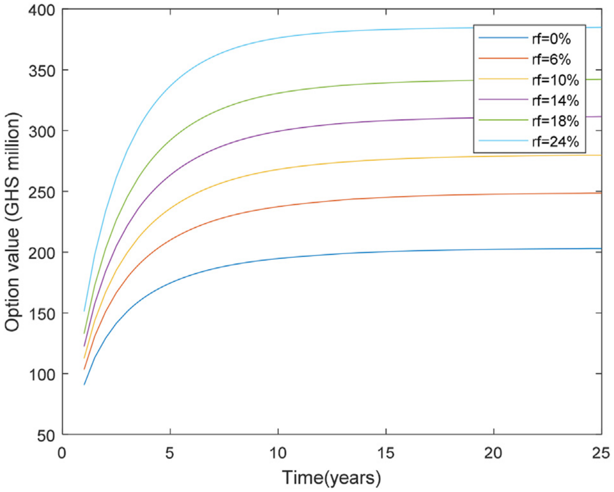

Fig. 6. Sensitivity analysis for changes in the discount rate.

Table 5
Results of sensitivity analysis.

	Volatility		Leakage rate		Discount rate	
Sensitivity value	Optimal option value[a]	Investment trigger[a]	Option value	Investment trigger	Option value	Investment trigger
100% reduction	0.00	Do not invest	779.48	8.50	187.79	5.00
50% reduction	109.31	4.50	418.73	6.50	228.30	5.00
20% reduction	209.42	4.5	319.54	5.50	256.86	5.00
20% increment	334.06	5.00	233.32	5.00	286.31	5.50
50% increment	417.11	5.5	188.47	4.50	315.58	5.50
100% increment	528.40	6.0	137.01	4.00	358.12	5.00

[a] Optimal values are measured in GHS millions, and the investment trigger period is measured in years.

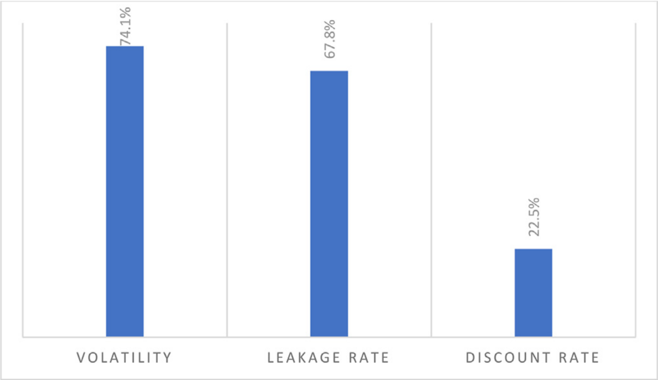

Fig. 7. Sensitivity of input parameters to option value.

for which national targets for renewable energy generation may be missed. The study highlights that policy support is required for renewable energy investments to thrive and to fairly compete with conventional fossil fuel-based energy resources. Inadequate political will and the lack of policy support are major sources of risk to the investor. The antecedents to such policy risks which affect revenues include industry regulation, tariff policies and tax policies on renewable energy materials, among others [17].

Renewable energy has witnessed significant reductions in installation costs, reducing global capital costs over the past decades. However, the benefits of cost reductions are seen in the developed world compared to the developing nations. For developing countries, giant steps towards renewable energy penetration require private sector investors whose objective is profitability, besides ensuring environmental sustainability. Moreover, the risks inherent in utility-scale renewable energy investments in such an environment require decision-making that considers risk reduction through optimal investment timing.

Utility-scale renewable energy projects in Africa and, for that matter, Ghana are scant, and as a result, there is limited data on costs, revenues, capacity factors and purchase obligations. Therefore, the limitation of this study is the utilisation of estimated values for the parameters of this study. As the technologies become more mature in Africa, data will be available in real-time, depicting the actual scenarios for such projects. However, in the absence of real data on costs and other variables, simulations represent the reality of the appraisal of renewable energy projects.

Further studies can investigate how governments can make decisions to drive investor interest in renewable energy. This includes levels of subsidies and FITs that are attractive for investors as they can be further researched. In addition, trade-offs between renewable energy generation increased FITs, and end-user tariffs can be further investigated to generate an optimal tariff scheme beneficial for industries, power generators and residential consumers.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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