Research Article

Optimal Investment Timing for Renewable Projects based on Binomial Tree Real-option-based Model: A Real-life Case Study of Iran

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Abstract
Encouraging foreign and private sectors to participate in renewable projects in developing countries, which not only experience rapid growth in energy demand but also encounter challenges in financing clean projects, presents a complex issue for their governments. To address this challenge, two contentious issues must be addressed concurrently: 1) accurate long-term valuation of Renewable Energy (RE) projects and 2) the assessment of the ideal timing for investments. This paper introduces a binomial tree real-option-based model as a valuable tool for valuing Renewable Energy (RE) projects and determining the optimal timing for investments in developing countries. Three key factors influencing project cash flow were considered in the calculation: Feed-in Tariff (FiT), Maintenance and Operation (M&O) costs, and energy production. Three scenarios were analyzed for exercising option to either improve project profitability, maintain the current profit, or prevent further losses. A real life case study involving a solar photovoltaic (PV) park in Iran has also been investigated to validate and verify the proposed model. The results revealed that, unlike traditional methods such as Net Present Value (NPV) which yielded a negative value suggesting that the project lacks financial viability, the option-based model demonstrated the project's investment potential by generating a positive value through the incorporation of option values inherent in growth projects.
Keywords: Investment decision analysis, Project valuation, Real Options Analysis, Sustainable Development, Photovoltaic Projects

Introduction

The consumption of fossil fuels in many countries poses a significant obstacle to economic growth and presents a high-risk constraint to sustainable development. (Aslani et al., 2012). The primary sources of fuel for electricity generation in The Middle East and North Africa (MENA) countries are predominantly natural gas and oil (IEA, 2020). Carbon-intensive technologies have a detrimental impact on the environment, exacerbate climate change, and pose risks to public health (Wagner, 2017) while the volatility of fossil fuel prices, along with the substantial capital requirements of conventional power plants intensify the negative side of their further

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exploitation. Although recent capital cost reduction has significantly influenced the development and penetration of renewable energies in power grids, the current generating capacity of REs in developing countries of MENA region represents a subtle fraction of the total installed capacity. In this situation, renewable project development regarding their competitive capital costs and environmental advantages over fossil fueled plants emerges as a secure and promising option for long-term energy supply in emerging economies as it can be concluded from leading economies' experiences (Erdogan et al., 2023; Kartal et al., 2024). Hence, further RE exploitation in power sector must be promoted by regulators and governments to gain investors' confidence.

Iran, as a developing country located in MENA region, is also following this trend. The country's energy sector heavily relies on inexpensive fossil fuels, posing potential environmental and economic challenges in the near future (Krupa, 2019). Iran supplies only 0.2% of its energy demand from renewable resources. Encouraging Foreign direct and private sector investment can play a profound role in complementing country's efforts to fund capital costs in further development of renewable energy projects. While Clean Development Mechanism (CDM), Feed-in Tariffs (FiT), and deregulation are among the various supportive mechanisms introduced by actuaries to facilitate investment in long-term clean projects and make them financially viable, it is evident that a robust valuation tool is necessary to further incentivize investment in RE projects in this country. In order to achieve this goal, a comprehensive valuation model that accounts for the risks inherent in the renewable energy investment environment is essential.

Generally, the risks arising from RE investments are broadly classified to market risks and private risks. RE market risks can be considered to be due to government policies (Bellakhal et al., 2019), market and economic factors (Krupa, 2019), technology improvements (Ren et al., 2021), and climatic factors (Hosseini et al., 2013). While the primary concern of investors is maximizing their profit from the investment, minimizing the exposure to downside risk associated with such investments must be accounted for in project valuation process. In the face of uncertainties, it may be of more value to take contingent decisions into consideration for postponing judgment on investment to gather more information and wait for favorable circumstances. Acknowledging managerial flexibility allows investors to optimize their decisions, minimizing losses and maximizing returns. It offers investors an opportunity to gain on the upside uncertainty and reduce the downside potential. Investment timing flexibility also provides investors additional value and mitigates potential losses arising from immediate investment with inadequate knowledge of market uncertainties. However, it poses the risk of competitors' entry and forgone cash inflows (Kachoee et al., 2018). Thus, renewable project valuation must be done by thoroughly considering uncertainties and factors influencing the project pathway. The irreversibility of investment, the uncertainties of future cash flow, and the availability of resources and technologies can be named as distinctive attribute of RE projects that must be dealt with properly.

Net Present Value (NPV) is an extensively used method in investment theory (Damodaran, 2012). Numerous analysts and other professionals in project valuation have taken advantage of NPV as a standard tool, which in many cases it served the purpose appropriately (Fisher, 1930; Dean, 1951; Fama, 1977; Bhattacharya, 1978). However, such traditional methods are not the best solution for evaluating RE projects with inherited uncertainty and high volatility. The core element of the Discounted Cash Flow (DCF) based models like NPV is based on the project's ability to compensate for the capital costs. Further, the assumption of risk as a fixed element in these approaches is a controversial issue (Shimbar and Ebrahimi, 2017; Espinoza, 2014). Such methods apply the same discount rate over the project lifetime without considering the reduction of systematic risks arising from flexible projects (Halliwell, 2001). Harpaz and Thomadakis (1984) argue that these methods do not take into consideration the lack of information about the future cash flow of a new project. In addition, DCF models have some sort of inconsistencies when it comes to RE investment evaluation in highly volatile environments such as developing countries due to the inherent characteristic of these projects including: 1) the irreversibility of investment costs 2) uncertainties in timing and amount of energy production 3) the high uncertainty of payoff 4) lack of collective information, technology maturity, and high investment risk 5) substantial dominance of national policies (Wang et al., 2014).

Real Options Analysis (ROA) is a complementary tool to overcome some limitations of previous models. Real options originated from financial options for real asset valuation and is fundamentally a right but not an obligation. It takes advantage of DCF method as a building block while incorporating uncertainty and flexibility in making investment decisions directly into the project valuation. ROA also reflects the impacts of volatile inputs like costs and revenues, technology changes, and policy and regulation instability on investment valuation. The main advantage of such valuation summarizes in two facets as it captures the upside potential value of the project by considering proper managerial action while at the same time limiting the downside risk. In general, ROA adds more value to high-potential projects that might be rejected due to misinterpretation.

There is a plethora of research conducted using different type of real options techniques for handling uncertainties and complications in RE projects investment valuation, but a few of them have been done in the context of developing countries. Accordingly, current study aims to offer a solid solution based on ROA methodology to encounter risky renewable energy investment in emerging economies. This research seeks to address three major questions: 1) how can a long-term renewable energy project in developing countries be effectively evaluated? 2) When is the best time to make carefully considered investment decisions? 3) To what extent do risks arising from various parameters impact the value of the RE project? In doing so, a real option-based model has been employed to analyze the renewable project value and estimate appropriate investment timing. Uncertainties related to energy production, government incentives programs and policies, and technological improvement in the RE industry have been taken into account in this study. The binomial decision tree integrated with the model enabled it to effectively incorporate flexibilities needed in the RE projects investment planning.

Real Options Analysis for RE Projects

Investments in renewable projects are often perceived as volatile and uncertain (Kim et al., 2017). The method used to evaluate these projects needs to meet various requirements, especially in developing countries where economic instability and political uncertainties are among the main concerns (Shimbar and Ebrahimi, 2020). Future uncertainties and an ever-changing environment can either negatively or positively impact investment, so it necessitates acknowledging managerial flexibility to adjust project pathways. Investment projects usually consist of several decision stages in which management can decide whether or not, and when to make the investment based on information gained throughout the process as uncertainties are resolved or reduced. Incorporating possible managerial actions can redirect a project's path in a way that is adaptable to changing conditions and can maintain or improve its profitability (Prasad Kodukula, 2006). In addition to this, the strategic position of renewable investments resulting from their intrinsic value adds more potential to the project, so it must be considered in investment appraisals.

ROA as a dynamic framework considers three main real-world factors of investment decisions: uncertainty, irreversibility, and flexibility (Dixit and Pindyck, 2012). Myers (1977) first analyzed ROA as the application of option pricing theory for the valuation of non-financial or "real" assets. ROA has also found its way into application in RE investment as its nature "the right, but not the obligation" favors risk-averse investors in deciding to invest in renewable projects (Das Gupta, 2021; Fleten et al., 2016; Liu and Ronn, 2020; Schröder, 2020). In a nutshell, ROA embedded in an investment project makes the project more valuable compared to the one without it since it offers investors the capability of change to account for the changing environment and maximize their gains.

Over the past few years, an appreciable number of research has been carried out by taking advantage of ROA as an analytical tool in RE investment valuation. Venetsanosa et al. (2002) presented an evaluation model for wind energy under uncertainties in the deregulation environment of the electricity market in Greece. The study outlines the impact of uncertainties after deregulation, compares valuation methodologies, and introduces a new approach using real options. Kjærland (2007) presented a conceptual framework based on the real option for estimating the value of investment opportunity in the hydropower industry in Norway by considering different timing and investment behavior. Kumbaroğlu et al. (2008) proposed a policy planning model using the integration of learning curve information on renewable technologies into dynamic programming featuring real options analysis. The research evaluated a set of investment alternatives through a backward recursive fashion on a yearly basis and concluded that the flexibility to delay has a significant impact on the diffusion prospects of renewable power generation technologies.

While real-option-based models add extra value to the high potential investment projects by involving managerial decisions in the investment process, complementary tools like the decision tree technique can improve their ability to be applied as a comprehensive valuation method in RE sectors. Such techniques contribute to option-based models to be more flexible in modeling uncertainties when projects are multistage investment projects and involve contingent decisions. Smith and Nau (1995) first utilized decision trees in energy investment analysis and then its usage was generalized to renewable projects by Espinoza and Rojo (2015). In this technique, future uncertainties are mapped on the branches of a tree, and probabilities of outcomes are assigned to each branch. Lee and Shih (2010) utilized a binomial tree structure to present an optimum policy framework for renewable energy development. Integrating cost efficiency into real options, the presented model quantitatively evaluated the policy value provided by developing renewable energy in the face of uncertainties in fossil fuel prices and policy factors.

Boomsma et al. (2012) analyzed investment timing and capacity choice for RE projects under different supportive schemes. The study considered feed-in tariffs and renewable energy certificate trading as the most extensively employed supportive mechanism to examine investment behavior. Wang et al. (2014) developed policy-benefit real option model for evaluating biomass power investment in china. Considering uncertainties in straw purchase price, government incentives, and technological improvements, they concluded that the immediate investment was not optimal. Kim et al. Kim et al. (2016) developed a real option-based framework to assess the economic feasibility of PV investment projects. The model considered changes in temperature and insolation as the main factors affecting photovoltaic outputs.

Kim et al. (2017) took in to account risks arising from uncertainties such as rapidly growing technology and host government condition to propose a real option framework for assessing renewable energy investment in developing countries. Agaton and Karl (2018) analyzed the dependency of investment timing in RE projects on the volatility of diesel prices, electricity prices, and the externality of using oil. The study results showed how waiting for investment in renewables incurs losses. A stochastic dynamic programming and real options model also utilized by Li et al. (2019) in their research to identify optimum feed-in tariff rate for wind power projects in china. They considered intermittency of renewable technologies as uncertainty.

Zhang et al. (2020) proposed a model based on recombining the trinomial tree model using changing volatility to generate transition probability. The changes in volatility is generated by considering the electricity market price, carbon price, and lending rate as multiple random variables. The authors concluded that the changing volatility may advance investment decisions and change the project value. Nunes et al. (2021) assessed different variations of option investment namely the switch-output option and the option to defer the project based on their future in the Brazilian electricity market. The study concluded that using the proposed approach clearly increases the value compared with traditional investment analysis methods.

Bangjun et al. (2022) established a real option model about photovoltaic power generation projects to investigate optimal investment opportunity, optimal installed capacity, and phased investment. Zhang et al. (2023) evaluated investment in a utility-scale solar power plant by applying a real-options method. The research considered electricity price time-varying volatility and lack of certainty in subsidy programs as the main sources of uncertainty. Finally, Li et al. (2024) investigate the impact of different RE support policies, specifically FiT and Tradable Green Certificates (TGC), on investor behavior and environmental value using real options theory and envelope theory within china's electricity market.

Most of the previous studies addressed the issues of RE investment using ROA by considering uncertainties related to electricity and fossil fuel prices, technology improvement, and RE policy issues. These studies improve the application of ROA as an assessment methodology to RE projects. However, only a limited number of studies have focused on addressing uncertainties and complexities in the energy markets of emerging economies. Accordingly, this study aims to offer a solution based on ROA applicable to the turmoil environment of developing countries by examining investment timing while considering other sources of uncertainty. Beyond uncertainties in tariffs, the study takes into account technical, market, regulatory, and economic uncertainties.

The main contribution of current study is to encounter the manifold difficulties in dealing with RE investment valuation in developing countries by offering a comprehensive but interpretable and easy-to-use approach. Second, the results supply power enterprises with meaningful information on making investment decisions in real assets like RE projects. Third, it helps policymakers in developing countries to scale up investment in the renewable market as a solution to both securing electricity supply and mitigating climate change. These contributions can greatly help developing countries that are net exporters of fossil fuels to take a big step toward sustainable development programs.

Binomial Tree Real-Option-Based Approach

The cash flow volatility is affected by risks from uncertainties. The higher the uncertainty, the higher the risk level and the higher the fluctuation of cash flow. Renewable projects in underdeveloped countries have some uncertainties over the project life cycle that can affect its value and change the project's pathway. Many investment projects with negative present values have the possibility to yield positive net present values when there is the option to defer or delay the investment for gaining new information and reducing uncertainties to some degree. Theoretically, the investor can decide whether or not to make the investment by reevaluating the investment project value each year. Assume a project with a lifetime of T and an initiation time of t. The investment value (V_t) is formulated as follows where (Π_t) is the present value of cash flow and (I_t) is the total investment cost:

$$V_t = \Pi_t - I_t \quad (1)$$

The sign of V_t determines whether the project is financially viable or not. The investment will occur if $\prod_t - I_t > 0$ and V_t is positive; otherwise, the project will be abandoned and the investment value is zero. This implies a call option with I_t as strike price and $\prod_t$ as asset value that is formulated in Equation (2):

$$V = Max(\Pi_t - I_t, 0) \quad (2)$$

There is a considerable body of literature that used different numerical methods for the evaluating real options, including Partial Differential Equations (PDE), binomial trees (or lattice), simulation, fuzzy set based approaches, and dynamic programming. However, in his research, Zhao (2018) concluded that the binomial tree method has the best performance for evaluating options efficiently.

The binomial tree model used in this study is based on the project underlying asset value (S) and the project value under proposed options. It is assumed that the underlying asset value of the project can increase or decrease at each time step (Δt) throughout option life ($\tilde{t}$) via a ratio determined by constant risk-neutral probabilities (q) and underlying asset volatility (σ). Risk-neutral probabilities allow the proposed model to adjust the risk in cash flow toward neutral. Thus, if the current underlying asset value is S_0, it will be uS_0 in upward movements and dS_0 in the downward movements where u and d correspond to up and down coefficients. Let r be the risk-free interest rate, then:

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

$$d = \frac{1}{u} \tag{4}$$

$$\tilde{V} = e^{-r\Delta t}[qS_u + (1-q)S_d] \tag{5}$$

Here, S_u and S_d referred to underlying asset value associated to up and down movements. The option value at each node is calculated step-by-step in a backward recursive fashion from the last time step to the current step using Equation (5). The investor can decide among alternatives of investing in the project and deferment of investment in the period of option to defer, as each one is a more economically favorable decision. Hence, the total project value including real options value (TV) is recalculated as in Equation (6):

$$TV_{ij} = max\,(V_{ij}, \tilde{V}_{ij}) \tag{6}$$

Since the investment can be exercised at any time step that brings benefits in option life, it is considered as an American call option to defer. In brief, the proposed methodology can be summarized in the following steps:

Step 1: Calculate the underlying asset value at each node of the binomial tree model in option life for deferring investment. The current asset value is the underlying asset value at $t = 0$.

Step 2: Calculate the investment value under provided option value step-by-step in an awkward recursive fashion from last time step to first time step according to Equation (5). The option value in the first step is the project total investment value under the rule of real options.

Step 3: Make a decision according to Equation (6) at each node in binomial tree (i, j), which means that the investor will defer investing if the option value at that node is greater than the investment value.

Step 4: Make the final decision at each node in the last year of options life according to obtained option value.

In the following section, a solar park in Iran is considered as a case study to evaluate and validate the presented model. The reason for selecting Iran is that the country had an increasing rate of energy demand over the last decades and an excellent potential for solar renewable energy production because of its high exposure to sunlight which is 17% higher than the global average (Breyer and Schmid, 2010).

Case Study: A Solar Park in Iran

Case description

The electricity consumption in Iran has reached the peak of its production capacity (about 51 GW) over the last few years. Electricity shortage in the country is unavoidable in the upcoming years as electricity demand has been predicted to grow by 6% per year while growth in its generation is limited to less than half of that amount. Iran is now supplying only 0.2% of its energy using renewable resources, which encouraged the government to draw a plan for moving away from fossil fuel resources in power plants to low carbon form of energy supply as can be inferred from its 5th and 6th development plans (2010 to 2015 and 2016 to 2020) for the installment of the renewable capacity of 5,000 MW. In addition to this, the Iranian government has now set a new target to install an additional 2,500 MW renewable power plant by 2030. This ambitious target requires private and public-private investment foundations to engage in and partner with the government in RE projects. In doing so, an effective analysis tool that assesses RE project value and determines potential investment timing plays a major role.

In this paper, the proposed case study is a photovoltaic power station with a generation capacity of 35 MW located in Tehran, Iran. The contract is organized as public-private funding and is going to generate electricity for the next 20 years. Details of the project regarding the most likely condition (base scenario) are listed in Table 1.

Table 1. The case study details based on base scenario

Items	Values
Installed generation capacity	35000 kW
Type of power plant	photovoltaic
Total project cost	US$ 11.20 Million
Construction period	2 years
Exploitation period	20 years
Risk-adjusted discount rate	20%
Risk-free interest rate	18%
O & M costs (yearly)	US$ 0.37 Million
Feed-in Tariff ($/kWh)	0.046 $/kWh

Classic NPV analysis

The expected annual revenues and costs need to be calculated in order to perform NPV analysis. Energy production forms the main part of annual revenue for renewable power plants; so, it must be calculated deliberately. For this purpose, the following equation has been used:

$$P_t = kwp \times h \quad (7)$$

Where P_t is total annual power generation, *kwp* is the nominal capacity of the solar power plant (in this case 35000 kW), and h is the average irradiation factor. Renewable energy production is highly dependent on renewable resources which is difficult to predict. In our case study, the most likely situation for the irradiation factor has been taken into calculation using the global atlas solar map for the Middle East and North Africa (MENA) region. Accordingly, the average irradiation factor (h) is approximately equal to 1439 kWh/kWp which implies a high potential location for harnessing solar energy. Moreover, the project site enjoys about 300 sunny days yearly which indicates its potential for generating electricity.

According to the International Renewable Energy Agency's (IRENA) recent report, globally the total cost of PV projects is 490 $/kwp; however, the lower cost of required labor and land in underdeveloped countries like Iran suggests the total cost of 320 $/kwp which is remarkably lower than the global average cost. The Feed-in Tariffs (FiTs) rate in Iran is provided by the renewable energy organization of Iran (SUNA) regarding different technologies devised for harnessing energy from natural resources. In the case of solar technology, the guaranteed electricity purchase tariff is 0.036$ per KWh. FiT increased by 2.2% yearly commensurate with the inflation forecast for the dollar in 2024 (https://data.oecd.org/price/inflation-forecast.htm). Following the SUNA policy, FiT was also reduced by 30% after 10 years of production. The annual maintenance and operation costs (M&O) are 3% of total installed costs according to IRENA. It is also assumed that the yearly generation capacity shrinks by the coefficient factor of 0.5% yearly. The free cash flow can be calculated by having the key parameters after subtracting the 25% tax rate. Table 2 represents the project's expected cash flow.

The common expected rate of return applied in Iran's RE sector is 18%, and by adding a 2% premium for the country's risk, the conventional NPV is a negative value of US$ -1.98 million. Therefore, as the negative value obtained from NPV analysis implies, the project is not worth investing in and it may have investors to decide not to take part in the project.

Real Options Valuation

The underlying asset value

The value of the underlying asset is one of the main input parameters in the options valuation. The asset value in real options is estimated from the expected cash flow over the project life cycle. In this study, we considered a solar renewable energy project which generally has a useful life cycle of 25 to 40 years. However, due to technological and operation & maintenance circumstances in the case study, the minimum lifetime of the project regarding 2 years of construction period is considered to be 22 years. So, the underlying asset value is defined as the present value of the yearly discounted future cash inflow of the project at a discounted rate of *r* over the project exploitation period:

$$\Pi = \sum_{t=1}^{T} \frac{E(CF_t)}{(1+r)^t} \tag{8}$$

$$E(CF_t) = R_t - I_t \tag{9}$$

$$R_t = PG_t \times FiT_t \tag{10}$$

$$h = CAPA \times 8760 \text{ hours} \tag{11}$$

In Equation (8), $E(CF_t)$ is expected cash flow in the period of *t* and *r* is the discount rate. In Equation (9), I_t expresses the summation of maintenance and operation costs and revenue taxation in each year. The yearly revenue of the project (R_t) is determined by the amount of power generation multiplied by feed-in tariffs as shown in Equation (10). The amount of yearly power generation depends on the solar plant total installed capacity, the system capacity factor (CAPA) and the power plant working hours in a year, as outlined in Equation (11).

Table 2. The project cash flow in the base scenario (MM$)

	1	2	3	4	5	…	16	17	18	19	20	21	22
Installed capacity (MWp)			35.00	34.83	34.65	…	32.79	32.63	32.46	32.30	32.14	31.98	31.82
Average radiation factor (kWh/kWp)	1439	1439	1439	1439	1439	…	1439	1439	1439	1439	1439	1439	1439
Feed-in Tariff ($/kWh)	0.036	0.0368	0.0376	0.384	0.0392	…	0.0349	0.0357	0.0365	0.0373	0.0267	0.0273	0.0279
Total power generation (GWh)			50.37	50.11	49.86	…	47.19	46.72	46.72	46.48	46.25	46.02	45.79
Total Revenues			**1.89**	**1.92**	**1.95**	**…**	**1.65**	**1.68**	**1.71**	**1.73**	**1.23**	**1.26**	**1.28**
Total installed costs	(15.3)	(22.9)				…							
Total M&O costs			(0.34)	(0.34)	(0.34)	…	(0.34)	(0.34)	(0.34)	(0.34)	(0.34)	(0.34)	(0.34)
EBIT			**1.55**	**1.58**	**1.61**	**…**	**1.31**	**1.34**	**1.37**	**1.39**	**0.89**	**0.92**	**0.94**
Income Tax (25%)			0.39	0.4	0.4	…	0.33	0.34	0.34	0.35	0.22	0.23	0.24
Net operating income			1.94	1.98	2.01	…	1.64	1.68	1.71	1.74	1.11	1.15	1.18
Free cash flow	**(4.48)**	**(6.72)**	**1.94**	**1.98**	**2.01**	**…**	**1.64**	**1.68**	**1.71**	**1.74**	**1.11**	**1.15**	**1.18**

The volatility of project value

The project's volatility measures the variability of the total value of the underlying asset over the project life cycle. The framework proposed in this study considers three variables that have the most influence on renewable projects' cash flows: Feed-in Tariff (FiT), Maintenance and Operation costs (M&O), and energy production. These variables are selected for the following reasons. First, FiT is a policy mechanism that offers long-term contracts to RE investors to accelerate investment in renewable projects based on each generation technology cost. The establishment of such schemes plays an effective and supportive role in RE investment as it compensates initial investment costs and covers inflation. FiT can also be connected to other supportive programs like tax exemption or capital subsidies. It is adjusted annually according to both the inflation rates in the country and the governments' RE policy schemes. Developing countries are characterized by unstable economies with high inflation and interest rates; so, in situations like sanctions or war, authorities might have limitations in financing their activities and FiT reduction can be an alternative for administration.

Second, the M&O cost is another factor in RE project valuation that can reflect high inflation and interest rate, so it poses an unavoidable risk in renewable projects. M&O costs involve preventive maintenance, solar panel repair, and other expenses for the commercial management of the solar plant (Steffen et al., 2020). The risks stemming from M&O costs are related to operation costs soaring, terminating the contract with the current provider, and signing a more expensive contract with another maintenance provider. Therefore, the volatility related to M&O costs can impose uncertainty on cash flows which must be carefully considered in the calculation.

Third, PV energy production highly depends on the efficiencies of PV cells and panels, solar irradiation or insolation, and ambient temperature. Solar cells available in the market convert up to 24.6% of the energy they receive to electrical energy while, under controlled conditions, laboratory-scale cells can be 46% efficient. Besides, the position of the sun above the solar panels and the atmospheric conditions greatly affects the amount of irradiation received by PV panels. Thus, it can remarkably vary based on area and day of operation and is a critical parameter in the estimation of energy production. In order to consider different situations, a three-point scenario based on the aforementioned variables as inputs have been conducted for real option valuation. An optimistic (best) scenario refers to a situation where all the input variables of tariffs, O&M costs, and energy production are at the best level. The pessimistic (worst) scenario deals with situations where input variables yield the worst values, while the base (most likely) scenario is the situation between the worst and the best case. Table 3 shows different scenarios used for the calculation of cash flow.

Table 3. Input variables in three-point scenario

Variables	Best case	Base case	Worst case
Feed-in-Tariff (FiT)	$\text{Feed-in-Tariff}_{best}$	$\text{Feed-in-Tariff}_{base}$	$\text{Feed-in-Tariff}_{worst}$
M & O costs	$\text{M \& O costs}_{best}$	$\text{M \& O costs}_{base}$	$\text{M \& O costs}_{worst}$
Energy production	$\text{Energy production}_{best}$	$\text{Energy production}_{base}$	$\text{Energy production}_{worst}$
combined	$cash\ flow_{best}$	cash flow_{base}	cash flow_{worst}

Supposing that the project income follows a lognormal distribution, the volatility of underlying asset value can be calculated as follow:

$$\sigma = \frac{ln\left(\frac{S_{opt}}{S_{pes}}\right)}{4\sqrt{T}} \tag{12}$$

Where S_{opt} refers to underlying asset value in the best scenario, while S_{pes} indicates the value of the underlying asset in the worst scenario, and T is the project exploitation period.

Leakage rate

Despite the fact that the option to wait offers investors the potential value, it also poses some costs for every period that the investment is delayed. The opportunity cost of delay can be simulated as forgone cash flow. The more an investment is delayed in terms of holding the option open, the more loss in potential cash flow. In addition, the entrance of competitors that are able to gain a strategic advantage in a competitive environment would make the leakage or the opportunity costs greater.

The leakage rate varies depending on the project and investment environment. It can be at a constant rate or varying rate, a single cash payment, or a variable with time or underlying asset value. Adjusting the option model to account for these leakages makes the model more realistic. For this analysis, the risk-free rate in risk-neutral probability is replaced by the difference between the risk-free rate (r) and the leakage rate (l) in order to present the varying leakage rate for investment waiting:

$$q=\frac{(e^{(r-l)\Delta t}-d)}{u-d} \tag{13}$$

Option value

Determining the option value of the project within the ROA framework initially requires the estimation of future cash flow in different scenarios. The values of key variables using a three-point estimation of best, base, and worst scenarios are specified for the calculation of volatility of project cash flow. The values of three variables in each scenario are shown in Table 4. In the case of the feed-in tariffs, it is assumed that the value of the base case increases by 40% present for presenting value in the best case and decreases by 40% to show the value in the worst case. The M&O costs in the base case also fluctuate in the range of 40% of its base case value to express the worst and best case values, respectively. Since the capacity factor influences energy production, it works as a key energy generation factor and its mean value of 16.4% is considered in the base scenario. The best value for the capacity factor is supposed to be 24.6%, and it is assumed to be 8.2% for the worst case, nearly 50% above and below its mean value respectively. Using Equation (12) and the values of variables in three-point scenarios, the volatility of the project cash flow is estimated to be 16.74%.

Table 4. Input variables in three-point scenario

Variables	Best case	Base case	Worst case
Feed-in-Tariff (FiT)	0.0644 $/kWh (140%)	0.0460 $/kWh (100%)	0.0276 $/kWh (60%)
M&O cost	0.45 MM$ (60%)	0.76 MM$ (100%)	1.06 MM$ (140%)
Capacity Factor (CAPA)	24.6%	16.4%	8.2%

The option value of the project can be calculated by having the value of parameters following the explained procedure. In the first step, the underlying asset value of the project was calculated to be $10.10 million using the base case cash flows illustrated in Table 2. The project volatility value and the time interval of option life determine the value of the upward movement coefficient to be 1.15 while, from Equation (4), the value of the downward coefficient is 0.87. The annual cost of delay was calculated to be 14%, and the risk-free discounted rate was assumed to be 18%. By considering these values and using Equation (13), the risk-neutral probability of the project was calculated to be 62%. Table 5 shows input parameters for real option valuation. The underlying asset values in upward and downward movement throughout the binomial tree branches were calculated using respected equations. The upper value of each node in Figure 6 illustrates the expected future value of the underlying asset.

Table 5. Input parameters for real options model.

Items	Values
Underlying asset value (S_0)	USD$ 10.67 million
Option life ($\tilde{t}$)	4 years
Time interval (Δt)	1 year
Volatility (σ)	13.64%
Leakage rate (l)	14%
Risk-neutral probability (q)	62%
Upward Coefficient (u)	1.15
Downward Coefficient (d)	0.87

In the second step, the investment value in the base scenario under provided option was discounted back step by step to the present time. The use of Equation (5) requires considering underlying asset values of up (S_u) and down (S_d) movement in the next level. The project option value (strategic net present value, SNPV) regarding the proposed framework was calculated to be $0.70 million. The multistage of investment decision timing regarding the proposed option model is shown in Figure 1.

At each node of the binomial tree, Investors can decide whether to invest in the project or defer the investment to the following year. The economically favorable decision is determined among the alternatives of investing the capital investment cost (It is assumed that the capital costs decline due to technology maturity, rising learning curve, and economies of scale; however, it is offsetted by changes in inflation and exchange rate) and deferring the investment in the period of options life. The decision is based on comparing option value with the project expected underlying asset value at each point. For instance, the asset value in year 1 at the best situation (node 2) is about $11.58 million which means the investment would result in a net present value of $0.38 million; however, keeping the option open until the next year when the option value is expected to be $1.25 million based on the expected future decision is more rational. In the same year, the underlying asset value in the worst situation would result in the expected net present value of -$2.39 million while if the investor keeps the waiting option open, the expected option value will be the positive value of $0.19 million. The same procedure goes on till the fourth year which is the final year of option life. At this time, the investor has to make the ultimate decision regarding whether to invest in the project at the expense of $11.20 million or abandon the project. In the case that the project is economically feasible, in nodes 11 and 12, the investment would be executed. The option value at node 11 is $6.23 million presenting a more ideal situation compared to $2.07 million at node 12. Nodes 13, 14 and 15 present the cases where the project is regarded as unfeasible and the decision would be to decline the investment. The real options value (ROV) of the project equals $0.70 million which represents the project as a potential investment even though it contradicts the result of classic NPV. The additional value proposed by the options defines as the difference between ROV and NPV which is $2.68 million. Such substantial additional value may have the investor consider alternatives other than abandoning the project at the first stages. It highlights the value of waiting and offers a strategic roadmap for future contingent investment decisions.

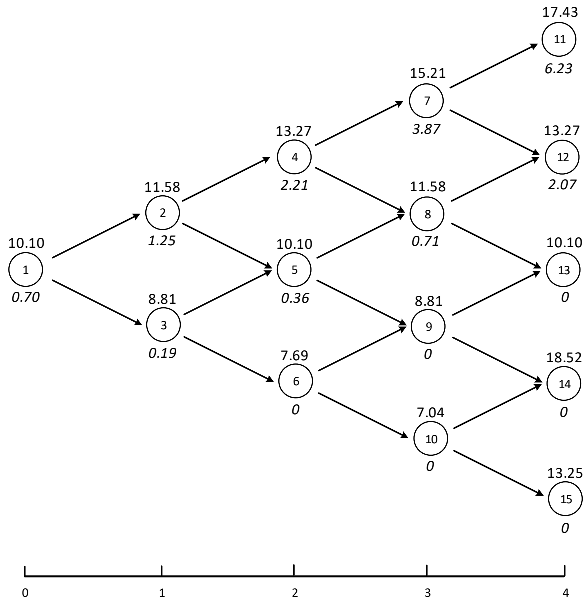

Figure 1. Binomial lattice for calculation of options and underlying asset value

Results and Discussions

Three parameters affect the real options value of the proposed framework: volatility (σ), leakage rate (l), and discount rate (r). In order to examine the changes in options value, a sensitivity analysis is carried out given the changes in these parameters. For this purpose, six scenarios are considered for each of these parameters as the main assumptions: 1) 75% reduction of the base case value, 2) 50% reduction of the base case value, 3) 25% reduction of the base case value, 4) 25% increment of base case value, 5) 50% increment of base case value, and 6) 75% increment of base case value.

Changes in volatility reflect fluctuations in the revenue and costs of the project, specifically related to feed-in tariffs, M&O costs, and energy production. The greater the volatility of a project's underlying asset value, the higher the value that options model provides. This is due to the combination of higher FiT rates, reduced M&O costs, and improved performance of the generation system. When volatility increases by 75% and the underlying asset value of the project is volatile at 23.9%, the options value peaks at 1.14, reaching its highest level.

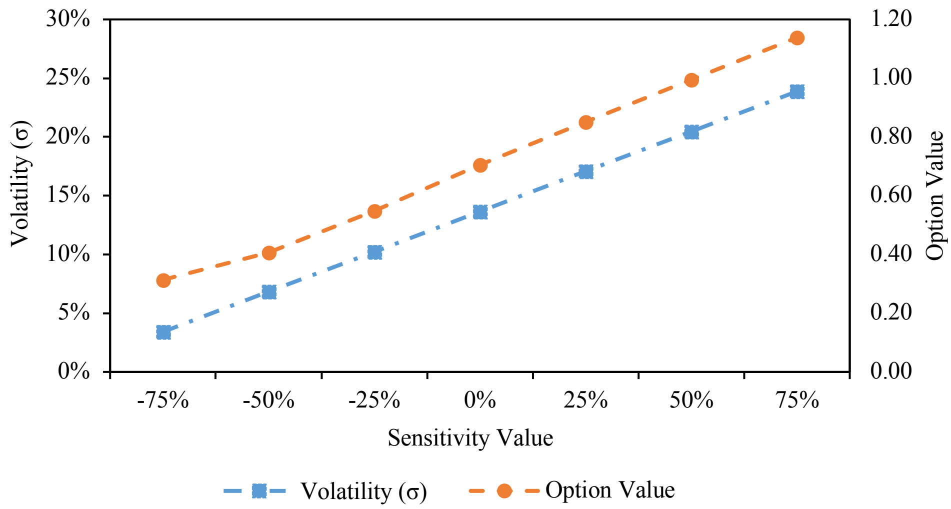

Figure 2. Options value sensitivity to underlying asset volatility (σ) changes

Conversely, when the project's volatility is lowered to 3.4%, the options value decreases to 0.31 (refer to Figure 2). As expected, government subsidies play a critical role in offsetting the investment cost of renewable energy. Nevertheless, even in the scenario where volatility increased by three-fourths of its base rate, the options value increased by around 63%.

In a separate scenario, a significant rise in the leakage rate led to a sharp decline in the options value, with a 75% increase resulting in the options value dropping to zero. Therefore, when penalties increase or a higher opportunity cost is imposed for delaying investment, the project's options value decreases. On the other hand, a 75% decrease in the base value of the leakage rate results in the options value skyrocketing to 3.33 (see Figure 3). This can largely be attributed to the significant impact that opportunity cost has on deferment options.

The third case examines how fluctuations in discount rates affect the value of options. Fluctuations in the discount rate directly impact the value of options. An increase in the discount rate results in a rise in option value up to 2.61, whereas a decrease in the discount rate lowers the option value to a minimum of -0.01 (see Figure 4). The data reveals a direct relationship between the discount rate and the value of the options.

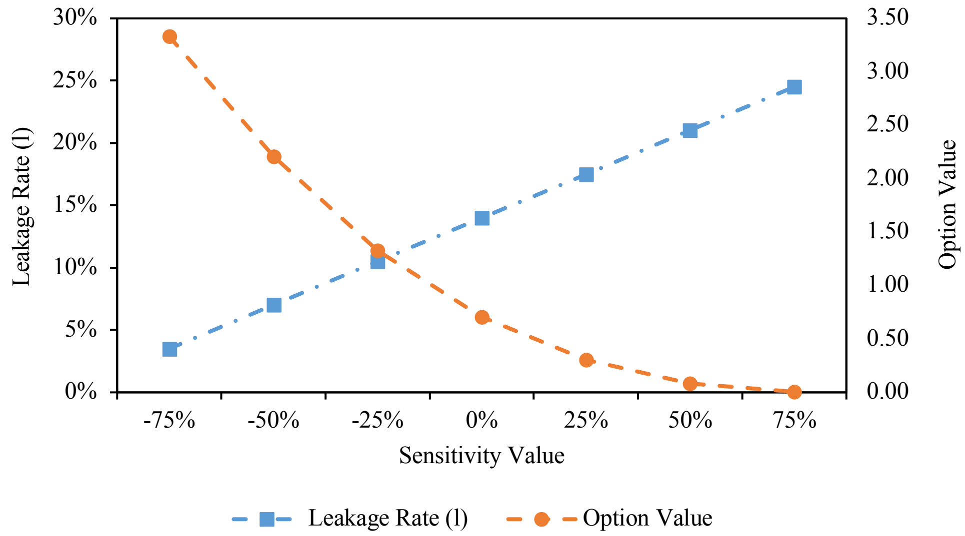

Figure 3. Options value sensitivity to leakage rate (r) changes

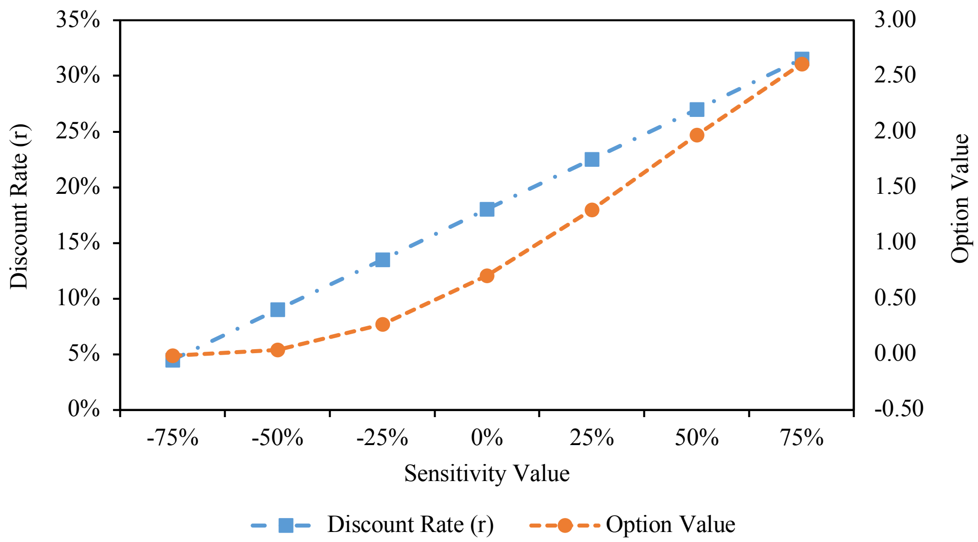

Figure 4. Options value sensitivity to discount rate (l) changes

In consonance with MacDougall (2015), the findings highlight that leakage rates and discount rates play a crucial role in shaping the investment decisions of investors in renewable energy markets while the underlying asset volatility slightly influences its value (Figure 5). The sensitivity outcomes of leakage rate and discount rate totaled more than 90%, meaning that these two strongly impacted the option value of the case study project. In brief, the sensitivity analysis of the case study highlights the necessity of policy support for the flourishing of renewable energy investments, enabling them to compete effectively with conventional fossil fuel-based energy resources. Insufficient political resolve and a dearth of policy backing pose significant risks to investors.

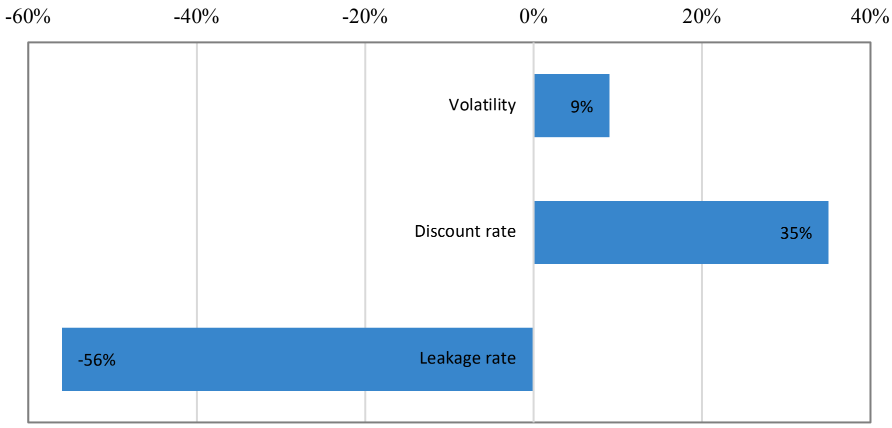

Figure 5. Sensitivity analysis final result of parameters impact on options value in case study options value.

Managerial Insights

Evaluating investment projects using traditional methods is somehow influenced by Boolean logic that implies taking or leaving the project. In the real world, possible managerial actions can change the project path in order to adapt to changing conditions and maintain or enhance its profitability. The ROA framework provides decision makers additional information to ease the investment decision when an investment project is almost equal to present value of net payoff or in the gray zone. The Real Options Value (ROV) of a project serves as a measure of the potential profitability of an investment. The greater the Real Options Value (ROV) of a project, the higher its potential for upside gains. Managerial flexibility can take advantage of this salient feature of real-options-based model to re-evaluate promising project that rejected due to misinterpretation of controversial methods.

Private risk is another type of uncertainty that the proposed evaluation model enables managers to deal with adequately. It is related to technical success probability and successful completion of the project within the specified timeframe and budget constraints. Typically, this uncertainties are referred to as technical uncertainty and can be resolved by active or passive learning. The study results offered actuaries and other financial DMs useful information to mitigate private risks by enabling then to decide whether or not, and when to make an investment in RE projects in a highly uncertain environment. Based on the aforementioned results, the following managerial insight can be derived.

- Preparing situation for conducting active learning in which up-front management action involves till related uncertainties are cleared or decreased to some degree. Therefore, the project could be fully implemented as initially intended, downsized, or even completely abandoned.

- The model by means of decision tree allows mangers to test the effectiveness of the solution by executing up-front investment (active learning) or simply wait until uncertainties be cleared by a competitor (passive learning) which stymie gaining the first-mover advantage.
- Enabling decision-makers to negotiate the riskiness of the path that the project might go through and reach an agreement on a feasible risk management mechanism. It has the advantage of considering flexibilities and uncertainties that are characteristics of investment decisions.

Conclusions

In this study, a binomial tree real-option-based model was proposed to assess RE investment from the perspective of risk-averse investors. It showed that using classical models like NPV in the investment feasibility of long-term renewable plants might lead to the misinterpretation of promising projects. These tools have some limitations in dealing with highly uncertain investment projects, especially in cases where contingent decisions are a factor. Although there are many investment valuation tools that are targeted to attract investors into renewable projects, the proposed approach is a practical and convenient tool that doesn't require complex computation and elaborate historical data. In this study, the proposed method utilizes the key variables of PV projects in the unstable environment of developing countries including Feed-in tariff, M&O costs, and energy production to evaluate investment feasibility. By considering managerial flexibility where investors can change the course of the project, the presented model showed that the project has a positive value generated by the option characteristic of the project related to high uncertainty.

The presented application example of valuing investment in a solar park proved that the method is capable of yielding distinct and reliable results. The study results show that while traditional NPV with a predefined risk-adjusted discount rate interpreted the project as not financially viable by reporting negative value of US$ -1.98 million, the proposed ROA model contradict that result by showing a positive options value of $0.70 million. It presents the potential value of the project that can offer high profit to investors and the government. According to the options values on each node of binomial tree, investor can make investment at the first year where the project brings them the highest options value in node 2 while the project provides much lower positive value in node 1. Investors can also increase their profit by waiting till second year when at the best situation in node 4 the options value is $2.21 million. In the same year, however, the options value can decrease to $0.36 million or even reach to zero, meaning that the project is not profitable. At the end of year 4, the investor cannot wait any longer to invest because the option expires. In brief, nodes 2, 4, 7, 11 bring investor the highest options values while nodes 3, 5, 8, 12 offer lower positive options value throughout option life. Furthermore, making investment in node 6, 9, 10, 13, 14, 15 is not financially viable and investing in project in these situations is declined. The sensitivity analysis shows that leakage rate and discount rate are the dominant drivers in determining the option value of the project. The leakage rate negatively influences the option value while the discount rate has a positive correlation with project strategic value. They account for 56% and 35% changes in options value respectively. Although volatility does influence revenues and costs of the project, the other two parameters totally have a stronger impact on the option value of the case study project. In summary, it can be concluded that investors must put more weight on the importance of the leakage rate and discount rate determined by government policies.

Renewable energy projects are still in their early stages in Iran and, for that matter, data on costs, revenues, capacity factors, and purchase obligations are limited. As a result, estimated values based on literature review have been used for parameters in this study. As technologies mature and more renewable energy projects are developed in the region, real-time data will provide accurate depictions of project scenarios. Nevertheless, without actual data on costs and other variables, simulations serve as a reliable means to assess the feasibility of renewable energy projects. The authors believe that the framework presented in this paper has the potential to be adapted by other renewable investment projects in developing countries, offering mutual benefits to investors and host country alike. Further studies can strengthen the body of investment decision literature by incorporating state-of-the-art sciences like big data analysis approaches in determining the influence of uncertainties in developing countries. The uncertainty in the exchange rate is also another direction of this research in the future studies.

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