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A Valuation of Onshore Wind Energy Investments Using a Real Options Approach: The Case of Onshore Wind Energy in Türkiye

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Reel Opsiyon Yaklaşımı ile Kara Tipi Rüzgâr Enerjisi Yatırımlarının Değerlemesi: Türkiye'de Kara Tipi Rüzgâr Enerjisi Yatırımı Örneği

Abstract

This paper aims to evaluate the investment value of an onshore wind farm in Türkiye using traditional methods and the simple abandonment-option approach, and to demonstrate how real options analysis captures the value of managerial flexibility under uncertainty. The results indicate that the onshore wind farm project is more sensitive to changes in electricity prices, discount rates, installed costs, and capacity factors, respectively. The abandonment option increases the strategic net present value by $65,583, reaching $2,811,575, while the project value with flexibility is $17,120,419. This paper contributes to the literature on the country-specific valuation of onshore wind energy investments.

Keywords : Investment Valuation, Renewable Energy Sources, Real Options, Binomial Tree.

JEL Classification Codes : D81, G11, G31, Q42.

Öz

Bu çalışmanın amacı, Türkiye'de bir kara tipi rüzgâr enerjisi yatırımını geleneksel proje değerleme yöntemleri ve terk etme reel opsiyon yaklaşımı kullanarak değerlemek ve reel opsiyon analizinin belirsizlik altında yönetimsel esnekliğin yatırım değerini nasıl etkilediğini tespit etmektir. Duyarlılık analizi sonucunda kara tipi rüzgâr enerjisi yatırımının sırasıyla elektrik fiyatlarındaki, iskonto oranlarındaki, kurulum maliyetlerindeki ve kapasite faktörlerindeki değişikliklere daha duyarlı olduğu sonucuna ulaşılmıştır. Terk etme opsiyonu ile birlikte yatırımın stratejik net bugünkü değeri 65.583 $ artarak 2.811.575 $'a ulaşırken, yönetimsel esneklikle birlikte yatırım değeri 17.120.419 $'a yükselmiştir. Bu çalışma, karasal rüzgâr enerjisi yatırımlarının ülke bağlamında değerlemesine yönelik literatüre katkı sunmaktadır.

Anahtar Sözcükler : Yatırım Değerleme, Yenilenebilir Enerji Kaynakları, Reel Opsiyon, Binom Ağacı.

1. Introduction

The United Nations General Assembly adopted the Sustainable Development Goals in 2015, establishing a comprehensive framework for global collaboration to achieve a sustainable future for the planet. Agenda 2030 includes 17 Sustainable Development Goals and 169 associated goals, which focus on eradicating extreme poverty, combating injustice and inequality, and safeguarding the environment. Energy lies at the core of the 2030 Agenda. Sustainable Development Goal 7 ensures access to affordable, reliable, sustainable, and modern energy for all. Achieving Sustainable Development Goal 7 is increasing the proportion of renewable energy in the world's energy mix and energy efficiency worldwide.

The global transition to renewable energy is essential for sustainable development and for preventing catastrophic climate change. Wind technology is at the forefront of this transition, supporting the goals of the 2015 Paris Agreement (IEA, 2021). In 2024, with 117 GW of wind power installed, this energy source is expanding into new regions and solidifying its role as a key component of the global energy transition. According to GWEC Market Intelligence, new installations are projected to exceed the previous record, reaching 138 GW by 2025. Over the next five years, a total of 982 GW of new capacity is expected to be added under current policies, averaging 164 GW annually until 2030 (GWEC, 2025). Annual financial commitments in onshore wind energy have increased to $140.70 billion, with a 117% increase (IRENA & CPI, 2023).

Global developments and Türkiye's ratification of the Paris Agreement have compelled the country to take strategic action in renewable energy. These external commitments coincide with domestic pressures; the impressive growth in Türkiye's population and industrial landscape has sparked a dramatic increase in electricity consumption. While this is exciting, it also highlights a challenge: current electricity production struggles to keep up with this rising demand. Consequently, Türkiye relies heavily on foreign energy sources, resulting in a considerable current account deficit and raising serious environmental concerns associated with non-renewable fossil fuels. This situation presents an urgent opportunity to pivot towards more sustainable energy solutions. Research conducted in 2016 revealed that the most significant concern within the Turkish energy system was its dependence on imported energy. Subsequent studies from 2017 to 2019 highlighted the increasing burden of expensive energy (Ediger et al., 2017, 2018, 2019). Leveraging renewable energy sources is crucial for reducing this reliance and mitigating escalating energy costs. Increasing renewable energy production can significantly enhance national energy security, reduce reliance on energy imports, fuel economic growth, and lower trade deficits. Moreover, a substantial increase in renewable energy usage may play a key role in stabilising oil and natural gas prices, ultimately benefiting consumers and businesses (Öztürk, 2014: 2).

Türkiye ranked among the top 10 countries for onshore wind electricity generation in 2022, producing 34.945,4 GWh. The installed onshore wind energy capacity in Türkiye reached 12,973 MW in 2024 (IRENA, 2025). Despite positive developments in the wind energy sector, progress in the renewables sector is assessed as "slow progress" in Türkiye. Türkiye needs to adopt additional policies and actions to halt emissions growth and begin reducing them to achieve decarbonization. The Roadmap for Renewable Energy to 2035 policy of Türkiye, combined with investments in grid infrastructure, is a crucial step towards decarbonising the grid. The recently announced Roadmap aims to deploy renewables at a rate of "at least" 7.5-8 GW a year until 2035, along with investments of USD 28 bn to upgrade the grid. To improve its climate targets and action rating, Türkiye could strengthen its wind and solar targets to bring 150 GW of capacity online by 2035 and enhance and substantiate its recently submitted long-term climate strategy to reach net zero by 2053. Türkiye could also set a stronger 2030 Nationally Determined Contributions (NDCs) target and submit a 2035 NDCs that go beyond current policies and drive emissions reductions (CAT, 2025).

The increasing investments in wind energy, government incentives, and global sustainable development commitments highlight the importance of valuing wind energy investments. Traditional valuation methods, such as the payback period and net present value, often fail to capture uncertainty and managerial flexibility. More sophisticated financial tools are needed to assess renewable energy investments, as policy, price, and technological uncertainties significantly affect investment decisions in the sector. Frolova et al. (2025) analysed abandoned renewable energy power plants in Europe and South America. They identified reasons for abandonment as economic issues, poor planning, lack of management, technological issues, and other interests. Abandonment of renewable energy plants should be considered in the valuation of renewable energy investments, as Mun (2006:32) states that the strategic abandonment option has significantly increased the investment's value and hedged its downside risk.

Global and domestic developments, as well as national net-zero commitments, underscore the value of renewable energy investments in Türkiye, which has a slowly progressing renewables sector and significant potential. This paper aims to value an onshore wind farm investment in Türkiye using the abandonment options approach and to demonstrate how real options analysis captures the value of managerial flexibility under uncertainty. The results of this paper are significant for wind energy investments in Türkiye, which has high potential but has made less progress in the renewables sector. This paper contributes to the existing literature by modelling onshore wind energy investments in depth using real options for abandonment and sensitivity analysis. This paper fills a gap in the literature concerning country-specific valuation of onshore wind energy investments in Türkiye. This paper contributes to the literature by focusing on future abandonment decisions for onshore wind plants, which pose an increasing risk to valuation and the planet.

The paper is structured as follows. Section 2 details the literature on real option valuation of wind energy investments. Section 3 presents the research model, methods, data, and assumptions for the financial model of onshore wind energy investment. Section 4 discusses the results and their implications. Section 5 is the conclusion.

2. Literature Review

The energy sector faces significant uncertainty due to volatility in energy and energy commodity prices in international markets. Investment projects in this sector are time-consuming, large-scale, and high-cost (Lin & Wesseh Jr., 2013: 475). These uncertainties in the energy sector significantly impact the feasibility of energy investments. Conventional capital budgeting methods often fail to account for expected market uncertainty.

Wu and Sun (2015) conducted a comparative analysis of methods used across different projects by surveying Chinese enterprises about their evaluation practices for wind power projects. Their findings revealed that Chinese enterprises primarily relied on traditional methods, specifically, the income method and the market method, to assess wind power projects. Only a small percentage of companies utilised the relatively new real options method. The enterprises indicated that their reluctance to adopt this method stemmed from its difficulty in meeting the internal rate of return standards.

The real option method, which incorporates management's decision flexibility in response to uncertainty into the model, is widely used in the valuation literature on renewable energy investments, even though the industry has not fully adopted this method, as shown by the results of Wu and Sun (2015). Table 1 summarises various studies that have utilised the real options method to analyse the feasibility of wind energy investments and assess the impact of several uncertainties on these investments. A summary of the references reviewed throughout this work is shown in Table 1.

Table: 1
Literature on Wind Energy Investment Analysis by Real Option Analysis

Year	Authors	Country	Uncertainties
2002	Venetsanos et al.	Greece	Fossil fuel prices, environmental regulations, demand and supply, initial capital cost, and technology
2004	Fleten & Maribu		Price
2006	Yu et al.	Spain	Price and demand
2007	Zhou et al.	California	Price
2008	Kumbaroğlu et al.	Türkiye	Tariff
2008	Dykes & de Neufville	Ohio	Price and policy
2010	Lee & Shih	Taiwan	Fossil fuel price and feed-in-tariff guarantee
2010	Cheng et al.		Price, cost, and policy
2011	Lee	Taiwan	Underlying price, exercise price, time to maturity, risk-free rate, volatility
2013	De Mare et al.	Italy	The selling price of electricity, the plant's annual manufacturability, and the price of green certificates.
2013	Detert & Kotani	Mongolia	Coal price
2014	Abadie & Chamorro	England	The electricity price, the level of wind generation, and the certificate price
2014	Kim et al.	Korea	Price
2014	Barroso & Iniesta	Germany	Price, cost, technology
2014	Kroniger & Madlener	Germany	Price and wind
2016	Toptaş	Türkiye	-
2017	Loncar et al.	Serbia	Discount rates, capacity factor, FİT guaranteed, inflation rate, capital expenditures, corporate tax, CAPEX, OPEX escalation rate, and electricity FİT premium
2018	Gazheli & van den Bergh	-	Energy prices and technology costs

As shown in Table 1, many studies noted that various factors affect wind energy investments. Those studies demonstrated that the real options evaluation model is appropriate for evaluating the value of wind energy investments. Renewable energy investments face several political and technical uncertainties, and real options modelling allows for the evaluation of these uncertainties in wind energy investments. Therefore, the research model in this paper utilises the real options method.

The vast real option valuation literature on wind energy primarily focuses on price as an uncertainty, as shown in Table 1. There are no more papers that include a full range of uncertainties in the real option modelling of wind energy investments. The in-depth study by Loncar et al. (2017) demonstrates that incorporating flexibility enhances project value compared to static discounted cash flow (DCF) analysis. They found that, specifically, the sequential and expansion options improve expected returns, while contraction, repowering, and abandonment options provide downside protection under unfavourable scenarios.

Kumbaroğlu et al. (2008) proposed a policy planning model that accounts for both renewable and non-renewable energy costs, availability factors, capacity factors, learning rates, and construction lead times. This model integrates learning-curve information for renewable power generation technologies into a dynamic programming framework that incorporates real options analysis. The empirical data, drawn from the Turkish electricity supply industry, examine six energy portfolio allocation policies and offer valuable insights into how uncertainty influences the adoption of emerging renewable energy technologies. Additionally, Toptaş (2016) assessed a wind energy investment in Türkiye using a delayed real options method.

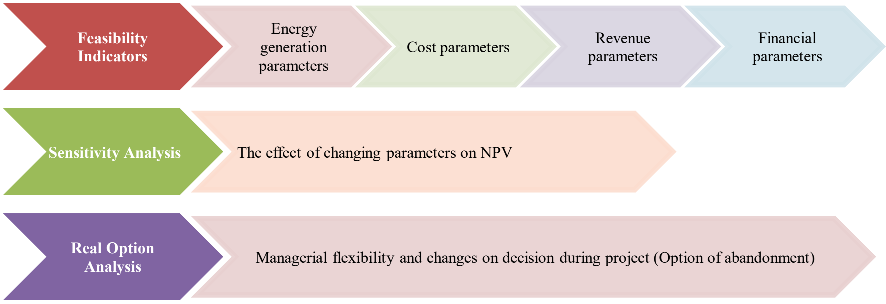
The literature review highlights the need for a more comprehensive and country-specific analysis. Therefore, this study aims to evaluate the investment value of an onshore wind farm in Türkiye using traditional methods and the simple abandonment-option approach, and to demonstrate how real options analysis captures the value of managerial flexibility under uncertainty. This paper also contributes to the country-specific renewable energy investment analysis literature by conducting a sensitivity analysis to examine how investments respond to various operational and economic factors in Türkiye. Accordingly, the following section introduces the methodological design developed to evaluate onshore wind energy investments.

3. Methodology

3.1. Research Model

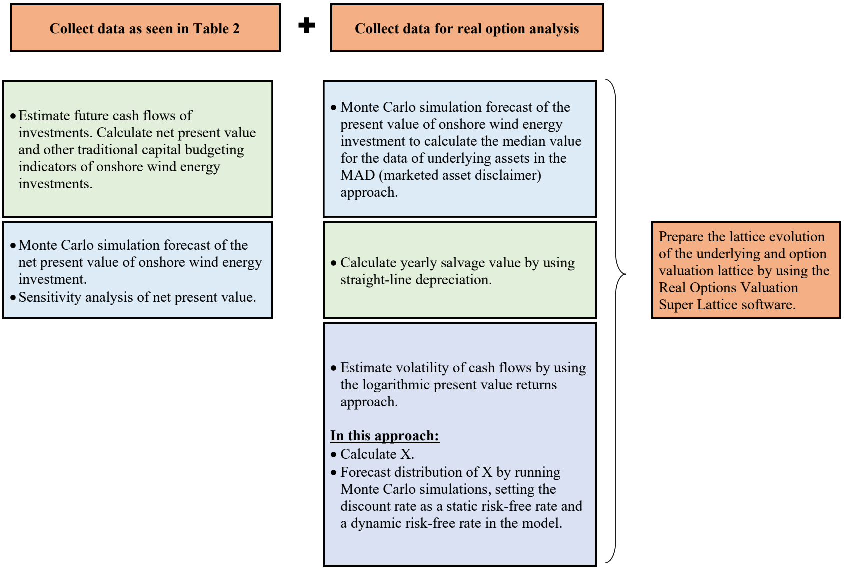
The research model is presented in Figure 1. In the initial stage, the net present value (NPV) of onshore wind energy investments is calculated by evaluating production, costs, revenues, and various financial parameters. Subsequently, a sensitivity analysis is conducted to assess the impact of variations in these parameters on the NPV. Finally, the analysis addresses the implications of management's decision to abandon possible investments, which may arise from the low efficiency of turbines or other materials utilised during installation due to rapid technological advancements, on the feasibility of onshore wind energy investments throughout the economic life.

Figure: 1
The Research Model



The research steps are presented in Figure 2 for clarity.

Figure: 2
The Research Steps



3.2. Real Option Analysis Method

A real option is simply an integrated solution and a systematic approach that applies financial theory, economic analysis, management science, decision sciences, statistics, and econometric modelling to the valuation of real physical assets, rather than financial assets, in an uncertain and flexible business environment (Mun, 2006: 30).

Traditional capital budgeting approaches, such as discounted cash flow analysis and payback periods, do not fully capture project value for several reasons. They assume that investment decisions are irreversible, overlook interactions between current and future decisions, and ignore management's flexibility in decision-making over the project's economic horizon. However, managerial flexibility adds value to investment because management can utilise it to enhance asset value in favourable conditions or to minimise losses in unfavourable situations by exercising real options (Vintila, 2007: 47). Through the application of real option analysis, investors can analyse market conditions more effectively, as better information is obtained and uncertainty is reduced. Unlike traditional methods, which neglect uncertainty in electricity prices, real options modelling considers such uncertainty and other uncertainties (Santos et al., 2014: 593).

Since energy investments are technology-intensive, rapid technological change significantly affects their valuation. Developments in technology enable turbines, which account for the largest share of the cost in wind farms, to be produced more cheaply, thereby rapidly reducing the cost of power plant installations. With the abandonment option, when market conditions worsen, or capital equipment becomes obsolete due to technological changes, management can abandon the investment by disposing of the power plant at its scrap value (Lee, 2011: 4447). The positive side of abandonment is that it prevents the loss from growing further, which reduces cash outflows, especially in the case of a large-scale, irreversible investment project that was abandoned earlier. If the value of continuing the investment is less than the salvage value, the project should be abandoned. Traditional capital budgeting neglects this option (Myers & Majd, 1983: 2).

The real options method offers several advantages, but personnel may lack the necessary skills to conduct a thorough analysis, necessitating the involvement of external experts. Additionally, real option analysis demands continuous monitoring and evaluation of the available options. This flexibility and the need for options come with a cost in terms of attention and computing power. Moreover, decision-makers often fear that altering their strategy in a politically sensitive context may be viewed as a sign of failure. Thus, they require unambiguous strategies when facing an uncertain future. Implementing the real options method also depends on high-quality data on uncertainty and the costs of flexibility, which can be challenging to estimate, especially in infrastructure projects. To address these challenges, it is beneficial to employ flexible and innovative infrastructure solutions rather than traditional ones, justifying any additional costs through real options analysis (Herder et al., 2011: 963-966).

This paper uses the binomial method for real options analysis. The binomial method is a numerical method used in option valuation. Since the decision can be made at any time using the discrete-time approach, this method is suitable for real options analysis (Brach, 2003: 52).

The input parameters for the binomial lattice approach include the underlying asset’s value (S), the strike price (X), the time to maturity (T), the volatility of the underlying asset (σ), the risk-free interest rate (rf), and continuous dividend payments (b) (Mun, 2006: 129).

There are two different approaches to solving binomial lattices. The first approach is the replicating portfolio approach, where a replicating portfolio is created to match the NPV, but its payouts must match those of the deferral option. The second approach is the risk-neutral approach, in which a hedge portfolio is constructed to determine the option's value (Peters, 2016: 21). Mun (2006) states that the results from the market-replicating portfolio approach are identical to those from the risk-neutral probability approach.

The binomial lattices divide the option's life into small time intervals, where the probability of the underlying asset price rising or falling by a specific rate is calculated (Arnold, 2014: 44). In the binomial lattices, it is crucial to compute the factors (u and d) representing the upward and downward movements of the underlying asset value, as specified in Equations 1, 2, and 3, along with the risk-neutral probability measure (p) (Mun, 2006: 128).

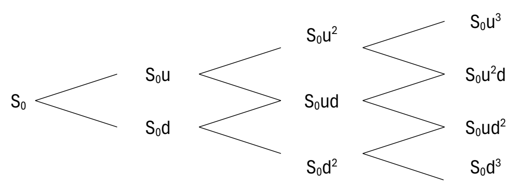
$$u = e{}^\wedge(\sigma\sqrt{\delta t}) \tag{1}$$

$$d = e{}^\wedge(-\sigma\sqrt{\delta t}) = 1/u \tag{2}$$

$$p = (e{}^\wedge((rf - b)(\delta t)) - d)/(u - d) \tag{3}$$

In the initial stage of the binomial lattices, the first binomial lattice illustrated in Figure 3 is generated by multiplying the underlying asset’s current value by both the up and down factors (Mun, 2006: 165).

Figure: 3
Binomial Lattice of the Underlying Asset Value



Calculating the option valuation lattice is the second step. The intrinsic value of the option, Max [(X−S), 0] for a put option and Max [(S−X), 0] for a call option, is the option value at each last node of the lattice, or when the option expires (Loncar et al., 2017: 362).

The construction of the option valuation lattice occurs in two phases: first, the valuation of the terminal nodes, and second, the valuation of the intermediate nodes using backward induction. The first lattice values are generated in a forward multiplication of up and down factors, from left to right. The second lattice calculates values in reverse order, beginning with the terminal nodes, so that the nodes at the end of the lattice are valued first, progressing from right to left using Equation 4 (Mun, 2006: 164).

$$Intermediate\ Value = (p * P\_u + (1 - p) * P\_d\ ) * e\text{^}(-rf * \delta t) \tag{4}$$

P_u: The value of a put option when the underlying asset's value increases

P_d: The value of a put option when the underlying asset's value decreases

The last step is to calculate the strategic value of NPV, which includes management flexibility, using Equation 5. The expanded net present value (eNPV) is the sum of the base-case net present value and the value of strategic options. The eNPV accounts for both base-case analysis and the added value of flexibility, while the options value considers the value of flexibility, which is the capacity to execute on a strategic choice without being obligated to do so (Mun, 2002: 168).

$$eNPV = NPV + Options\ Value \tag{5}$$

3.3. Data

3.3.1. Data for Discounted Cash Flow Analysis

The discounted cash flow method, which is one of the traditional investment valuation models, is used to calculate feasibility indicators such as net present value, internal rate of return, and profitability ratios. The cost, production, revenue, and financial assumptions, which are inputs to the discounted cash flow method, are clearly outlined in Table 2 for the installation of a 10 MW onshore wind power plant. The weighted average cost of capital is used as the discount rate for calculating the net present value. The Capital Asset Pricing Model (Ross et al., 2003: 279) was employed to determine the equity cost of capital for calculating the weighted average cost of capital (WACC), as shown in Equation 6.

$$WACC = Cost\ of\ equity\ x \left[\frac{Equity}{Debt + Equity}\right] + \ Cost\ of\ debt\ x \left[\frac{Debt}{Debt + Equity}\right] = Risk\ free\ rate + (Beta\ xEquity\ Risk\ premium)x \left[\frac{Equity}{Debt + Equity}\right] + Pretax\ rate(1 - Tax\ rate)x \left[\frac{Debt}{Debt + Equity}\right] \tag{6}$$

Table: 2
Assumptions and Probability Distributions for Monte Carlo Simulation

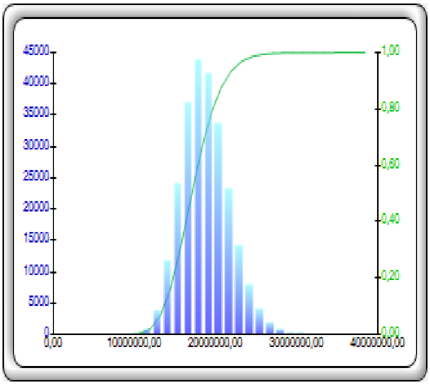
Assumption		Unit	Value	Distribution	Source
Production	Capacity factor	%	37	Triangular (min 0,3 - max 0,43)	IRENA (2024) Average of 2018-2022
	Rated capacity	MW	10		
	Yearly electricity generation	MWh	32.412	It is calculated using the formula below: Capacity factor=Annual generation MWh / (365 days x 24 hours/day x Nameplate capacity MW)	
Revenue	Electricity price escalation	%	3	Lognormal (mean 0,028 - std. dev. 0,0028)	Inflation in USD is used.
	Electricity price	USD/MWh	83,65	Normal (72,925-94,365)	EPİAŞ Transparency Platform
	Investment horizon	years	25*		
Financial	Debt Ratio	%	70	This capital structure is assumed for the Renewable Energy Resource Area in Türkiye.	
	Equity Ratio	%	30		
	Risk-free interest rate	%	5,75%	Normal (mean 0,0575 - std. dev. 0,00575)	The Eurobond with ISIN US900123CM05 has a coupon rate of 5.750%. The bond will mature on May 11, 2047.
	Equity risk premium	%	12,42	Damodaran Online (Average of 2023-2025) (Damodaran, 2023;2024;2025)	
	Relevered beta		1,375	It is calculated using the unlevered beta for the green energy sector, sourced from Damodaran Online. (Damodaran, 2025 May)	
	Default spread	%	5,84	Damodaran Online data for Türkiye (Average of 2023-2025) (Damodaran, 2023;2024;2025)	
	Pre-tax cost of debt	%	11,59	It is calculated by summing the risk-free rate and the default spread (Damodaran, 2002)	
	Cost of equity	%	22,83	Calculated using the capital asset pricing model.	
	Weighted average cost of capital (WACC)	%	12,93	Normal (0,113 - 0,146)	
	Tax rate	%	25	Uniform (min 0,2 - max 0,3)	
Cost	Operational expenditure (OPEX)	$	286.800	Triangular (207.530,43 - 366.069,57)	2% of CAPEX
	OPEX escalation	%	3	Triangular (min 0,014 - max 0,042)	
	Installed cost (CAPEX)	USD	14.340.000	Normal (12.502.255,06 - 16.177.744,94)	IRENA (2024)

Note: WindEurope indicated that the standard lifetime of a wind turbine is approximately 20-25 years. Therefore, a 25-year investment horizon was chosen (WindEurope, 2025).

3.3.2. Data for Real Option Analysis

Loncar et al. stated that because each wind farm project is different, regardless of its modular and scalable nature, and depends on a wide range of inputs, it is practically impossible to find such twin assets in the financial or commodity markets or in the world of real projects. The Marketed Asset Disclaimer (MAD) approach is designed to address the challenge of identifying the underlying asset in real option analysis (Guj & Chandra, 2019). The MAD approach uses the present value of the wind farm project as an underlying asset. Once the Monte Carlo simulation with 250,000 trials has been conducted on the discounted cash flow model using Risk Simulator software developed by Mun, the median PVP50 value for the Wind farm project is $17,054,836, as shown in Figure 4. It is used as the underlying asset value in real option modelling.

Figure: 4
Monte Carlo Simulation Forecasts of Present Value of Onshore Wind Energy Investments ($)



Number of Data Points	250,000
Mean	17.263.210
Median	**17.054.836**
Standard Deviation	2.913.813
Variance	8.490.305.859.236
Coefficient of Variation	0
Maximum	38.409.312
Minimum	6.849.983
Range	31.559.329
Skewness	0
Kurtosis	0
25% Percentile	15.211.979
75% Percentile	19.082.432
Error Precision at 95%	0

The salvage value at any time is the market value of the asset in its subsequent most productive use (Myers & Majd, 1983: 9). The strike price of the underlying asset is the salvage value of the asset in the abandonment real option (Smit & Trigeorgis, 2004: 117). The abandonment salvage value can change over time (Mun, 2006: 167). The straight-line depreciation method is used to calculate the investment's salvage value at the end of each year.

Probably one of the most difficult input parameters to estimate in a real options analysis is the volatility of cash flows (Mun, 2002: 197). The Logarithmic Present Value Returns Approach is used to estimate volatility. The cash flows are discounted to Time 0 and then to Time 1, with the Time 0 cash flows ignored (treated as a sunk cost). Then, the values are summed, and the following logarithmic ratio is calculated, as shown in Equation 7, where $PVCF_i$ represents the present value of future cash flows at different periods i. CF shows cash flows, and D is the discount rate in Equation 7.

$$X = \ln\left(\frac{\sum_{i=1}^{n} PVCF_i}{\sum_{i=0}^{n} PVCF_i}\right) = \ln\left(\frac{\frac{CF_1}{(1+D)^0}+\frac{CF_2}{(1+D)^1}+\frac{CF_3}{(1+D)^2}+\cdots+\frac{CF_N}{(1+D)^{N-1}}}{\frac{CF_0}{(1+D)^0}+\frac{CF_1}{(1+D)^1}+\frac{CF_2}{(1+D)^2}+\cdots+\frac{CF_N}{(1+D)^N}}\right) \quad (7)$$

To achieve the forecast distribution of variable X, it is recommended to conduct a Monte Carlo simulation based on the discounted cash flow model using the intermediate value of X. In the context of real option analysis, the risk-free interest rate was specifically employed as the discount rate. When implementing this approach, it is advisable to maintain the discount rate as a fixed risk-free rate. Subsequently, simulate the inputs for the discounted cash flow and calculate the resulting volatility. After completing this process, the discount rate should be reset to its original value (Mun, 2006: 198-199).

As a result of the Monte Carlo Simulation, volatility is determined to be 14.15% and 15.42%, respectively, when the simulation's risk-free interest rate is held constant and allowed to vary. The average volatility of 14,78% is used in binomial lattices.

3.4. Research Limitations

This paper excludes decommissioning costs because reliable decommissioning cost data are not available in any report for Türkiye. Residual value is also negligible because there is no policy in place for recycling or reusing wind turbines and other materials in Türkiye. Revenues from carbon reduction and working capital are not considered in the analysis of this study. Government incentives and subsidies are excluded from the analysis due to their variability.

4. Findings and Discussions

4.1. Risk Modelling Based on Net Present Value

Table 3 presents the results of conventional capital budgeting methods used in the financial modelling of onshore wind energy investments, without accounting for uncertainty.

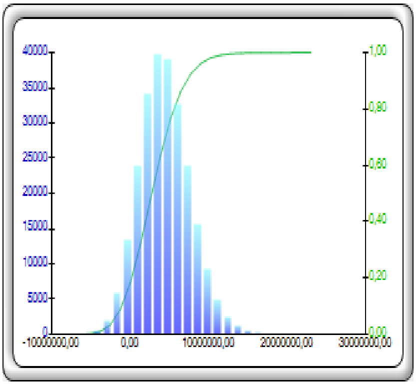
Table: 3
The Results of Discounted Cash Flow Analysis

Indicator	
Net Present Value	US$ 2.952.412
Internal Rate of Return	%15,60
Payback Period	6,75 years
Discounted Payback Period	11,75 years

The results indicate that the net present value of the investment is positive. The internal rate of return is close to the discount rate. The payback period is short, but this method cannot account for the time value of money. The discounted payback period, considering the time value of money, is too long.

After 250,000 trials have been conducted on the discounted cash flow model, the median NPV_{P50} value for the onshore wind farm project is US$ 2,745,992, as demonstrated in Figure 5. There is a slight difference between the static net present value in the previous step and the simulated median net present value.

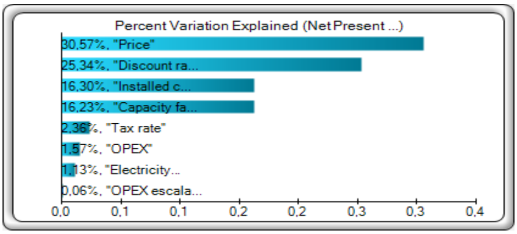
Figure: 5
Monte Carlo Simulation Forecasts of Net Present Value of Onshore Wind Energy Investments ($)



Number of Data Points	250.000
Mean	2.917.877
Median	**2.745.992**
Standard Deviation	3.219.148
Variance	10.362.914.741.173
Coefficient of Variation	1
Maximum	23.060.566
Minimum	-8.939.000
Range	31.999.566
Skewness	0
Kurtosis	0
25% Percentile	682.608
75% Percentile	4.960.628
Error Precision at 95%	0

The net present value sensitivity chart, detailed in Figure 6, shows that the wind farm project is highly sensitive to electricity prices, with a sensitivity rate of 30.57%. The net present value of onshore wind investment is sensitive to the discount rate and installed cost, with a sensitivity of 25.34% and 16.30%, respectively. The wind farm's feasibility is sensitive to the capacity factor, which contributes 16.23%. Sensitivity to all other uncertainties is relatively minor, each being less than 3%.

Figure: 6
Sensitivity Analysis Results



4.2. Real Option Modelling

The Abandonment Option examines the value of a project's flexibility to be abandoned over the life of the option. The American option type is selected to analyse the effect of abandonment flexibility on the value of onshore wind energy investments because American options can be exercised at any time before or on maturity.

Real Options Valuation Super Lattice software, developed by Mun, is employed to address the real-option abandonment problem. Table 4 demonstrates the assumptions used in the abandonment real option analysis. Monte Carlo simulation using the Risk Simulator software indicates that the volatility of this investment is estimated at 14,78%. The median PV_{P50} value for the wind farm project, $17.054,836, as shown in Figure 4, is used as the underlying asset.

Table: 4
Assumptions for Real Option Analysis

Assumptions			***Intermediate Computations***	
PV Asset Value ($)	$17.054.836		*Stepping Time (dt)*	1,0000
Volatility (%)	14,78%		*Up Step Size (up)*	1,1593
Risk-free Rate (%)	5,75%		*Down Step Size (down)*	0,8626
Dividends (%)	0,00%		*Up Probability*	0,6626
Maturity (Years)	25,00		*Down Probability*	0,3374
Lattice Steps	25		*Discount Factor*	0,9441
Option Type	American			

Table 5 illustrates the results of a simple abandonment option with a 25-step lattice, while Table 6 shows the option valuation lattice generated from this analysis. The option value (RO) is calculated to be $65.583. The abandonment option increases the net present value by $65,583.

$$eNPV = NPV_{P50} + RO = \$\ 2.745.992 + \$\ 65.583 = \$\ 2.811.575$$

while the project value with flexibility is:

$$PV_{P50} + RO = \$\ 17.054.836 + \$\ 65.583 = \$\ 17.120.419$$

Table: 5
Lattice Evolution of the Underlying ($)

0	1	2	3	4	5	6	7	8	9	10	11	12	13
17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
		12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
			10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
				9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
					8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356
						7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348
							6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563
								5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654
									4.509.714	5.228.026	6.060.751	7.026.114	8.145.241
										3.890.096	4.509.714	5.228.026	6.060.751
											3.355.611	3.890.096	4.509.714
												2.894.562	3.355.611
													2.496.860

Table: 5
(continued)

14	15	16	17	18	19	20	21	22	23	24	25
135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284	592.075.286	686.381.640
100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284
74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769
55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987
41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906
30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135
22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356
3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348
2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563
2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654
	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241
		1.602.610	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751
			1.382.418	1.602.610	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714
				1.192.478	1.382.418	1.602.610	1.857.876	2.153.800	2.496.860	2.894.562	3.355.611
					1.028.636	1.192.478	1.382.418	1.602.610	1.857.876	2.153.800	2.496.860
						887.305	1.028.636	1.192.478	1.382.418	1.602.610	1.857.876
							765.393	887.305	1.028.636	1.192.478	1.382.418
								660.231	765.393	887.305	1.028.636
									569.517	660.231	765.393
										491.268	569.517
											423.769

Table: 6
Option Valuation Lattice ($)

0	1	2	3	4	5	6	7	8	9	10	11	12	13
17.120.419	19.777.742	22.920.956	26.571.371	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
	14.904.893	17.074.109	19.772.598	22.920.594	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
		13.259.329	14.769.611	17.058.672	19.771.492	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
		Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
			12.619.200	12.864.947	14.723.323	17.055.289	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
			Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
				12.045.600	11.472.000	12.726.277	14.712.984	17.054.839	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
				Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue
					11.472.000	10.898.400	11.056.973	12.694.703	14.711.572	17.054.836	19.771.348	22.920.548	26.571.356
					Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue
						10.898.400	10.324.800	9.780.206	10.960.623	12.690.274	14.711.563	17.054.836	19.771.348
						Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue
							10.324.800	9.751.200	9.177.600	9.486.426	10.946.736	12.690.248	14.711.563
							Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue
								9.751.200	9.177.600	8.604.000	8.282.592	9.442.882	10.946.654
								Abandon	Abandon	Abandon	Continue	Continue	Continue
									9.177.600	8.604.000	8.030.400	7.456.800	8.146.055
									Abandon	Abandon	Abandon	Abandon	Continue
										8.604.000	8.030.400	7.456.800	6.883.200
										Abandon	Abandon	Abandon	Abandon
											8.030.400	7.456.800	6.883.200
											Abandon	Abandon	Abandon
												7.456.800	6.883.200
												Abandon	Abandon
													6.883.200
													Abandon

Table: 6
(continued)

14	15	16	17	18	19	20	21	22	23	24	25
135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284	592.075.286	686.381.640
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769	440.554.341	510.726.284
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987	327.809.878	380.023.769
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906	243.918.414	282.769.987
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135	181.496.034	210.404.906
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305	135.048.477	156.559.135
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921	100.487.546	116.493.305
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973	74.771.276	86.680.921
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975	55.636.185	64.497.973
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108	41.398.051	47.991.975
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
7.028.670	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356	30.803.669	35.710.108
Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	6.068.776	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348	22.920.548	26.571.356
Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	5.736.000	5.253.218	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563	17.054.836	19.771.348
Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	5.736.000	5.162.400	4.588.800	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654	12.690.248	14.711.563
Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	Continue	End
6.309.600	5.736.000	5.162.400	4.588.800	4.015.200	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241	9.442.623	10.946.654
Abandon	Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	Continue	End
	5.736.000	5.162.400	4.588.800	4.015.200	3.441.600	3.890.096	4.509.714	5.228.026	6.060.751	7.026.114	8.145.241
	Abandon	Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	End
		5.162.400	4.588.800	4.015.200	3.441.600	2.894.562	3.355.611	3.890.096	4.509.714	5.228.026	6.060.751
		Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	Continue	End
			4.588.800	4.015.200	3.441.600	2.868.000	2.496.860	2.894.562	3.355.611	3.890.096	4.509.714
			Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	Continue	End
				4.015.200	3.441.600	2.868.000	2.294.400	2.153.800	2.496.860	2.894.562	3.355.611
				Abandon	Abandon	Abandon	Abandon	Continue	Continue	Continue	End
					3.441.600	2.868.000	2.294.400	1.720.800	1.857.876	2.153.800	2.496.860
					Abandon	Abandon	Abandon	Abandon	Continue	Continue	End
						2.868.000	2.294.400	1.720.800	1.382.418	1.602.610	1.857.876
						Abandon	Abandon	Abandon	Continue	Continue	End
							2.294.400	1.720.800	1.147.200	1.192.478	1.382.418
							Abandon	Abandon	Abandon	Continue	End
								1.720.800	1.147.200	887.305	1.028.636
								Abandon	Abandon	Continue	End
									1.147.200	660.231	765.393
									Abandon	Continue	End
										573.600	569.517
										Abandon	End
											423.769
											End

5. Conclusion

Sustainable development goals entail a shift to renewable energy for countries. The increasing investment in renewable energy underscores the importance of financial modelling for long-horizon projects, as traditional capital budgeting methods often fail to account for market uncertainties over the entire horizon. Poor planning, lack of management, economic and technological issues, and other interests can affect the resumption of operations of renewable power plants, as Frolova et al. (2025) identified. Managers would abandon the project and sell facilities to stop the losses during the investment horizon. Therefore, this study discusses the valuation of an onshore wind energy investment using real options with the option to abandon.

Traditional feasibility indicators, such as net present value, internal rate of return, payback period, and discounted payback period, are calculated for onshore wind energy investments in the first step of this study. In real option analysis, the binomial tree method is used as an approach based on the risk-neutral valuation principle. In the valuation of onshore wind energy plant investments with real options, it is almost impossible to determine an asset with a similar risk and return profile that can be used as an underlying asset due to the differences in wind speed, energy loss, incentive amounts received, and various financial parameters of the power plants. Therefore, the Marketed Asset Disclaimer (MAD) approach was used in determining the underlying asset in real option analysis. In line with this approach, the present value of future cash flows from the discounted cash flow model for the onshore wind energy investment was used to determine the underlying asset value in real option modelling. In estimating volatility, the Logarithmic Present Value Returns Approach was used. Salvage value is estimated using the straight-line depreciation method.

Traditional capital budgeting methods determine that the onshore wind power plant project is feasible. The net present value of the investment is above zero. The internal rate of return is close to the discount rate. The payback period is short, but this method does not account for the time value of money. The discounted payback period, considering the time value of money, is too long. Sensitivity results demonstrate that the wind farm project is sensitive to electricity prices, the discount rate, installed costs, and capacity factors.

The value of a simple American-type abandonment option with a 25-step lattice is calculated as $65.583. The abandonment option increases the strategic net present value by $65,583, bringing it to $2,811,575, while the project value with flexibility is $17,120,419. These results are consistent with the literature, as they reflect the increasing strategic net present value of investments when using real options modelling.

Policymakers should not only focus on improving the legal and regulatory framework but also incorporate real options thinking to provide flexibility in managerial decision-making and address investor concerns in high-risk environments. This paper enhances the existing literature by providing financial modelling that equips decision-makers with sophisticated tools to evaluate market uncertainties and risks, potentially increasing investor interest in wind energy investments by reducing their concerns. Furthermore, the paper demonstrates that real options modelling is an essential tool for investors seeking to adopt flexible investment strategies and manage uncertainties effectively. There is a gap between real options theory and its practical application due to the theory's complexity and investors' limited knowledge of uncertainty modelling in investment. Collaboration between academia and industry on modelling renewable energy investments could help bridge this gap. This paper specifically examines the modelling of abandonment decisions in real options, deliberately excluding decommissioning costs. This exclusion is based on the observation that wind farm decommissioning often falls short of expectations due to insufficient regulatory obligations. However, it is essential to establish effective regulations and policies regarding wind farm decommissioning plans to ensure that these initiatives fulfil their intended sustainability objectives. Moreover, procedures for abandoning or prematurely stopping projects should be clearly defined. If investors choose to abandon their renewable energy investments, a platform that facilitates the transfer of low-yield renewable power plants would be beneficial, rather than exiting the market entirely.

References

Abadie, L.M. & J.M. Chamorro (2014), “Valuation of Wind Energy Projects: A Real Options Approach”, *Energies*, 7(5), 3218-3255.

Arnold, T. (2014), *A Pragmatic guide to real options*, New York: Palgrave Macmillan.

Barroso, M.M. & J.B. Iniesta (2014), “A Valuation of Wind Power Projects in Germany Using Real Regulatory Options”, *Energy*, 77, 422-433.

Brach, M.T. (2003), *Real Options in Practice*, USA: John Wiley & Sons, Inc.

CAT Climate Action Tracker (2025), <https://climateactiontracker.org/countries/turkey/policies-action/>, 22.05.2025.

Cheng, H. et al. (2010), “Wind power investment in thermal system and emissions reduction”, *Proceedings of IEEE Power and Energy Society General Meeting*, Minneapolis.

Damodaran, A. (January 5, 2025), *Total Beta By Industry Sector / Europe*, <https://pages.stern.nyu.edu/~adamodar/New_Home_Page/datacurrent.html>, 22.05.2025.

Damodaran, A. (March 05, 2025), *Equity Risk Premiums (ERP): Determinants, Estimation, and Implications - The 2025 Edition*, <https://ssrn.com/abstract=5168609> or <http://dx.doi.org/10.2139/ssrn.5168609>, 22.05.2025.

Damodaran, A. (March 23, 2023), *Equity Risk Premiums (ERP): Determinants, Estimation and Implications - The 2023 Edition*, <https://ssrn.com/abstract=4398884> or <http://dx.doi.org/10.2139/ssrn.4398884>, 22.05.2025.

Damodaran, A. (March 5, 2024), *Equity Risk Premiums (ERP): Determinants, Estimation, and Implications - The 2024 Edition*, <https://ssrn.com/abstract=4751941> or <http://dx.doi.org/10.2139/ssrn.4751941>, 22.05.2025.

De Mare, G. et al. (2013), “The economic evaluation of investments in the energy sector: a model for the optimization of the scenario analyses”, *International Conference on Computational Science and Its Applications*, Berlin: Springer.

Detert, N. & K. Kotani (2013), “Real Options Approach to Renewable Energy Investments in Mongolia”, *Energy Policy*, 56, 136-150.

Dykes, K. & R. De Neufville (2008), “Real options for a wind farm in Wapakoneta, Ohio: incorporating uncertainty into economic feasibility studies for community wind”, *7. World Wind Energy Conference*, Ontario.

Ediger, V.Ş. et al. (2017), *Turkish Public Preferences for Energy*, Kadir Has University.

Ediger, V.Ş. et al. (2018), *Turkish Public Preferences for Energy*, Kadir Has University.

Ediger, V.Ş. et al. (2019), *Turkish Public Preferences for Energy*, Kadir Has University.

Fleten, S.E. & K.M. Maribu (2004), “Investment timing and capacity choice for small-scale wind power under uncertainty”, *IASTED International Conference on Power and Energy Systems*, Florida.

Frolova, M. et al. (2025), “Abandoning Renewable Energy Projects in Europe and South America: An Emerging Consideration in The Recycling of Energy Landscapes”, *Energy for Sustainable Development*, 85, 101676.

Gazheli, A. & J. van den Bergh (2018), “Real Options Analysis of Investment in Solar vs Wind Energy: Diversification Strategies Under Uncertain Prices and Costs”, *Renewable and Sustainable Energy Reviews*, 82, 2693-2704.

Guj, P. & A. Chandra (2019), “Comparing Different Real Option Valuation Approaches as Applied to A Copper Mine”, *Resources Policy*, 61, 180-189.

GWEC (2025), *Global Wind Report 2025*, Global Wind Energy Council.

Herder, P.M. et al. (2011), “Buying real options-Valuing uncertainty in infrastructure planning”, *Futures*, 43(9), 961-969.

IEA (2021), *Net Zero by 2050: A roadmap for the global energy sector*, International Energy Agency, Abu Dhabi.

IRENA & CPI (2023), *Global landscape of renewable energy finance*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2024), *Renewable power generation costs in 2023*, International Renewable Energy Agency, Abu Dhabi.

IRENA (2025), *Renewable capacity statistics 2025*, International Renewable Energy Agency, Abu Dhabi.

Kim, K.T. et al. (2014), “Evaluation Of R&D Investments in Wind Power in Korea Using Real Option”, *Renewable and Sustainable Energy Reviews*, 40, 335-347.

Kroniger, D. & R. Madlener (2014), “Hydrogen Storage for Wind Parks: A Real Options Evaluation for An Optimal Investment in More Flexibility”, *Applied Energy*, 136, 931-946.

Kumbaroğlu, G. et al. (2008), “A Real Options Evaluation Model for the Diffusion Prospects of New Renewable Power Generation Technologies”, *Energy Economics*, 30(4), 1882-1908.

Lee, S.C. & L.H. Shih (2010), “Renewable Energy Policy Evaluation Using Real Option Model: The Case of Taiwan”, *Energy Economics*, 32, S67-S78.

Lee, S.C. (2011), “Using Real Option Analysis for Highly Uncertain Technology Investments: The Case of Wind Energy Technology”, *Renewable and Sustainable Energy Reviews*, 15(9), 4443-4450.

Lin, B. & P.K. Wesseh Jr (2013), “Valuing Chinese Feed-In Tariffs Program for Solar Power Generation: A Real Options Analysis”, *Renewable and Sustainable Energy Reviews*, 28, 474-482.

Loncar, D. et al. (2017), “Compound Real Options Valuation of Renewable Energy Projects: The Case of A Wind Farm in Serbia”, *Renewable and Sustainable Energy Reviews*, 75, 354-367.

Mun, J. (2002), *Real options analysis: Tools and techniques for valuing strategic investments and decisions*, New Jersey: John Wiley & Sons, Inc.

Mun, J. (2006), *Real option analysis tools and techniques for valuing strategic ınvestments and decisions (Second Edition)*, New Jersey: John Wiley & Sons, Inc.

Myers, S.C. & S. Majd (1983), “Calculating Abandonment Value Using Option Pricing Theory”, Sloan School of Management *Working Paper*.

Öztürk, İ. (2014), “Energy Dependency and Energy Security: The Role of Energy Efficiency and Renewable Energy Sources”, *International Growth Center Working Paper*, E-37113-PAK-1.

Peters, L. (2016), *Real Options Illustrated*, Switzerland: Springer.

Ross, S.A. et al. (2003), *Corporate Finance (Sixth Edition)*, McGraw-Hill Companies.

Santos, L. et al. (2014), “Real Options Versus Traditional Methods to Assess Renewable Energy Projects”, *Renewable Energy*, 68, 588-594.

Smit, H.T. & L. Trigeorgis (2004), *Strategic Investment, Real Options and Games*, New Jersey: Princeton University Press.

Toptaş, B. (2016), “Rüzgâr Enerjisi Santrali (RES) Yatırımlarının Değerlemesinde Reel Opsiyon Yaklaşımı ve Örnek Bir Uygulama”, *Master’s Thesis*, Balıkesir: Balıkesir Üniversitesi, Sosyal Bilimler Enstitüsü, İşletme Anabilim Dalı.

Venetsanos, K. et al. (2002), “Renewable Energy Sources Project Appraisal Under Uncertainty: The Case of Wind Energy Exploitation Within a Changing Energy Market Environment”, *Energy Policy*, 30(4), 293-307.

Vintilã, N. (2007), “Real Options in Capital Budgeting. Pricing The Option to Delay and the Option to Abandon a Project”, *Theoretical and Applied Economics*, 7(512), 47-58.

WindEurope (2025), *Why Is Sustainability Important in the Wind Industry?*, <https://windeurope.org/policy/topics/sustainability>, 18.09.2025.

Wu, Z. & H. Sun (2015), “Behavior of Chinese Enterprises in Evaluating Wind Power Projects: A Review Based on Survey”, *Renewable and Sustainable Energy Reviews*, 43, 133-142.

Yu, W. et al. (2006), “Valuation of Switchable Tariff for Wind Energy”, *Electric Power Systems Research*, 76(5), 382-388.

Zhou, H. et al. (2007), “Analytical assessment of wind power generation asset in restructured electricity industry”, *Universities Power Engineering Conference*, United Kingdom.