Real Options and Renewable Energy Investment

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Overview

Preparatory Works

- Site Selection
- Grid Application
- Planning Application
- Environmental Impact Assessment
- Financing
- Leasing Negotiations
- Wind Measurements
- Selection of Turbine Manufacturer
- Design and Layout
- Grid Connection Construction
- Contractor Selection

High CAPEX for Wind Turbines

- The capital expenditure for the wind farm is about 75% - 80% of all expenditure during the lifespan of the wind farm. The rest is OPEX and decommissioning expenses. (NREL)
- Similar situation for other renewable energy sources

Options

- **Planning and Preparation is like a European Call Option**
- The holder may buy an asset at a pre-determined price at a specified date in the future. For example, you may have an option to buy one litre of diesel for €1.70 on 1st December 2024. How much is that option worth?
- The Asset = Cash flows from Wind Farm
- The Expiry = Final Investment Decision Day
- The Strike Price = Cost of Building the Wind Farm
- Risk increases the option's value.
- Starting far in the money increases the option's value.

Cash Flows Depend on

- Construction Cost
- Interest Rates
- Planning Consent
- Electricity Production
- Electricity Price
- Repairs Costs

Decommission, Extend Life or Repower?

At the end of the planning permission period (20 years) choose one of:

- **Decommission** Remove the structure and foundations, return the land to its original state.
- **Extend Life** Replace parts of the turbines so that they can keep producing electricity for another few years.
- **Repower** Replace the towers, turbines and possibly increase the capacity of the grid connection. New turbines are usually fewer in number, taller and more powerful.

Data Sources

- Wind Data from Met Eireann - Malin Head hourly wind speeds from 1955 to 2024.
- Electricity Prices from Mean Reversion Model using monthly mean wholesale prices for Europe during twelve years 2008 - 2019. Monthly prices used to mimic Power Purchase Agreements (PPAs) which are common in the wind industry.
- Failure data from Tazi et al (2017) and Lantz (2013)

Electricity Price Model

Brennan-Schwartz Mean Reversion Model
EU average Monthly prices in €/MWh,

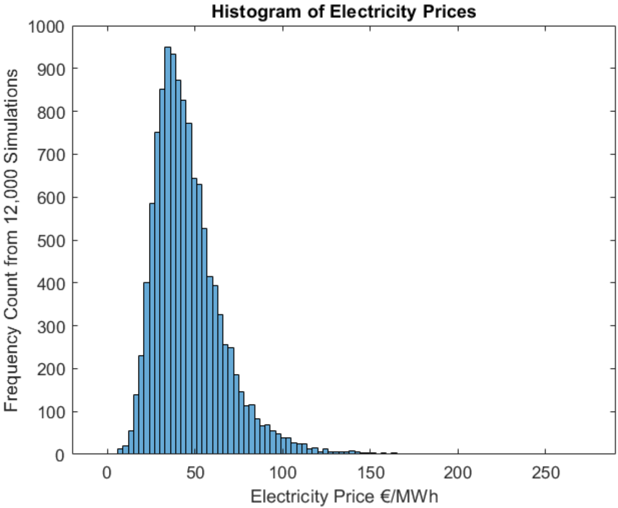
$$dX_t = \alpha(\mu - X_t)dt + \sigma X_t dB_t$$

where the parameters

$$\alpha = 0.25; \mu = 46.9; \sigma = 0.26;$$

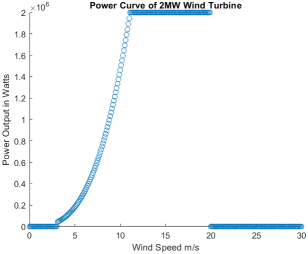
are calculated using Marin, Sanchez and Palacio (2013)

Distribution of Electricity Prices



Power Production

$v_{\text{cut-in}} = 3m/s$; $v_{\text{rated}} = 11.1m/s$; $R = 44m$; $v_{\text{cut-out}} = 20m/s$; η is the efficiency; ρ is the density of air.



$$P_t = \begin{cases} v < v_{\text{cut in}}, & 0 \\ v_{\text{cut in}} \leq v \leq v_{\text{r}}, & \frac{\pi}{2}\rho\eta R^2 v_t^3 \\ v_{\text{r}} \leq v \leq v_{\text{cut out}}, & \frac{\pi}{2}\rho\eta R^2 v_{\text{r}}^3 \\ v_{\text{cut out}} < v, & 0 \end{cases}$$

Repair Costs

- Using a 2 factor Weibull distribution for time between failures, from Mikindani et al. (2024) for generators, gearboxes and blades.
- Assumes constant availability of access to turbines (true for onshore, not true for offshore)
- Repairs take 24 hours plus a random time for delivery of parts, with mean 72 hrs, and an exponential distribution (onshore not offshore)

Additional Model Assumptions

- r the risk free rate is taken as the mean of the mean reversion model during production, this speeds conversion for the Monte Carlo Simulations.
- Investment cost is not known precisely at time $t = \alpha = -5$, approximated by $X_0 = 1.3mN(1, 0.25^2)$ per MW, 20% of that for life extension
- O&M costs €68,000 per year per MW
- O&M costs triple during life extension

Standard Approach to Strike Price

Proceed with the investment if

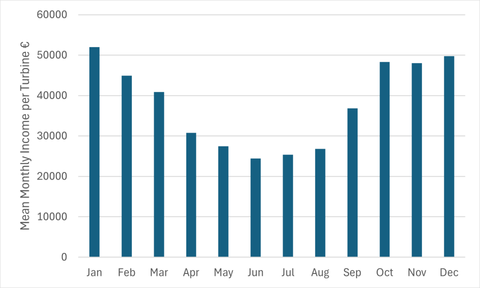
$$\mathbb{E}\left[\sum_{t=0}^{\omega}(E_t - M_t)e^{-rt}\right] - X_0 > 0$$

where, E_t is the income from electricity during time t, X_0 is the construction cost, M_t is the running and maintenance cost, r is the risk free rate, ω is the expected end of life and the expectation is taken at time $t = 0$, thus the value of the option, c, is

$$c = \mathbb{E}\left[max\left\{\mathbb{E}\left[\sum_{t=0}^{\omega}(E_t - M_t)e^{-ri}\right] - X_0,\, 0\right\}\right]$$

where the expectation is taken at time $t = \alpha$, typically $\alpha = -5$, note that X_0 is inside the expectation.

Monthly Income Rates



Due to the high CAPEX and variable income, the model assumes there is a zero strike price and the loan repayments have first call on the income until the loan is repaid.

Zero Strike Price Setup, Due to Loan

Proceed with the investment if

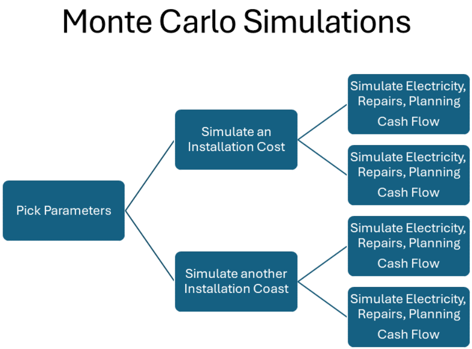
$$\mathbb{E}\left[\sum_{t=0}^{\omega}(E_t - M_t - L_t)e^{-rt}\right] > 0$$

where, E_t is the income from electricity during time t, M_t is the running and maintenance cost and L_t is the loan repayment. Thus the value of the option is,

$$c = \mathbb{E}\left[max\left\{\mathbb{E}\left[\sum_{t=0}^{\omega}(E_t - M_t - L_t - 0)e^{-ri}\right], 0\right\}\right]$$

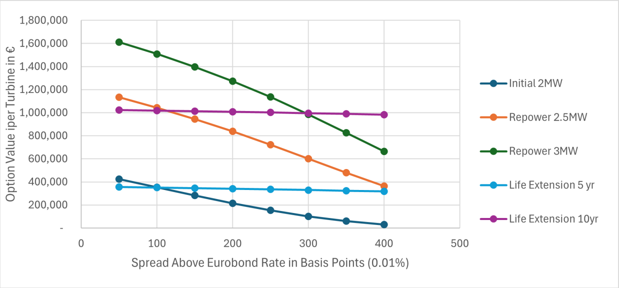
where L_t is the loan repayment per month which is the total income until the loan is paid.

Monte Carlo Arrangement

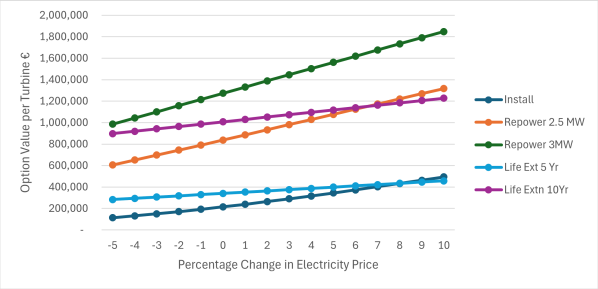


Instead of 2 x 2 shown here, the model uses 50x20x68x20x20
Construction, Electricity Prices, Production, Interest Rate, Failures

Option Value and Interest Rates



Option Value and Electricity Prices



Interest Rates and Electricity Prices

		Change in Electricity Price									
		-10%	-8%	-6%	-4%	-2%	0%	2%	4%	6%	8%
	50	267	330	394	458	523	588	652	717	783	848
Basis	100	160	226	292	358	424	491	557	624	691	757
Points	150	43	110	178	247	315	384	452	521	590	659
above	200	- 82	- 16	53	123	194	265	337	408	479	550
Eurobond	250	- 210	- 148	- 82	- 12	61	134	208	282	356	430
	300	- 334	- 281	- 221	- 155	- 84	- 10	65	142	219	296
	350	- 448	- 406	- 356	- 298	- 234	- 164	- 89	- 12	67	147
	400	- 547	- 520	- 482	- 436	- 381	- 319	- 250	- 176	- 98	- 18
	450	- 625	- 615	- 593	- 561	- 519	- 468	- 409	- 343	- 270	- 193
	500	- 677	- 685	- 682	- 667	- 641	- 604	- 558	- 503	- 440	- 370

Figure: 3MW Repower Option Value less 10 yr Life Extension

There is an assumption here that the cost of the preparatory work is the same for both. This will be adjusted as required.

Professional Help, Just Like R&D

Offside is only an offence if the player is interfering with play.

Is professional help interfering with play?

- **No Professional Assistance** A minimal, (if irrational), approach to wind farm planning where only regulatory obligations are carried out.
- **Professional Assistance** The work improves the income and reduces the expenditures from the wind farm. This is achieved by making better than average choices for location, size of farm, leasing agreements, OEM selection, layout of wind farm, financial planning,... etc.

Some References

Bernardi, L. (2022) Model for an evaluation of electricity production and economical affordability of a wind turbine in Ireland, Masters Thesis, University of Padua

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The End

Thank You,

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Slides at www.windvalue.ie

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Taighde Éireann
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