Real Options in Renewable Energy Investment

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Overview

The Slides are Online, Search for

- "Wind Value Research Output" or,
- "Peter Deeney Presentations and Meetings"

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, 2023)
- Similar situation for other renewables.

Options

- **Planning and Preparation is like a European Call Option**
- The Asset = Cash flows from Wind Farm
- The Expiry = Final Investment Decision Day
- The Strike Price = Cost of Building the Wind Farm

Preparatory Works, 5 yrs

- 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

Cash Flows Depend on

- Construction Cost (strike price) - Frechet
- Interest Rates - Mean Reversion
- Planning Consent - Bernoulli
- Wind Speed - Empirical Data
- Electricity Price - Mean Reversion
- Repairs Costs - Weibull

Build, Decommission, Extend Life or Repower?

- **Build** The beginning stage which will have a fixed life due to planning consent of 20 or 25 years. New Turbines

Before the end of the planning permission period (15 to 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. Used Turbines
- **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.

Turbine Purchase and Installation Cost

Following Love et al., (2013) based on an Australian dataset with N = 276. The results suggested the following parameters for the Frechet distribution the CDF, $F(x)$ of which is given by:

$$F(x) = e^{[-(\frac{\beta}{x-\gamma})^{\alpha}]}$$

Love et al. (2013) finds the following to be the parameters which fit the data best,

$$\alpha = 10.158, \beta = 90.215, \gamma = -84.29$$

These figures produce the following percentage increase distribution compared with initial cost.

$$Mean = 12.00\%, Median = 9.24\%, Mode = 5.10\%$$

Electricity Price Model

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

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

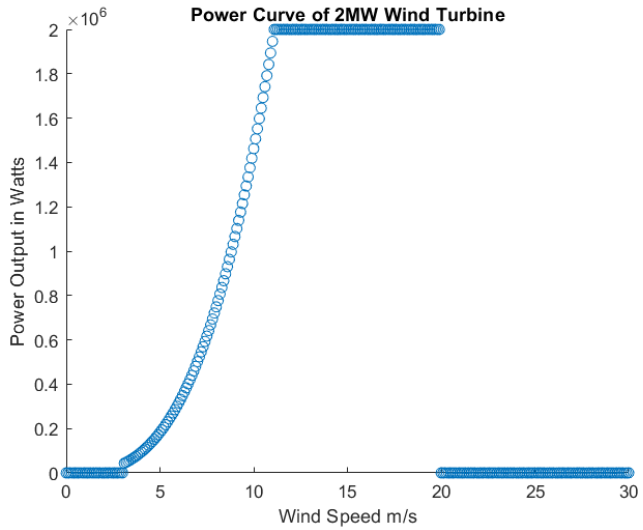
where the parameters for electricity price were found to be

$$\alpha = 0.123; \mu = 107; \sigma = 0.121;$$

are calculated using Marin, Sanchez and Palacio (2013)

Power Production

$v_{\text{cut-in}} = 3m/s$; $v_{\text{rated}} = 11.1m/s$; $R = 44m$; $v_{\text{cut-out}} = 20m/s$;$\eta$ 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

- Not relevant for First Installation and Repowering, as these typically have wrap around contracts from manufacturers.
- Relevant for Life Extension (or if negotiated by developer).
- Using a 2 factor Weibull distribution for time between failures.
- 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)

Data Sources

- Wind Data from Met Eireann - Malin Head hourly wind speeds from 1955 to 2024.
- Electricity Prices 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.
- Lending rates from EuroBond 10 year monthly data.
- Failure data from Bernardi (2022) and NREL (2023)
- Planning Consent from Renewables First (2024) for the UK

Additional Model Assumptions

- r the risk free rate is taken as the mean of the mean reversion model.
- Wrap arround contract costs €68,000 per year per MW
- O&M during life extension is €1,000 per month per MW

Standard Approach to Strike Price

Proceed with the investment if

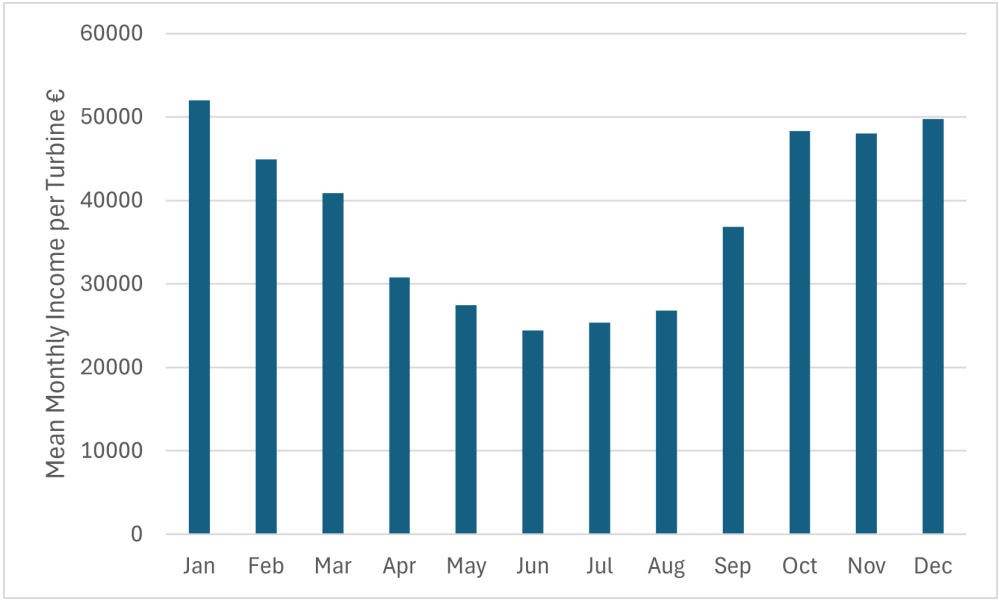
$$\mathbb{E}\left[\sum_{t=0}^{\omega}(E_t - M_t)e^{-rt}\right] - X > 0$$

where, E_t is the income from electricity during time t, X 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

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

where the expectation is taken 5 years before the investment decision.

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.

Using a Loan to Pay for the Construction

Proceed with the investment if

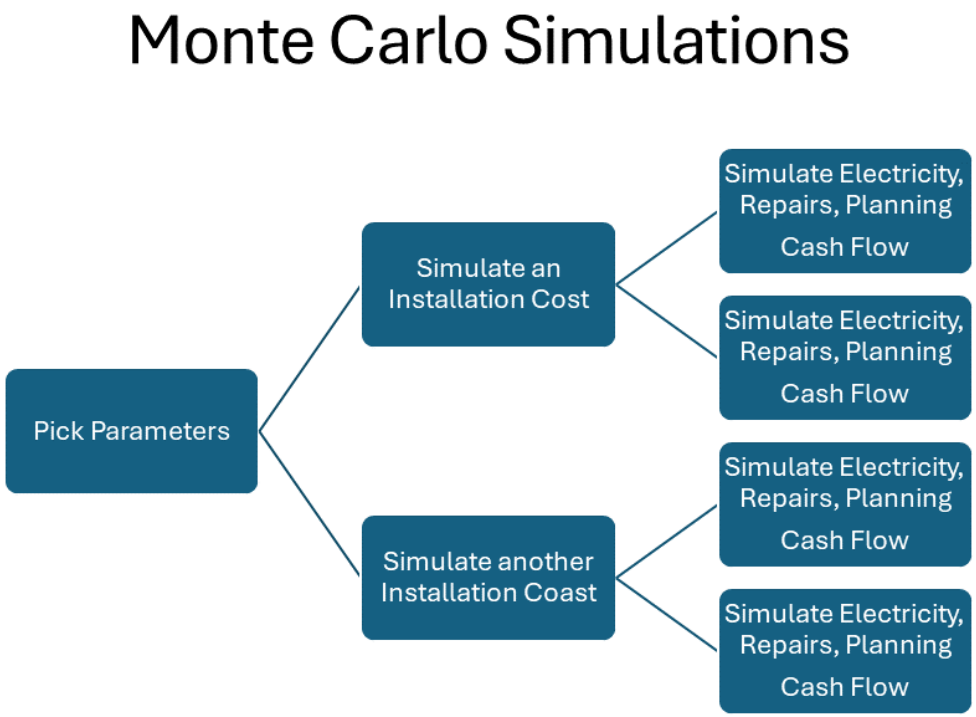
$$\mathbb{E}\left[\sum_{t=0}^{\omega}(E_t - M_t - L_t)e^{-rt}\right] > 0$$

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,

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

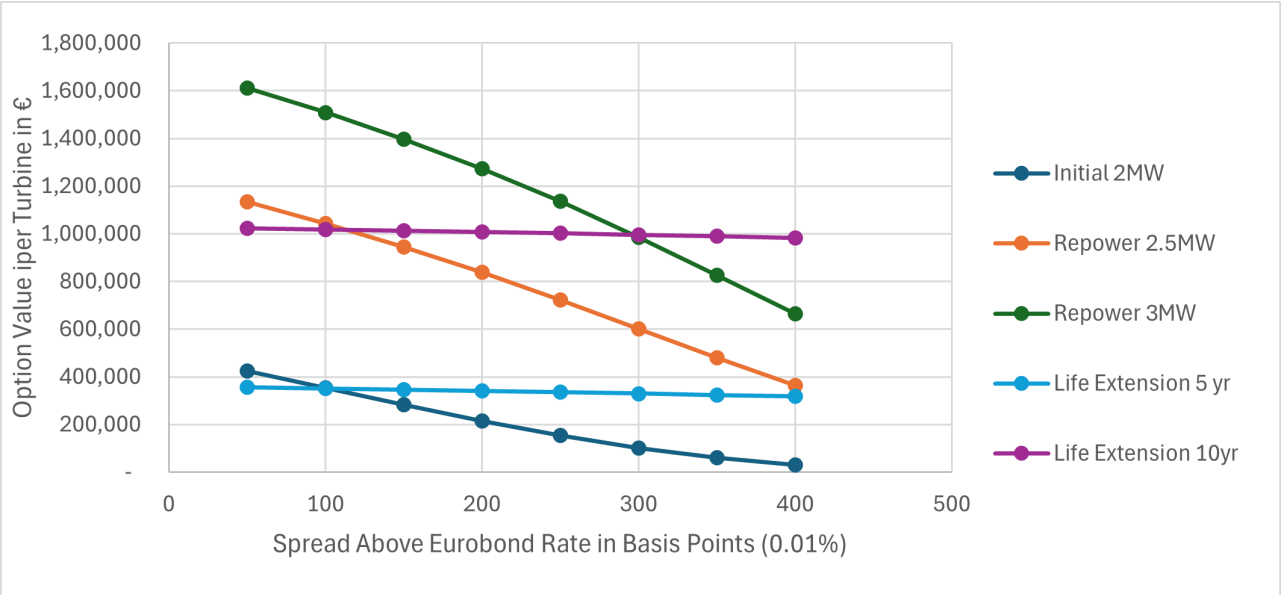
where L_t is the loan repayment per month which is the total income until the loan is paid.

Monte Carlo Arrangement

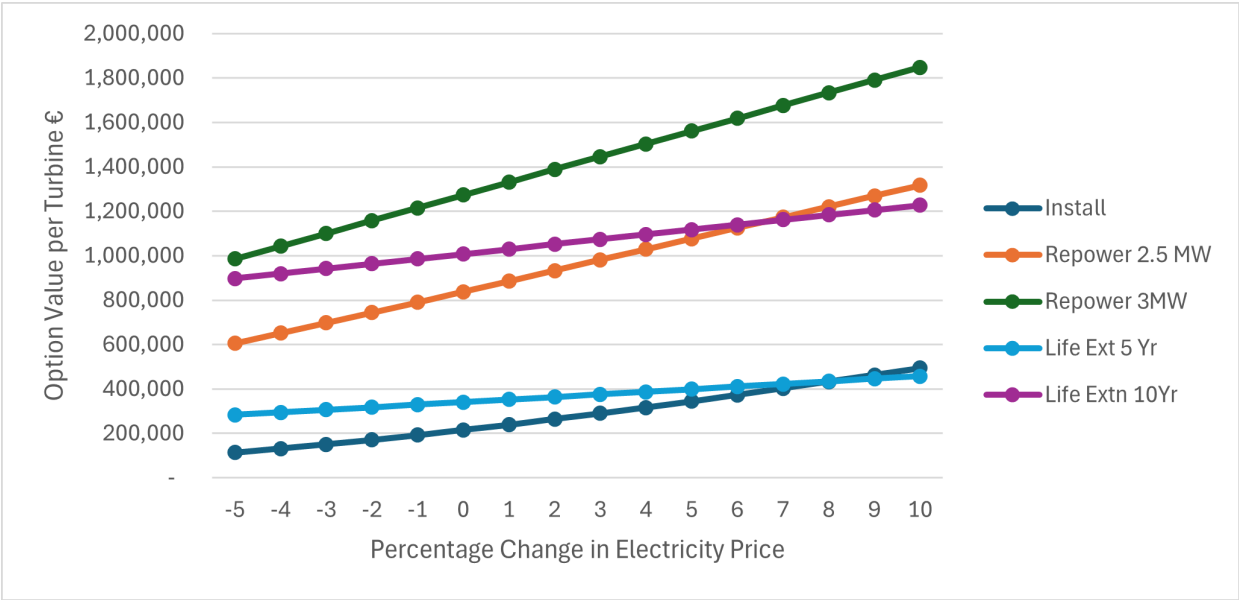


Instead of 2 x 2 shown here, the model uses 100x100x68x100x100 Construction, Electricity Prices, Production, Interest Rate, Failures

Option Value and Interest Rates



Option Value and Electricity Prices



New Build Interest Rates and Electricity Prices

Electricity Prices in columns €/MWh

Interest	54	76	97	119	140	162	183	205	227	248
2.25	-	0.004	103,885	621,881	1,261,774	1,908,406	2,557,637	3,208,389	3,860,140	4,512,596
3.25	-	-	35,337	454,759	1,113,584	1,780,174	2,442,946	3,103,548	3,762,784	4,421,079
4.25	-	-	6,304	285,477	933,880	1,629,102	2,311,059	2,984,952	3,654,012	4,319,843
5.25	-	-	132	141,675	717,262	1,446,731	2,156,763	2,849,107	3,531,262	4,206,911
6.25	-	-	-	47,553	483,346	1,221,589	1,972,061	2,690,983	3,391,035	4,079,669
7.25	-	-	-	8,435	271,070	947,820	1,744,486	2,502,866	3,228,341	3,934,565
8.25	-	-	-	156	114,117	651,718	1,459,160	2,272,416	3,035,605	3,766,536
9.25	-	-	-	-	31,723	379,189	1,118,558	1,981,913	2,800,538	3,567,926
10.25	-	-	-	-	3,713	173,738	761,547	1,619,685	2,504,317	3,326,288
11.25	-	-	-	-	25	56,921	441,656	1,207,884	2,128,416	3,021,983

Figure: Option Value of 2MW New Build

As the electricity price go higher and the interest rates go lower the value of the option increases.

New Build Interest Rates and Electricity Prices

	Electricity price in Euro per MWh									
Interest	**54**	**76**	**97**	**119**	**140**	**162**	**183**	**205**	**227**	**248**
2.25	1.28	0.63	0.11	0.002	0	0	0	0	0	0
3.25	1.62	0.93	0.28	0.01	0.00002	0	0	0	0	0
4.25	2.09	1.31	0.55	0.08	0.001	0	0	0	0	0
5.25	2.67	1.80	0.95	0.24	0.01	0.0001	0	0	0	0
6.25	3.41	2.43	1.47	0.56	0.08	0.003	0.00001	0	0	0
7.25	4.34	3.23	2.15	1.07	0.29	0.03	0.001	0.000002	0	0
8.25	5.51	4.25	3.02	1.80	0.70	0.14	0.01	0.0004	0.000001	0
9.25	6.97	5.55	4.15	2.76	1.41	0.45	0.08	0.006	0.0002	0.000002
10.25	8.80	7.18	5.59	4.01	2.43	1.07	0.30	0.05	0.005	0.0002
11.25	11.10	9.25	7.43	5.62	3.82	2.10	0.83	0.22	0.04	0.005

Figure: New Build Probability of Default on Loan in %

The probability of defaulting on the loan for construction of the wind farm depends on the electricity price and interest rate.

Repower Interest Rates and Electricity Prices

	Electricity price in Euro per MWh									
Interest	54	76	97	119	140	162	183	205	227	248
2.25	0.0001	300,338	1,629,404	3,089,765	4,559,541	6,034,225	7,511,809	8,991,320	10,472,148	11,953,899
3.25	-	109,379	1,290,247	2,808,195	4,315,242	5,815,164	7,311,072	8,804,395	10,295,954	11,786,291
4.25	-	19,349	890,923	2,470,277	4,031,668	5,566,217	7,086,300	8,597,472	10,102,650	11,603,690
5.25	-	444	500,386	2,054,109	3,695,884	5,279,436	6,831,992	8,366,463	9,889,095	11,403,605
6.25	-	-	200,381	1,543,475	3,287,436	4,943,128	6,540,582	8,105,955	9,651,213	11,182,869
7.25	-	-	46,283	990,811	2,775,863	4,539,071	6,201,188	7,808,584	9,383,605	10,937,382
8.25	-	-	2,892	506,912	2,141,012	4,037,655	5,797,071	7,463,839	9,078,938	10,661,696
9.25	-	-	-	183,246	1,442,907	3,399,282	5,300,723	7,055,818	8,726,832	10,348,383
10.25	-	-	-	39,193	806,405	2,617,299	4,669,597	6,558,483	8,311,650	9,986,961
11.25	-	-	-	2,344	346,925	1,778,467	3,865,930	5,929,479	7,807,919	9,561,638

Figure: 4MW Repower Value of Option

The same pattern is true for repowering except that the option values are higher.

Repower Interest Rates and Electricity Prices

	Electricity price in Euro per MWh									
Interest	54	76	97	119	140	162	183	205	227	248
2.25	0.68	0.05	1.03E-05	0	0	0	0	0	0	0
3.25	0.91	0.18	0.00	0	0	0	0	0	0	0
4.25	1.29	0.43	0.02	6.10E-06	0	0	0	0	0	0
5.25	1.78	0.80	0.11	0.001	0	0	0	0	0	0
6.25	2.41	1.30	0.34	0.02	5.34E-05	0	0	0	0	0
7.25	3.21	1.96	0.78	0.11	0.003	6.20E-06	0	0	0	0
8.25	4.23	2.81	1.45	0.37	0.03	0.0006	5.52E-07	0	0	0
9.25	5.51	3.91	2.36	0.92	0.16	0.01	0.0002	2.79E-09	0	0
10.25	7.15	5.32	3.55	1.82	0.54	0.08	0.005	0.0001614	9.30E-08	0
11.25	9.21	7.12	5.11	3.10	1.32	0.33	0.05	0.0037267	0.0002	2.01E-06

Figure: 4MW Repower Probability of Default in %

Similar pattern for the default risk.

Life Extension Interest Rates and Electricity Prices

Interest	54	76	97	119	140	162	183	205	227	248
2.25	9	40,654	222,804	449,039	680,197	911,782	1,143,475	1,375,233	1,607,028	1,838,849
3.25	-	34,785	211,849	438,803	671,005	903,332	1,135,529	1,367,649	1,599,722	1,831,766
4.25	-	29,291	200,521	428,095	661,423	894,570	1,127,321	1,359,837	1,592,210	1,824,491
5.25	-	24,212	188,855	416,892	651,422	885,473	1,118,835	1,351,783	1,584,481	1,817,019
6.25	-	19,595	176,861	405,156	640,972	876,019	1,110,054	1,343,476	1,576,525	1,809,339
7.25	-	15,493	164,583	392,860	630,039	866,182	1,100,959	1,334,900	1,568,332	1,801,442
8.25	-	11,967	152,074	379,969	618,589	855,935	1,091,530	1,326,041	1,559,889	1,793,319
9.25	-	9,019	139,392	366,456	606,584	845,245	1,081,745	1,316,880	1,551,182	1,784,959
10.25	-	6,633	126,621	352,305	593,989	834,080	1,071,578	1,307,400	1,542,198	1,776,349
11.25	-	4,765	113,887	337,497	580,764	822,405	1,061,003	1,297,581	1,532,921	1,767,478

Figure: Life Extension Value

Note that life extension is not as sensitive to interest rate changes as new building or repowering.

Life Extension Interest Rates and Electricity Prices

	Electricity price in Euro per MWh									
Interest	54	76	97	119	140	162	183	205	227	248
2.25	0.71	0.15	0.01	0.0006	0.00000003	0	0	0	0	0
3.25	0.75	0.18	0.02	0.001	0.0000007	0	0	0	0	0
4.25	0.82	0.21	0.02	0.002	0.000008	0	0	0	0	0
5.25	0.89	0.25	0.03	0.002	0.00003	0	0	0	0	0
6.25	0.96	0.29	0.04	0.003	0.0001	0	0	0	0	0
7.25	1.04	0.34	0.05	0.005	0.0002	0.00000009	0	0	0	0
8.25	1.13	0.40	0.06	0.007	0.000	0.0000008	0	0	0	0
9.25	1.22	0.46	0.08	0.009	0.001	0.000003	0	0	0	0
10.25	1.32	0.53	0.10	0.01	0.001	0.00001	0	0	0	0
11.25	1.42	0.61	0.12	0.02	0.001	0.00004	0.0000002	0	0	0

Figure: Life Extension Probability of Default in %

Again there is a stronger dependence on electricity price than on interest rates.

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.

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The End

Thank You,

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Taighde Éireann
Research Ireland

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