WindValue, End-of-Life Decisions for Wind Farms

Dorcas Mikindani[1,2,*]

[1]*CUBS, University College Cork, Ireland.*

[2]*Environmental Research Institute, University College Cork, Ireland.*

[*]*Corresponding author: dorcas.mikindani@umail.ucc.ie*

At a Glance

Wind farms have an estimated lifespan of twenty to twenty five years, and as they age, their value decreases, potentially becoming a liability. This article discusses a research project that aims to develop a decision support tool for wind farm owners. The tool will help estimate financial outcomes and assess risk profiles for different options such as repowering, life extension, or decommissioning. Additionally, the project will explore challenges and opportunities related to co-investment between local communities and wind farm owners.

Keywords: Wind farms; Repowering; Life-extension; Decommissioning

"An opportunity for climate action and for energy communities."

Wind Energy Facts

The wind energy industry is growing fast as nations pledge to meet the 2030-2050 science-based targets for reducing greenhouse gas (GHG) emissions. In 2021, Europe installed 17.4 GW of new wind power capacity, which is 18% more than in 2020.[1] Wind power has abundant availability, a low environmental footprint, and available technology to support its advancement. However, the lifespan of these projects is estimated to be twenty to twenty five years from commissioning.[2] As of 2022, the Republic of Ireland has just over 300 wind farms with 4,333 MW installed capacity, with the first commercial wind farm commissioned at Bellacorrick, Co Mayo in 1992.[3] This makes it clear that there are wind projects that are older than twenty years, and so many are approaching their end-of-life.

The wind energy business is characterised by a large initial investment, fixed production cycle, challenges in operation and maintenance, and political pressure to provide energy security while reducing carbon emissions.[4] Moreover, the operating permit granted for deploying these projects is fifteen to twenty years on average. These features make planning a very important aspect in running such business especially knowing what to do after the end of the lifespan of the equipment and the end of the operating permit.

End-of-Life Options

There are three end-of-life options to be considered for wind farms: repowering, life-extension, and decommissioning.

Repowering involves replacing older wind turbines with more powerful and efficient models that use the latest technology. This can increase the energy production and overall performance of the wind farm. Repowering is a way to extend the lifespan and optimise the output of renewable energy systems. It plays a crucial role in the energy transition by maximising the potential of existing infrastructure and improving sustainability.

Life extension refers to the practice of prolonging the operational lifespan of existing wind turbines. Instead of decommissioning and replacing older turbines, life extension strategies involve assessing the condition of the turbines and implementing necessary upgrades or repairs to extend their operating life. This may include refurbishing or replacing certain components, such as the generator or other critical parts, to ensure continued reliability and performance. By extending the operational life of wind turbines, life extension initiatives aim to maximise the investment in existing infrastructure, increase energy production, and optimise the overall efficiency and sustainability of the wind farm.

Decommissioning is the process of stopping wind farm operation and restoring the site to its original condition. The process involves dismantling and removing wind turbines and associated infrastructure at the end of their operational life. This includes safely disposing of or recycling the components, restoring the land, and ensuring any environmental impacts are minimised.

Opportunities at the End-of-Life

The end-of-life of wind farms brings out several opportunities for developers, operators and for energy communities. As the projects age, key performance indicators can be studied and further decisions to be taken can be structured in a way that resources are utilised efficiently. At this stage of the project, there is information on the cash flows, site conditions such as wind speed, regulatory policies such as permits and renewable energy subsidies, known government renewable energy plans for example energy storage and transmission plans, equipment performance such as turbine failure rates, and business risks from electricity markets.

This gives an opportunity to assess risk and returns with economic consideration, which results in the best end-of-life option to be taken. Negative Environmental impacts can be avoided by considering proper end-of-life management to mitigate environmental risks, for example recycling of the turbine blades and ways to restore the land to its original state after decommissioning. End-of-life provide an opportunity for energy transitioning measures through repowering the sites with newer, powerful, and more efficient turbines. Moreover, at the end-of-life, the value of the farms decrease, this provides an opportunity for the local community to own all or part of the wind farms as the wind farm's market value lowers.

Research Objectives

The WindValue project aims to, first, create a decision support tool which estimates the value from each of the three alternatives (decommissioning, repowering or life extension) by using a valuation model, and, second, to investigates opportunities and risks of community investment in the end-of-life plan for the wind farms.

The valuation model (Figure 1) is built based on power generation, operations and maintenance costs, and electricity prices. For the power generation, the existing models of power generation from wind farms will be matched to existing wind farms historical data. In operations maintenance, wind turbine industry failure data from the existing onshore wind farms to account for operational risks and costs are used. And lastly is the development of the new electricity price model, which will give an indication of the mean price and includes the variability in the electricity prices. From these three aspects a real options method will be used to conduct an economic valuation, which will enable estimates of opportunity costs given the three end-of-life options.

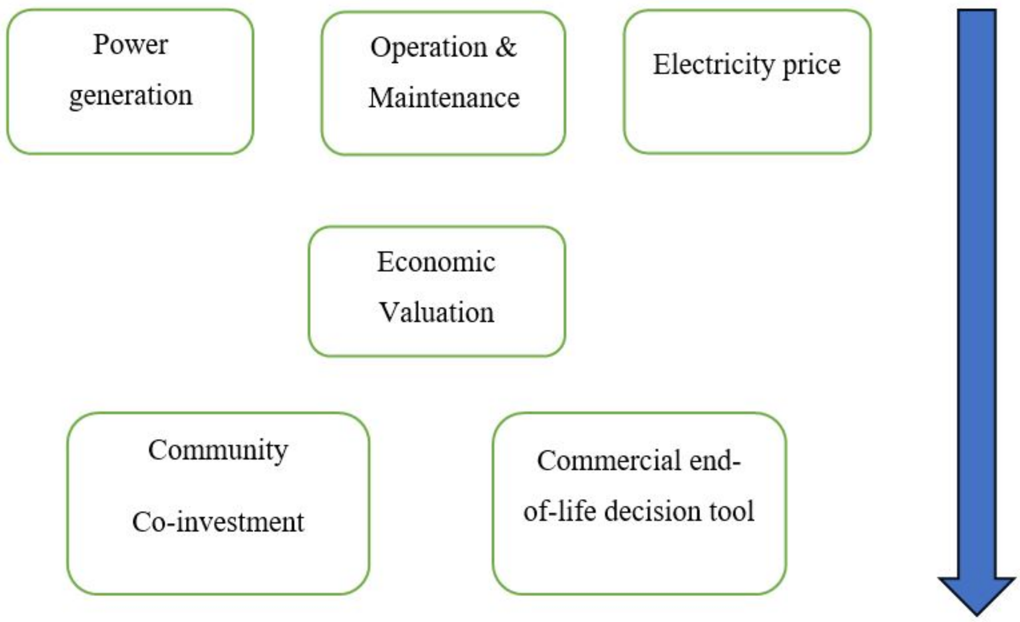

Figure 1: The Valuation Model

Initial Findings

The initial steps of the project focussed on the 'operation and maintenance' challenges by investigating the financial risks from wind turbine failures in twenty years of turbine operation and analysing the number of turbines in a wind farm sufficient for risk reduction.

The costs of running a wind farm over its lifetime are dominated by the initial capital investment, however the costs associated with wind turbine failures have a significant impact on profitability. These failures were modelled as random events over the lifetime of a windfarm based on industry data and the existing literature. The model includes both the direct cost of repairs and the opportunity cost due to loss of power generation when these repairs are taking place. Weibull distributions were used to model failure parameters, Monte Carlo simulations to estimate failures of wind turbines over their operation life, present value techniques were used to quantify the costs and risk distributions, finally, the Value-at-Risk (VaR) and Conditional VaR (CVaR) metrics were then used to understand the scale and potential impact of risks and these were expressed relative to the initial capital cost (CAPEX) to aid interpretation.

Two main findings are presented here. First, for a single turbine, the cost distribution of turbine failures reveals a range of expenses for turbine operators (Figure 2). Over the lifespan of a 2.5 Megawatt turbine, maintenance costs due to failures typically fall between €250,000 and €1,500,000. Notably, the distribution exhibits a peak at the lower end, where costs are zero, signifying that operators do not consistently incur expenses for repairs. Beyond the €2,000,000 mark, the distribution remains relatively flat, indicating that failure costs seldom exceed this threshold. The average twenty years expected cost from failures is 684,672.

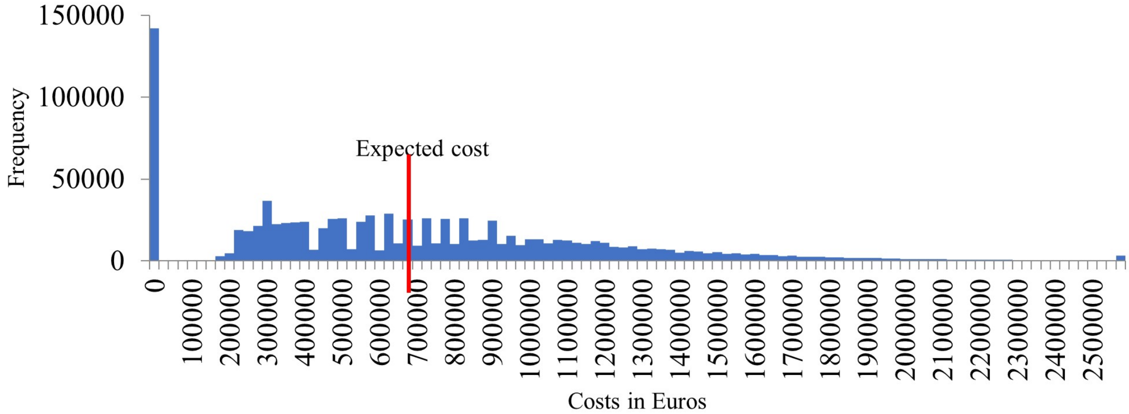

Figure 2: Turbine Failure Costs Distribution

Secondly, the risk analysis shows that, for a single turbine, the estimated costs from failures are equal to 23% of the CAPEX. In the most severe 5% of cases, repair costs can exceed 52% of the CAPEX and the CVaR is 63% of the CAPEX (Table 1). As the number of turbines increase in a farm, the results show a decrease in the percentage of capital expenditure required to mitigate potential losses (% CAPEX).

Specifically, the percentage of VaR to CAPEX decreases from 52% for a single turbine to 25% for a one hundred-turbine farm. A similar pattern emerges for CVaR, with a reduction from 63% to 25%. This trend follows a diminishing returns pattern, where the incremental impact decrease as additional turbines are integrated into the farm.

Farm Size	1	5	10	20	40	60	100
Expected Cost	685	3,423	6,847	13,693	27,387	41,080	68,467
95% VaR	1,624	5,371	9,540	17,449	32,598	47,500	76,716
95% CVaR	1,966	5,971	10,331	18,488	34,080	49,184	78,937
VaR per CAPEX	52%	34%	31%	28%	26%	25%	25%
CVaR per CAPEX	63%	38%	33%	30%	27%	26%	25%

Table 1: Risk Analysis for Wind Farms

This analysis reveals a substantial reduction in risk moving from one to forty turbines. Looking at the status of wind farms in Europe, in Ireland many wind farms fall into the category of one to ten turbines per farm. This implies that few operators are utilising the risk reduction advantages of running an average of twenty to forty turbines in a farm. However, there is a significant number of large-scale wind farms under construction in Ireland, the UK, Netherlands, and Germany.[1] This shows a promising future for less risky, and hence, more profitable wind energy businesses.

Conclusion

This study furnishes a valuable insight into the number of wind turbines required to effectively reduce the risk-per-CAPEX. This observation holds relevance for the evolving wind energy landscape in Ireland, where a slight increase in the number of turbines per farm appears to be steering the industry in the right direction.

The future steps of the project involve exploring electricity markets to check how electricity prices influence wind energy investment and end-of-life decisions.

Acknowledgements

I would like to express my gratitude to my supervisors Dr Peter Deeney, Dr John O'Brien and Dr Paul Leahy, and to my colleagues in both the Cork University Business School and the Environmental Research Institute for their help and support.

Declaration of Interests

Nothing to declare. This publication has emanated from research supported by a grant from Irish Research Council Pathway Award: IRC*21/PATH-A/9348. All ethical guidelines relating to the research and publication process were adhered to throughout this study.

Author Bio

Dorcas Mikindani is a second-year doctoral student in renewable energy finance. She is working under the supervision of Dr Deeney, Dr O'Brien and Dr Leahy in the Cork University Business School and the Environmental Research Institute. She holds a MSc in Global En-

vironmental Economics from the University of Galway and a BSc in Agricultural Economics Agribusiness from Sokoine University of Agriculture, Tanzania. She won an international competition to carry out this research, which is supported by the Irish Research Council through the Pathway Programme.

References

[1] Wind Europe. Wind energy in Europe. https://windeurope.org/about-wind/reports/wind-energy-in-europe-outlook-to-2023/, 2023.

[2] L. Ziegler, E. Gonzalez, T. Rubert, U. Smolka, and J. J. Melero. Lifetime extension of onshore wind turbines: A review covering Germany, Spain, Denmark, and the UK. *Renewable and Sustainable Energy Reviews*, 82:1261–1271, 2018.

[3] Wind Energy Ireland (WEI). Wind Stats. https://windenergyireland.com/about-wind/the-basics/facts-stats, 2023.

[4] H. Rashid Khan, U. Awan, K. Zaman, A. A. Nassani, M. Haffar, and M. M. Q. Abro. Assessing hybrid solar-wind potential for industrial decarbonization strategies: Global shift to green development. *Energies*, 14, 2021.