Economic Sensitivities and Options Surrounding Wind Farm Life Extension

R Carriveau¹, L Miller¹

¹Environmental Energy Institute, University of Windsor, Windsor, Ontario, Canada
rupp@uwindsor.ca

Abstract. Some North American wind owners and operators are approaching and surpassing the halfway points of their power purchase agreements (PPAs). The initial 20-year contracts were intended to align with the operational life of the assets, however it is expected that some assets will continue to be operational if proactively maintained. An LCOEEXT was previously proposed to evaluate the economic feasibility of lifetime extension. This metric is sensitive to many variables and a robust analysis of these sensitivities will provide improved guidance when considering lifetime extension. Lifetime extension is an attractive option, offering higher rates of return for projects when economic analysis supports this pursuit. Options for operating beyond the first PPA are also detailed and discussed.

1. Introduction
The wind fleet in North America is aging, with farms approaching and surpassing the halfway points of their power purchase agreements (PPAs). The majority of wind farms in Canada have long-term (typically 20-year) power purchase agreements with their utility to guarantee revenue over the often cited 20-year life of the assets. At the end of this period however, at least a portion of the assets will likely still be operational, and therefore could still be generating. The same generous PPAs that were provided in the early days of wind to encourage development and bridge the price gap between conventional and renewable energy are unlikely to be offered at the expiration of those first contracts. Wind farm operators could choose to accept a likely lower, PPA price from the utility or through a bilateral contract or choose to sell their energy at spot market prices. Owners and operators who are interested in lifetime extension of their farms are seeking guidance on how to assess economic feasibility in absence of a guaranteed contract and with uncertainty surrounding the true operational life of their assets.

Lifetime extension can offer higher rates of return for projects given the majority of lifetime costs are attributed to construction and interconnection [1]. Although European studies have demonstrated that turbines can operate beyond their design lifetime, and in the range of 23 – 41 years [2], there is still limited literature on the economic benefits of lifetime extension. We have previously proposed a lifecycle cost of energy through extension (LCOEEXT) to evaluate the possibility of lifetime extensions of wind farm assets [3]. Independent of the original LCOE, the LCOEEXT is calculated based on a CAPEXEXT which includes the anticipated costs of operating beyond the manufacturer stipulated end-of-life. While this metric informs initial discussions on feasibility of extension, there are many assumptions and sensitivities that should be evaluated further in order to provide increased confidence in lifetime extension decisions.
The LCOEEXT previously proposed assumes that annual energy production (AEP) remains constant into the extension period. Previous research has suggested that, in fact, the wind farm output can fall by ~16% per decade due to availability and wear [4]. This analysis is complex because the lifetime extension assessment aims to identify and repair components that may be experiencing wear, thereby complicating the relationship between turbine age and output. In this work, the sensitivity of AEP in LCOEEXT will be evaluated. Operation and maintenance (O&M) costs may also change in an extension period, which is a variable that will be further investigated. The LCOEEXT also depends on estimates for the type and number of repairs or retrofits that operators can expect to face at the end of their first PPA. Ziegler et al. [5] demonstrated that the business case for lifetime extension is very sensitive to modeling of failure and wear out rates. This work will consider a range of repair costs that owners could face at the end of the PPA1. Furthermore, there could also be additional costs that could impact feasibility of extension such as transmission upgrades or social license impacts. A thorough analysis of potential extension costs for North American wind farms will be conducted.

Experiences in Europe are revealing the importance of considering lifetime extension early on. Operators who are interested in extension can adjust their operational strategies to maximize the life of the assets for optimal economic value, rather than maximize the power produced during PPA1. Furthermore, data management and O&M records can be maintained to inform lifetime extension assessments. With a range of LCOEEXTs covering the various sensitivities, owners can make informed decisions regarding their end of PPA plans. This paper outlines the possible options that owners can select from at the end of their original PPA. The first option is for the owner to extend their contract with the utility. The second option is for the operator to enter into a non-utility contract, such as a corporate PPA. Operators could also choose to enter the open market. Alternatively, if there are no plans to operate beyond the end of year 20, operators can choose to sell or decommission.

2. Methodology
The calculation and rationale of the LCOEEXT is provided in Miller et al., 2019 [3]. Briefly, the levelized cost of energy (LCOE) is a commonly applied economic metric that provides a ratio of the present value of total costs ($) divided by the present value of all energy produced over the project lifetime (MWh):

\[
LCOE = \frac{NPV_{Total \ Cost}}{NPV_{Total \ Energy \ Yield}}
\]

**Equation 1.** Levelized cost of energy [6]

\[
NPV_{Total \ Cost} = \sum_{n=1}^{T} \frac{CAPEX_n + OPEX_n}{(1+i)^n}
\]

**Equation 2.** Net present value of total cost

\[
NPV_{Total \ Energy \ Yield} = \sum_{n=1}^{T} \frac{AEP_n}{(1+i)^n}
\]

**Equation 3.** Net present value of energy yield

Where:
LCOE = levelized cost of energy ($/MWh)
NPV_{Total \ Cost} = net present value of the total project costs ($)
NPV = total energy yield = net present value of the energy generated over the project lifetime (MWh)
CAPEX = capital expenditures ($)
OPEX = annual operating expenses ($/year)
AEP = net annual energy production (MWh/year)
i = interest rate (%)

While the LCOE is calculated during project development to inform PPA contract negotiations and to determine the expected internal rate of return for the project, the LCOE is calculated to evaluate the possibility of lifetime extension of the wind farm assets. Therefore, in Equation 2, the CAPEX is replaced by:

\[ \text{CAPEX}_{\text{EXT}} = C_{\text{VI}}n + C_{\text{LA}}n + C_{\text{OA}}n + C_{\text{RR}} \]

Equation 4. Capital expenditures associated with extension

Where:
CVI = Cost of visual inspection
CLA = Cost of loads analysis
COA = Cost of operations analysis
CRR = Cost of repairs and retrofits

The LCOE was calculated for a representative North American wind farm under various assumptions. The farm has a capacity of 101.2MW (44, 2.3MW turbines) with an estimated annual energy production of 7280 MWh/turbine. Based off historical operation and maintenance records, an annual O&M of $25/MWh was applied and an interest rate of 4% was assumed. First an LCOE was calculated for the base case (as described above). Next, variables were adjusted to investigate the sensitivity of the LCOE to AEP (loss of 10% and 20% in the extension phase), interest rates (6% and 10%), escalating O&M costs (2% and 5%/year), and component CAPEX (low, medium, and high). Each CAPEX cost included CVI, CLA, and COA values set at $3740/turbine, $7000/turbine, and $3000/turbine, respectively and adapted from Rupert et al. [6]. The CRR values were set to represent low, medium, and high levels. The CAPEX low was set at $10,000,000 which would represent the cost of replacing approximately 50% of the gearboxes on the farm. CAPEX medium was set at $17,500,000 which represents the cost of replacing approximately 50% of the blades. CAPEX high was set at $25,000,000 which represents the cost of replacing approximately 40% of blades, gearboxes, and generators. LCOE EXT were calculated for 5 and 10-year extension periods, resulting in a total of 56 cases.

3. Results
Table 1 summarizes the results of the LCOE calculations under the various assumptions.

| LCOE EXT values ($/MWh) under various assumptions. |
|-----------------------------------------------|
| Base Case                                      |
| CAPEX (low)                                    |
| CAPEX (moderate)                               |
| CAPEX (high)                                   |
| 5-year                                        |
| 10-year                                       |
| 5-year                                        |
| 10-year                                       |
| 5-year                                        |
| 10-year                                       |
| 5-year                                        |
| 10-year                                       |
| No O&M Escalator, No AEP Reduction             |
| $25.42                                        |
| $25.23                                        |
| $32.01                                        |
| $28.85                                        |
| $37.27                                        |
| $31.74                                        |
| $42.53                                        |
| $34.62                                        |
| O&M Escalator (2%)                             |
| $26.40                                        |
| $27.43                                        |
| $32.99                                        |
| $31.05                                        |
| $38.25                                        |
| $33.94                                        |
| $43.51                                        |
| $36.82                                        |
| O&M Escalator (5%)                             |
| $27.94                                        |
| $31.19                                        |
| $34.53                                        |
| $34.80                                        |
| $39.79                                        |
| $37.69                                        |
| $45.05                                        |
| $40.58                                        |
| AEP Reduction of 10%                           |
| $28.25                                        |
| $28.04                                        |
| $35.57                                        |
| $32.05                                        |
| $41.41                                        |
| $36.26                                        |
| $47.26                                        |
| $38.47                                        |
The base case assumes a simple life extension without repair and retrofit costs ($C_{RR} = 0$), that O&M costs would remain constant into the extension period, and that there would be no loss of AEP. This is the best case scenario that an operator could face at the end of PPA$_1$. In this case, the LCOE$_{EXT}$s are $25.42/MWh and $25.23/MWh for a 5-year and 10-year extension period, respectively. These values are lower than those reported for new developments which have ranged from $30-142/MWh [7 - 10]. As expected, the LCOE$_{EXT}$ values increase as the CAPEX increases and reach a maximum of $42.53/MWh in the case without an O&M escalator and with no AEP reduction.

In reality, it is likely that O&M costs will increase in the extension period due to the age of the assets. To account for this, the baseline O&M cost of $25/MWh was escalated at 2%/year and at 5%/year during the extension periods to evaluate how the LCOE$_{EXT}$ would change. The values do increase, for example, in the high CAPEX, 5-year extension case, the LCOE$_{EXT}$ increases from $42.53/MWh to $45.05/MWh. Another reality is that the AEP might decrease due to wear such as leading-edge erosion, and also due to increased downtime for maintenance and repair. To evaluate this, a 10% and 20% AEP reduction case were constructed. A loss of AEP has a significant impact on the LCOE$_{EXT}$ value as demonstrated in Table 1. Lastly, two different interest rates were applied, 6% and 10%, which impacted the LCOE$_{EXT}$s, more so for those with higher CAPEX costs. The general trends of the results, i.e., higher costs and lower AEP will increase the cost of producing energy, are expected. The intention is to demonstrate the range of values that could be expected when entering a lifetime extension contract so that operators can make informed decisions when considering a PPA$_2$ or selling on the open market.

The results demonstrate how sensitive the LCOE$_{EXT}$ is to the variables considered and will provide guidance for operators and investors when assessing lifetime extension based on economic feasibility. The results also demonstrate which variables are most impactful to the decision. While this analysis focuses on changing one variable at a time, there are also potential interactions between variables. For example, increased turbine maintenance could increase O&M costs and decrease AEP, as turbines are taken offline for repair. An informed LCOE$_{EXT}$ estimate can be relied upon to guide PPA$_2$ negotiations or to understand what open market values would support extending operations.

4. Discussion on Post PPA$_1$ Options

Armed with information on what energy can be sold for, operators can evaluate economic options for extending the life of their farm. To begin to understand how PPA$_2$ might differ from PPA$_1$, it is important to consider what has changed. Assets have aged since PPA$_1$ and operators have more experience. Furthermore, the assets are likely paid for as financing terms are set to coincide with the end date of PPA$_1$. Another consideration is that new policies, incentives, and environmental attributes have likely been introduced or amended since PPA$_1$. These changes will impact the structure and terms of PPA$_2$. For example, if the assets are paid for and the farm is operational, contract terms such as delay damages, guaranteed commercial operation date, and third-party financing would be non-issues in PPA$_2$. Furthermore, because the assets have aged, operators may want to adjust capacity or guaranteed availability in anticipated of more down time. The following discussion details the options available.

*Extend original (utility) contract*

Option 1, extending the original contract will likely be the first option that operators will consider. Operators would go to the utility and discuss the option of extending their PPA, likely with some amendments to the terms and rates. The first consideration will be the term of the extension. The commonly cited 20-year lifetime of wind turbines would suggest that if they are operational at the end...
of contract, they may only be so for a short time. A reasonable extension might be between 3 – 10 years. The utility may also offer a lower $/MWh price, knowing that the assets have aged and that the capital costs have been paid for. Both parties may be interested in discussing changes to curtailment clauses and distribution of environmental attributes. At the commencement of PPA\textsubscript{1}, for example, the environmental attributes associated with the renewable energy may have been of marginal value, however, due to policy changes such as carbon pricing, the value may now be a lucrative component of the deal.

Enter into new (non-utility) contract

If extension of PPA\textsubscript{1} is not an option or is not financially attractive, owners may consider entering into a new, non-utility contact such as a corporate PPA (CPPA). Corporate PPAs can be mutually beneficial to owners and corporations as they allow for corporations to meet sustainability goals and lock into stable energy pricing while providing a long-term revenue stream to the wind farm owner. Corporate PPAs are most often structured as a “virtual PPA” or “contract for differences”. In this contract structure, the buyer agrees to purchase renewable energy and renewable energy credits from a developer for a fixed price. The developer sends the energy to the wholesale market and the corporation purchases from the market. If the wholesale price is higher than the contracted price, the corporation pays the difference. If the wholesale price is lower than the contracted price, the corporation pays the difference. Selection of this options would come with new considerations. A financial settlement point; the hub or bus bar where the average real-time hourly locational price will be taken, would first need to be agreed upon. Furthermore, there is a high possibility for multi-party transactions since a single corporation is unlikely to have a demand for the entire energy output from a large wind farm. For this reason, many corporate deals are aggregated amongst multiple off-takers. This can still be a mutually beneficial option, however, requires coordination of timing and alignment of contract terms amongst more stakeholders than a utility PPA would.

Another potential benefit to owners is the possibility of better price negotiations. When settling on a “strike price”, owners are competing with the retail electricity rates paid by the corporation rather than the lower wholesale prices they are up against when negotiating with the utilities. Lastly, when considering a CPPA, environmental attributes will be a major driver as most companies are looking to promote sustainability and lower their environmental costs such as carbon pricing.

Sell to the open market

If a PPA contract is not an option or is not economically feasible, owners could choose to sell their energy to the open market at spot prices. There is considerable uncertainty surrounding future energy pricing, and therefore, it would be essential for owners to understand their costs of producing energy to understand what they could accept in the open market in order to maintain profit.

Sell assets (new owner)

If there are no plans for the current owners to continue operating beyond PPA\textsubscript{1}, one option is to sell the assets to a new owner. Information on LCOE\textsubscript{EXT} values could assist owners with demonstrating the value of the assets to a potential buyer.

Decommission

Lastly, owners can choose to decommission the farm in which case they could potentially pay, profit, or break even from this selection. Past literature has suggested that it is reasonable to assume that any revenue from scrap materials would be equal to the decommissioning costs [11]. For example, the seven-turbine community-owned Black Oak Wind Farm in New York State has a decommissioning plan the states a cost of $50,000 per turbine. The plan also assumed a salvage value of $45,000 per turbine, based on the worst-case scenario that the only salvage value is from the scrap steel [12]. The plan states that this is a conservative estimate and there could also be an opportunity for resale of some of the turbine components. In contrast, it has been argued that scrap value cannot
be estimated a year in advance, let alone 20 or more years in advance, due to the variable scrap value and fluctuating environmental conditions [13]. Many owners originally assumed that the revenue from scrap metal would cover the decommissioning costs, but this has been shown not to always be the case. Knauth et al. [13] estimated that it would cost of $58/kW, net of scrap value to decommission turbines at the Monticello Hills site.

5. Conclusions

LCOE_{EXT} values can be calculated to inform lifetime extension decisions. It is unlikely that similar secure, lucrative, long-term PPAs will be offered to wind farms considering extension, and therefore, it will be ever more important to have an accurate understanding of the cost of generating. To inform this, the variables that are relevant to LCOE_{EXT} calculations have been varied here to provide a more robust metric for evaluating lifetime extension cases. Interest rates, O&M escalators, AEP reduction, CAPEX costs, and extension periods have all been considered here to demonstrate the range of LCOE_{EXT} values that could be expected. The values reported generally remain lower than those reported for new developments and thus suggest that even with replacement costs and higher O&M, energy can be sold for less during an extension period. The use of economic metrics requires operators to be more familiar with the characteristics of the operating and financial targets which will ultimately, enable better management and investment decisions.

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