Valuation and Risk Modeling of Renewable PPAs

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DOI: *https://doi.org/10.17979/spudc.000024.24*

Abstract:
Renewable energy (RE) projects aim to sell electricity to the consumers, which may be carried out by means of a Power Purchase Agreement (PPA). These PPAs will yield payments over a long period of time so as to refinance the project. Nevertheless, the present literature which addresses the economic appraisal of renewable energy projects focuses on the project developer and whether an onsite PPA is deemed, the actual cost of energy is not taken into consideration and nor the embedded options of the PPA. We propose such a model and carry out a comparison with the most common approach, a swap between fixed and market price.

1 Introduction

The development of renewable energy (RE) projects has enabled the decarbonization of some regions. These projects involve a high capital expenditure, which is repaid over long periods of time. One way of ensuring this repayment and thus making the renewable deployment possible is by offering long term agreements, for instance, a Power Purchase Agreement (PPA), which is a bilateral contract between 2 parties: an energy producer and an energy consumer (the offtaker) which settle on a price for the electricity supply during a long period of time Peña et al. (2022).

The vast majority of the renewable projects appraisals take into consideration the viability of a project by computing a single value, the Levelized Cost of Energy (LCOE), which encompasses the capital expenditure, maintenance expenditure, the interest rate linked to the general market conditions and the riskiness of the project, and technical features of the project. This value is the unit cost of energy and yields a value which allows for a comparison with other projects Carrêlo et al. (2020). For the completion of the calculation, several features can be added such as a probability distribution for the energy production Freeman et al. (2018) and how the placement affects the projects' viability Gabrielli et al. (2022). Another common approach in projects assessments is that of real options, which is focused on the development stage of the project or on how it should be run.

It is clear that these approaches pay attention to the party that develops the project, while the offtakers' point of view is dismissed. Regarding this latter point, the valuations reviewed consider the value of a PPA as a swap between two parties. One of them pays a fixed amount and the other one the market price. Nevertheless, this is only true when the producer must purchase the electricity, that is, acting as a distributor company, while for the case the producer owns a RE project, the unit cost of energy (LCOE) is the real price of the supplied electricity.

Therefore, we aim at developing a model for the valuation of a PPA taking into consideration the embedded options of a PPA.

2 Mathematical model

In this section we briefly describe the main ideas to pose the mathematical modelling for RE PPA pricing, also including the specific stochastic model that has been considered for the electricity price evolution. Note that this price model is a building block and can be replaced by alternative models.

2.1 PPA model

The optional component of a RE PPA is assessed with respect to its alternative (that supplied amount of electricity at the market price). For that purpose, we will assume that a RE PPA is signed at t_0 and expires at t_M, having $M+1$ times when the electricity supply takes place. For each unit of supplied electricity $U(t_k)$ for $k = 0, \ldots, M$, which we will consider constant and equal to $1\,MW \cdot h$ for simplification, the offtaker will pay an amount P_{PPA}, and if at $t_k > t_0$ the offtaker decides not to pay, then s/he will quit the RE PPA. Therefore, by paying at t_0, the offtaker will obtain savings equal to the difference between the market price (P_t) and P_{PPA} and s/he also buys a call option on the underlying asset which matures at t_1, which we denote as $H^1(P_{t_1})$. By paying at t_0 and t_1, the offtaker will obtain savings at t_0 and t_1 and s/he buys a call option on the underlying asset which matures at t_2, that is $H^2(P_{t_2})$, and so on. In this way we have the following set of possible scenarios

$$
\begin{aligned}
&(P_{t_0} - P_{PPA}) + e^{-r(t_1-t_0)} H^1(P_{t_1}) \\
&(P_{t_0} - P_{PPA}) + e^{-r(t_1-t_0)} \Big((P_{t_1} - P_{PPA}) + e^{-r(t_2-t_1)} H^2(P_{t_2}) \Big) \\
&(P_{t_0} - P_{PPA}) + e^{-r(t_1-t_0)} (P_{t_1} - P_{PPA}) + e^{-r(t_2-t_0)} \Big((P_{t_2} - P_{PPA}) + e^{-r(t_3-t_2)} H^3(P_{t_3}) \Big) \\
&\ \vdots \\
&(P_{t_0} - P_{PPA}) + \cdots + e^{-r(t_{M-2}-t_0)} \Big(\left(P_{t_{M-2}} - P_{PPA}\right) + e^{-r(t_{M-1}-t_{M-2})} H^{M-1}\left(P_{t_{M-1}}\right) \Big) \\
&(P_{t_0} - P_{PPA}) + \cdots + e^{-r(t_{M-1}-t_0)} \Big(\left(P_{t_{M-1}} - P_{PPA}\right) + e^{-r(t_M-t_{M-1})} H^{M}(P_{t_M}) \Big).
\end{aligned}
$$

Due to the possibility of quitting the PPA at any time $t_k > t_0$, the offtaker will pursue the scenario with the maximum payoff. For this reason, the PPA value for the offtaker, which we will denote by V_{PPA}, will be given by the maximum of the possible values of the PPA

$$
V_{PPA}(t_k) = \max_{k+1 \leqslant m \leqslant M} \left(\sum_{j=k}^{m-1} e^{-r\left(t_j - t_k\right)} \left[P_{t_j} - P_{PPA}\right] + e^{-r(t_{m-1}-t_k)} e^{-r(t_m - t_{m-1})} H^m(P_{t_m}) \right), \tag{24.1}
$$

with $k = 0, \ldots, M-1$.

The financial appraisal of the PPA is not over, it remains some measurements which may be computed, more precisely, the default probability defined as

$$
PD(t_0) = \mathbb{P}\left[V_{PPA}(t_0) \leqslant 0\right] \tag{24.2}
$$

$$
PD(t_k) = \mathbb{P}\left[V_{PPA}(t_k) \leqslant 0 \mid V_{PPA}(t_{k-1}) > 0\right] \quad \text{for } k = 1, \ldots, M-1. \tag{24.3}
$$

This enables us to compute the collateral requirements the producer might demand. For that, it is supposed that at each time t_k the deemed loss will be equivalent to the investment not hedged, that is, the capital expenditure not amortized. The expression for the expected loss is

$$\begin{aligned} EL(t_k) &= PD(t_k) \cdot CAPEX^{not}_{amortized}(t_k) \\ &= PD(t_k) \cdot (CAPEX(t_k) - AMORTIZATION(t_k)), \end{aligned} \tag{24.4}$$

where $CAPEX$ refers to the capital expenditure, and the Total Expected Loss (TEL) will be

$$TEL(t_0) = \sum_{k=0}^{M-1} e^{-r(t_k - t_0)} EL(t_k). \tag{24.5}$$

2.2 Electricity Price model

Given that the electricity market price is the underlying variable of the model, it is necessary to set a model which describes the main features of the electricity market price such as the seasonality and the mean reversion. We have chosen the following model

$$P_t = e^{f(t)+Y_t}, \tag{24.6}$$

where $f(t)$ is the seasonality function and Y_t is the stochastic part of the price process, described respectively by a sinusoidal function and the Ornstein-Uhlenbeck process:

$$f(t) = a_0 + \sum_{i=1}^{4} a_i \cos(2\pi\gamma_i (t - \tau_i)) \tag{24.7}$$

$$dY_t = \alpha(\mu - Y_t)\,dt + \sigma dW_t, \quad Y_{t_0} = \log P_{t_0} - f(t_0). \tag{24.8}$$

3 Results and discussion

In order to shed some light into the valuation, a numerical simulation was carried out. Furthermore, we noticed that in Spain a toll is added up to the electricity market price, that is

$$P_t = \widehat{P}_t + \xi,$$

where ξ denotes this toll.

3.1 Numerical settings

The variables of the model were chosen as the actual values used in a RE PPA designed for a photovoltaic irrigation project in Spain, for which the offtaker was determined that s/he will need 300 $MW \cdot h$ in a yearly basis. For that purpose, the producer establishes that a 200 kWp system will be required, which implies a capital expenditure of 244960 €. The duration of the agreement is 20 years and payments will take place annually, $t_k = 0, 1, \ldots, 19$. The LCOE of that system has been estimated as $76.69 \frac{€}{MW \cdot h}$ and an interest rate of 2% was considered. The $AMORTIZATION$ variable of the Equation (24.4) is equal to 11484 € for years $1-10$ and 13012 € for years $11-20$ Carrêlo et al. (2020). On the other hand, the parameters of the seasonality part of the electricity price model were estimated by a least squares method (Nelder-Mead optimization algorithm) and the stochastic part by means of the maximum likelihood method using daily data of the electricity price from 2010 to 2022 in Spain. γ_i, for $i = 1, \ldots, 4$, was obtained analysing the periodogram of the raw data. Below is shown a summary of the parameters

Table 1: Estimated parameters of the seasonality function and stochastic process.

	i				
	0	1	2	3	4
a_i	4.001137	−0.187542	8.264600	−0.079046	0.637311
τ_i	–	−0.046877	0.100468	0.024929	0.647611
γ_i	–	1	$\frac{365}{7}$	$\frac{365}{7/2}$	$\frac{365}{7/3}$
	α	μ	σ	$\hat{P}_{t_0}$	ξ
	39.105053	0.004586	2.180066	143.17	20.00

3.2 Results

According to the methodology proposed, and given the numerical settings presented, for a $P_{PPA} = LCOE = 76.69\ \frac{€}{MW \cdot h}$ the expected value of the PPA at t_0 is $\mathbb{E}\left[V_{PPA}(t_0)\right] = 66630.84$ €, with a 95% CI equal to $(65721.46, 67540.23)$. A comparison using a swap-based approach was made so as to clarify the performance of our model. A swap-based PPA value may be computed as Edge (2015)

$$V_{PPA}\left(t_k\right) = \sum_{i=k}^{M} U(t_i)\left(P_{t_i} - P_{PPA}\right) e^{-r(t_i - t_k)}, \quad \text{for } k = 0, \ldots, M. \tag{24.9}$$

As a result, our proposed model provides PPA values greater than the first difference, that is $U\left(P_{t_0} - P_{PPA}\right)$, even for P_{PPA} values considerably higher than the $LCOE$ level. On the other hand, the swap approach provides negative values for a P_{PPA} value greater than 89 $\frac{€}{MW \cdot h}$.

For the other financial measurement, which determines the amount, in case of early termination, of the CAPEX that will not be repaid, the $TEL(t_0)$ amounts to 7448.69 € with a 95% CI equal to $(6103.72, 9258.43)$. A comparison with the swap-based approach has also been conducted and is plotted in Fig. 1, where we can observe that by applying our model, the amount required to hedge against default is lower than for the swap approach, indeed for a $P_{PPA} \in [70, 95]$, the collateral requirements are from 76% to 9% lower. Furthermore, for a P_{PPA} value equal to the $LCOE$ level in a swap-based approach the collateral requirements amount to 18362.33 € with a 95% CI equal to $(16091.37, 21093.69)$.

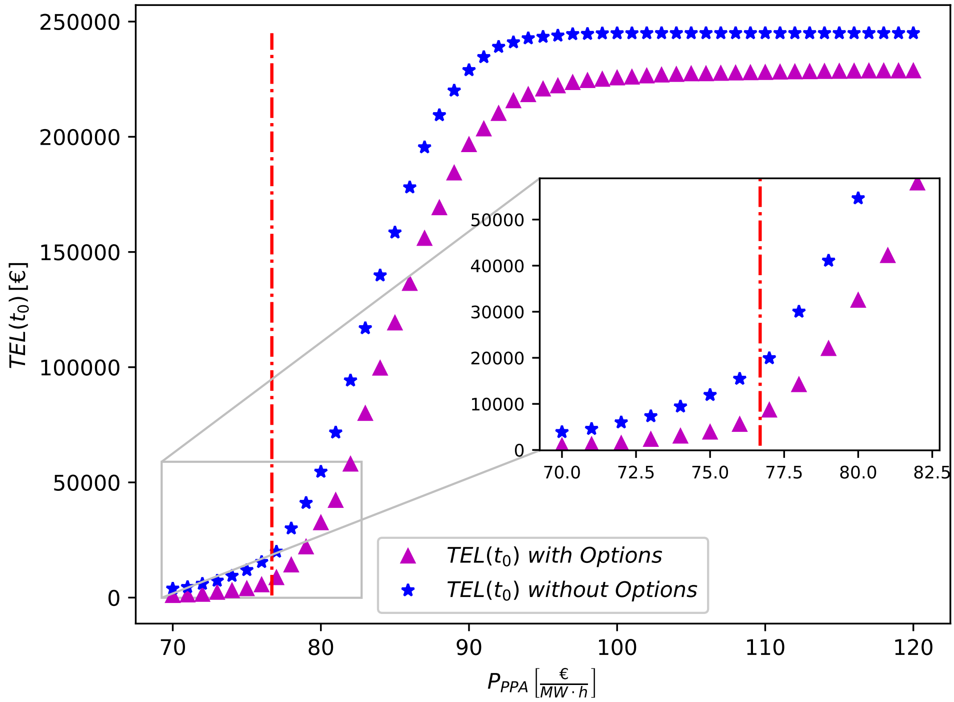

Figure 1: $TEL\,(t_0)$ assuming a RE PPA without optional value (blue stars) and $TEL\,(t_0)$ including the options (purple triangles) for different levels of P_{PPA}. Red-dotted line represents the LCOE value.

4 Conclusions and future research/work

We have found that the proposed model for the PPA valuation describes some features which were usually neglected in the modelling, such as the embedded options. Furthermore, it also tackles the specific terms of a PPA including the price and amount of energy to be supplied and the alternative source of electricity supply, the public grid, which in our case is the underlying variable. Once this model is given, the probability of default can be computed, which turns out to be the probability that the value of the PPA becomes negative.

Albeit the results depend on the electricity price model, we think that by plugging an alternative electricity price model the same methodology can be applied and the same kind of results may be obtained.

Future research related to this work should be focused on building a model which considers the agreed price as non-fixed, with payments taking place in a monthly basis and even a floating consumption.

Acknowledgements

CITIC is funded by the Xunta de Galicia through the collaboration agreement between the Consellería de Cultura, Educación, Formación Profesional e Universidades and the Galician universities for the reinforcement of the research centres of the Galician University System (CIGUS).

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