Wind Farms at End of Life:
Deciding Life Extension or Repowering

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Abstract

Wind Energy, as a renewable source, has seen its exploitation expand over the last decades. Since the 1980s, Portugal has invested in the wind sector both onshore and, more recently, offshore. This expansion, accompanied by technological evolution, allowed a decrease in national energy dependence from foreign assets, such as oil and gas. However, most Portuguese wind farms are reaching the end of their expected life. In this segment, investors are faced with a difficult decision to make: to continue the wind exploration or to finish operating the wind farm.

This dissertation develops a contribution to help that decision with the creation of a support model, focused on the economic aspects of farm implementation. Based on the constantly updated legislation and recent studies of the energy and wind markets, a model is implemented in MATLAB that estimates the incomes and outcomes for each Portuguese onshore wind farm, comparing them and thus obtaining results that facilitate an investor decision.

Still, in order to simplify the decision about the future of a wind farm, this dissertation analyses the vulnerability of the results to market changes, taking into account two factors: the discount rate and the costs of operation and maintenance when a wind farm sees its life extended.

The results obtained converge to the viability of both life extension and repowering, presenting itself as a contribution to the uncertainty existing in investors from the wind sector.

Keywords: Onshore Wind Energy, Wind Farms' End of Life, Extension, Repowering

1 Introduction

Renewable energies, in particular wind energy, are increasingly used in the production of electric energy, not only for the environmental improvement they provide in the face of alternatives derived from hydrocarbons, but also for the continuous technological progress that has allowed great cost reductions in their generation.

Since the 1980s, Portugal has adopted measures to encourage the use of

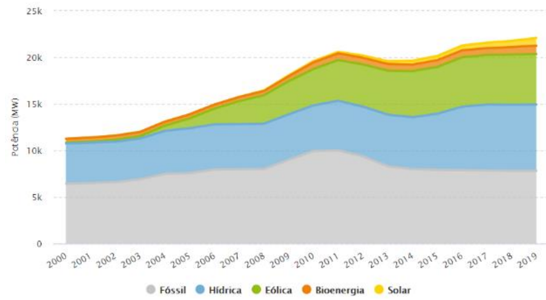

Figure 1 - Installed power evolution in the electricity production centres in mainland Portugal [2]

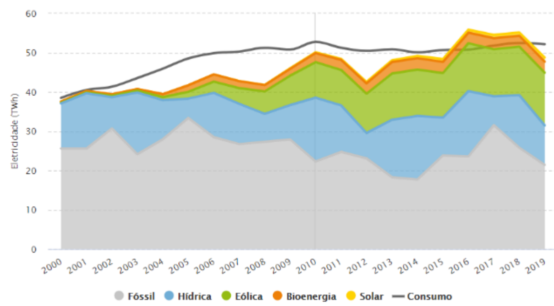

Figure 2 - Evolution of electrical production in mainland Portugal [3]

endogenous renewable energies, as well as their introduction into the electric market. The effects of these measures can be seen in the increase in installed power from renewable sources (Figure *1*) and their percentage contribution to the national energy production (Figure *2*).

However, Portugal currently has a large number of wind farms over 15 years of age or reaching that age. Since wind turbines have an expected life of 20 years of service, wind producers and farm owners are faced with a decision phase in relation to these farms.

On the one hand, the continuation of exploration, known as life extension, on the other, the dismantling of the park. This dismantling does not imply the complete abandonment of the farm or any investment already made. Here the possibility of repowering appears[1].

Thus, there is a need to evaluate and compare, from an economic point of view, several possibilities currently considered to continue wind exploitation in wind farms reaching their end of life. This will be the study carried out in this dissertation.

2 Background

Wind energy has been used since ancient times by humans [4], however, more recently, wind has been used as a means of producing electrical energy.

It was in 1985 that began the first experience of producing electric energy using wind energy in Lourel, thus starting wind exploration in Portugal [5].

To promote the implementation of renewable energies, Portugal adopts, among other policy mechanisms, a system of monetary incentives to produce electric energy from renewable sources in order to capture the attention of producers, making these projects more attractive.

This system, updated according to the national needs, is provided by law, the first legislation being presented in Decreto-Lei n.º 189/88, of May 28 [6], and the most recent in Decreto-Lei n.º76/2019, of September 2 [7].

However, these incentives represent only the positive part of a wind project, the revenue from Portuguese wind farms.

As such, it is necessary to carry out additional research regarding their expenses. These expenses are divided into three main components: capital expenditures (CAPEX), operational expenditures (OPEX) and decommissioning costs (ABEX).

After financial studies, it is also necessary to understand the national wind panorama. According to the database published, in partnership, by Associação Portuguesa de Energias Renováveis (APREN) and Instituto de Ciência e Inovação em Engenharia Mecânica e Engenharia Industrial (IRENA) [8], there are currently 234 active onshore wind farms in mainland Portugal, distributed mainly in the North and Centre areas. Of these 234, 95 farms (Figure *3*) are in a situation of advanced age, that is, reaching the end of their useful life of 20 years [9].

Figure 3 - Distribution of wind farms in mainland Portugal according to age, based on data collected from e2p - Energias Endógenas de Portugal [8]

With the end of life, there is a need to make a decision about the future of these wind farms. Several hypotheses arise here, with this work focusing on six: end of exploration after 20 years of operation; the life of the park is extended for an additional period of up to 5 years; the farm's equipment is replaced, and operation called repowering, and this new equipment will operate for an additional 25 years. Repowering can be carried out both during normal life and during the life extension of the farm, which is divided into two hypotheses. The first performs a replacement of the farm in which the initial farm's capacity remains. The second replaces the initial park, but equals the number of turbines, replacing them with newer ones, allowing a possible increase in the local and global installed capacity.

3 Methodology

In this study, two commonly used project evaluation methods were used to evaluate and compare economic solutions: the Net Present Value and the Internal Rate of Return, both applied to a set of 297 elements selected from a public database [8].

Figure *4* and Figure *5* show the methodology used to calculate the net present Value for a total of six situations: three in normal life and three for life extension situation, with Equations (1) and (2) being applied, respectively. The farm initially has a useful life of up to 20 years. Then the condition of repowering was evaluated, replacing the equipment, and operating for a period of 25 years. On the other hand, it was observed the situation in which the life of the initial farm extends for a maximum period of 5 years, during which the condition of repowering, similar to the precious one, is also analysed.

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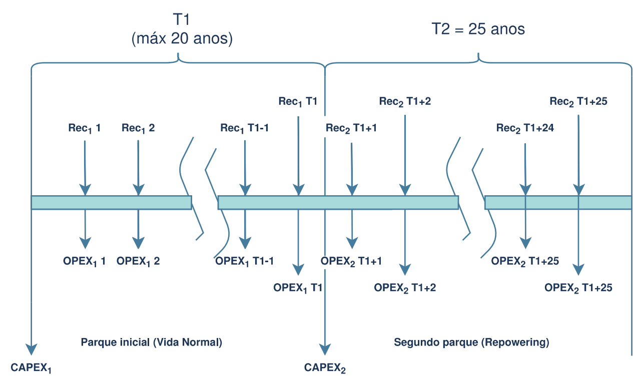

Figure 4 - Schematic of the model to find the optimal year of repowering under normal living conditions

$$VAL = -\frac{CAPEX1}{(1+r)^0} + \sum_{n=1}^{T1} \frac{Rec1_n - OPEX1_n}{(1+r)^n} - \frac{CAPEX2}{(1+r)^{T1}} + \sum_{n=1}^{T2=25} \frac{Rec2_{n+T1} - OPEX2_{n+T1}}{(1+r)^{n+T1}} \quad (1)$$

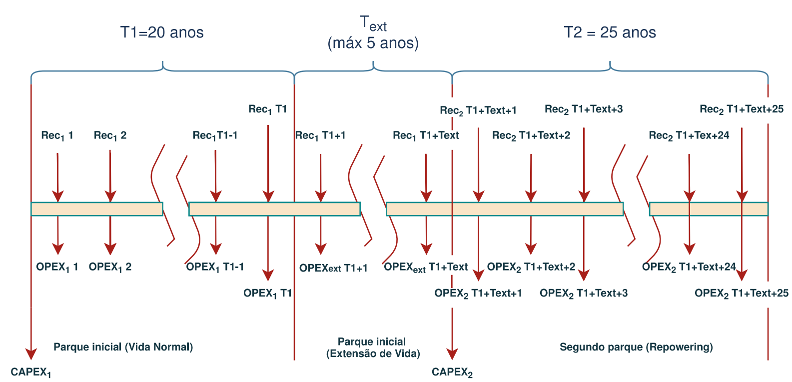

Figure 5 - Schematic of the model to find the optimal year of repowering under life extension conditions

$$VAL = -\frac{CAPEX1}{(1+r)^0} + \sum_{n=1}^{20} \frac{Rec1_n - OPEX1_n}{(1+r)^n} + \sum_{n=1}^{Text} \frac{Recext_{n+20} - OPEXext_{n+20}}{(1+r)^{n+20}} - \frac{CAPEX2}{(1+r)^{20+Text}} + \sum_{n=1}^{T2=25} \frac{Rec2_{n+20+Text} - OPEX2_{n+20+Text}}{(1+r)^{n+20+Text}} \quad (2)$$

Where $CAPEX_1$ and $CAPEX_2$ respectively represent the CAPEX of the initial farm and the farm when performing repowering, $OPEX_1$ and $OPEX_2$ respectively represent the OPEX of the initial farm and the farm when performing repowering, and REC_1 and REC_2 represent the revenues of each farm. And $OPEX_{ext}$ and REC_{ext} represent OPEX and revenues of the wind farm in life extension respectively. All values are updated using the discount rate, r.

In Figure 4, the best situation as a function of T_1 was evaluated, that is, the duration of operation of the initial farm, while in Figure 5, the best situation was assessed as a function of T_2, that is, the duration of operation of the farm during extension of life.

To obtain the data used in Equations (1) and (2), it was also necessary to acquire intermediate data, namely: the hours of equivalent production of each wind farm, the Consumer Price Index, specific values for each legislation previously studied (monthly rate power tariff of the voltage level immediately higher than that of interconnection; monthly power price of the medium-use tariff; a dimensionless coefficient that reflects the specific characteristics of the endogenous resource and the technology used in the licensed installation) and the price of electricity on the market.

In addition to actual values, future estimates were also made (hours of equivalent production, price of electricity on the market, capacity per turbine, CAPEX and OPEX) in order to predict the results necessary for the desired comparison at the end of the life of a wind farm.

For CAPEX, a study is made based on data from several sources: reports made available by the National Renewable Energy Laboratory [10], [11]–[17] [18], studies by Mark Bolinger e Ryan Wiser [19] and reports from International Renewable Energy Agency (IRENA) [20].

Regarding OPEX, reports from IRENA [20] and [21] are analysed.

Finally, decommissioning costs are studied by the University of Edinburgh in conjunction with ClimateXChange [22].

It is then possible to calculate the revenues and expenses of each Portuguese onshore wind farm, and then it is necessary to observe the situations to be evaluated after their end of life.

4 Results

After applying the model designed here to the 297 elements of the database created, the results of the six hypotheses previously considered were obtained: normal life, repowering during normal life (maintaining the initial farm capacity or maintaining the number of turbines), extension of life and repowering during the extension (again maintaining the initial farm capacity or number of turbines)., Figure 7 and Figure 8 show the values of the Net Present Value (NPV) when maximizing Equation (1), while Figure 9, Figure 10 and Figure 11 represent the results of the Net Present Value (NPV) when maximizing Equation (2).

It is possible to verify that life extension situations show better results than their analogues in normal life. However, repowering, keeping the number of turbines equal to those of the initial farm, is usually the best economic solution, particularly when the park has previously been extended.

Regarding the years of operation of the wind farm in normal life or in life extension that maximize Equations (1) and (2), respectively, when repowering is not performed, that is, when $CAPEX_2$, $OPEX_2$ and REC_2 take values of zero, they are unanimously 20 (T_1) and 5 (T_2) years, respectively.

When the hypothesis of repowering is posed, most farms converge to the same result, replacement after 20 years in normal life or after 25 years in life extension, however, there are some parks that differ from this result.

Two wind farms stand out for their results. The first, a farm that started operating in 1997, does not reach a positive Net Present Value at any point in its life, a reason attributed to CAPEX having an extremely high value in that year. The second, a farm that starts operating in 2018, is the only farm studied that obtains the best result in a normal life situation, performing repowering in which the number of turbines in the initial farm is maintained. No single reason was found to explain this anomaly, nonetheless, three possible reasons are highlighted: the high number of turbines, thus increasing the associated costs; the relationship between the variation of CAPEX and OPEX and the variation of turbines capacity; the stagnation of future prices of electricity, all due to the estimates considered.

The study of the Internal Rate of Return (IRR) for normal life situation (20 years of operation) presents values between 0,08% and 18,95%, shown in Figure 12.

As such, using the reference rate of 7,5%, the rate used in the model, it is possible to know what rate is necessary so the projects that obtained a negative NPV can prevent losses.

For instance, to get a positive NPV for every project a maximum rate 0,08% would be needed.

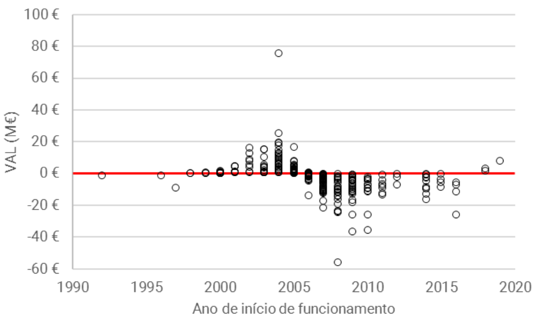

Figure 6 - NPV obtained by farm after 20 years of operation (normal life)

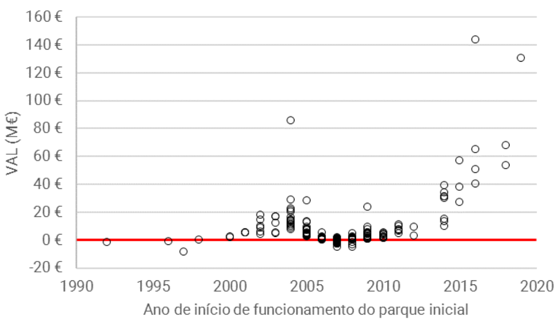

Figure 7 - Maximum NPV obtained with repowering maintaining the initial farm capacity, during normal life

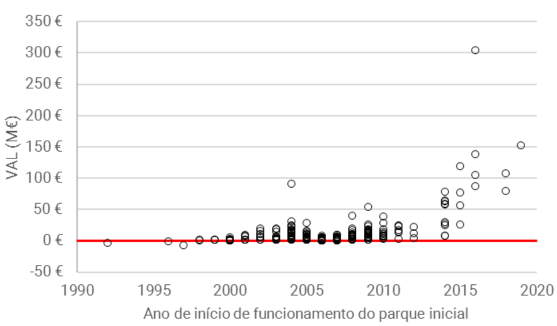

Figure 8 - Maximum NPV obtained with repowering maintaining the initial farm number of turbines, during normal life

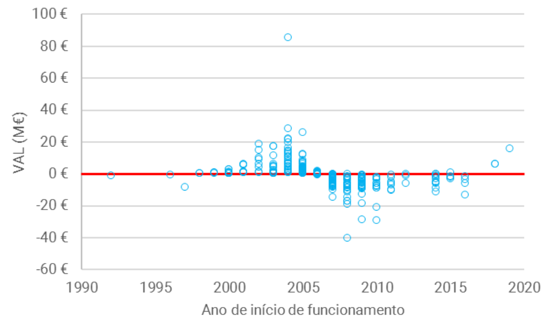

Figure 9 - NPV obtained by farm after 25 years of operation (life extension)

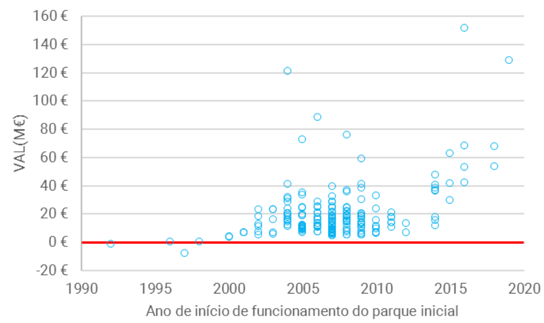

Figure 10 - Maximum NPV obtained with repowering maintaining the initial farm capacity, during life extension

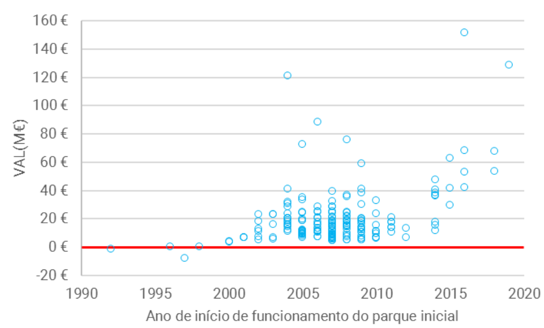

Figure 11 - Maximum NPV obtained with repowering maintaining the initial farm number of turbines, during life extension

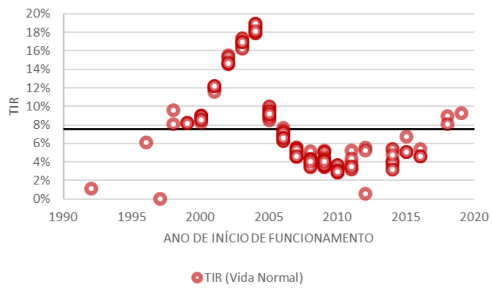

Figure 12 - IRR of wind farms for 20 years of operation (normal life)

5 Sensitivity Analysis

An analysis was carried out in order to assess the sensitivity of the results obtained with the variation of two factors.

First the discount rate. The value taken for the research was 7,5%, and the values of 5% and 10% were compared. This comparison resulted in a significant impact on a wind project and the results are better the lower the discount rate.

The second factor evaluated represents the OPEX under life extension conditions. This factor was chosen because there is little research on it, thus opening the door to a better understanding of this component in a wind project. The values of OPEX were compared in four different situations: OPEX does not change the expected value (a), OPEX is twice the expected value (b), OPEX is increased by 0,5 times per year of extension (c) and OPEX is increased by 1 times a year (d). Table *1* represents the multiplication factor of the expected OPEX according to the year of extension.

Table 1 – Multiplying factor of the expected OPEX

Extended Year	1	2	3	4	5
(a)	1	1	1	1	1
(b)	2	2	2	2	2
(c)	1,5	2	2,3	3	3,5
(d)	2	3	4	5	6

From this second analysis, a less notorious result was obtained than that from the first analysis, the results being better when OPEX does not have its expected value modified, as would be expected. Notice, however, that the effect this variation is practically negligible in repowering situations.

6 Conclusions

The focus of this research was the creation of a model that assists an investor in deciding on the future of a wind farm at the end of life.

With the model created, considering the legal changes and the relevant markets, six different situations were studied.

From the results of the application of the model, it is concluded that extending the life of a farm or replacing its equipment, repowering, tends to be beneficial to the investor, with the combination of the two solutions being the best economic decision.

Finally, it was also concluded that the discount rate plays an important role in wind projects, being necessary to be aware of its temporal variations.

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