Real Options and Wind Energy in Spain: A comparison between Onshore and Offshore Projects

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Abstract:

This dissertation performed an extensive research about valuation in the wind energy sector. A real options approach was taken in order to understand the optimal timing of investment in both onshore and floating offshore wind energy. This study also focused on the case of Spain, a leading country in onshore wind that is lagging behind in offshore wind. While the Spanish coast does not attract investment for bottom-fixed offshore projects, there is a suggestion that the floating offshore wind technology can be the solution. In order to develop a dynamic and flexible model, a stochastic approach was taken in order to compute the evolution of the uncertain variables. Moreover, a Monte Carlo simulation was performed, with 5000 paths being taken, together with 11 decision periods (in years). The results obtained showed the large economic value of waiting to invest in these technologies, due to high cost reductions over the simulated period. More specifically, floating offshore wind projects show huge growth prospects, having the capacity to possibly overcome onshore wind in value in the future. Finally, the study shows that even onshore wind projects still need time to maximize investment value, meaning investing today may not be optimal (in a scenario where no subsidies apply).

Keywords: Wind energy; Real Option; Valuation; Stochastic Processes; Spain; Renewable Energy future

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Abstrato:

Esta dissertação realizou uma pesquisa extensa sobre valorização no setor de energia eólica. O método escolhido para descobrir o tempo ótimo de investimento foi o de opções reais, tanto para a energia eólica terrestre como marítima flutuante. Este estudo também se focou no caso espanhol um país líder no setor eólico terrestre, mas que está claramente atrasado no setor eólico marítimo. Apesar das características da costa espanhola não permitirem um investimento lucrativo no caso de turbinas de vento fixas ao solo, há uma sugestão de que a tecnologia flutuante pode oferecer soluções. De forma a desenvolver um modelo dinâmico e flexível, uma abordagem estocástica foi introduzida para calcular as variáveis incertas. Consequentemente, uma simulação de Monte Carlo foi realizada, com 5000 caminhos diferentes a serem simulados para 11 períodos (anos) de decisão. Os resultados obtidos mostram o grande valor económico de esperar para investir nestas tecnologias, devido a enormes reduções de custo. Concretamente, a tecnologia flutuante mostra grandes perspetivas de crescimento, podendo até ultrapassar a energia eólica terrestre. Por último, o estudo mostra que até os projetos terrestres necessitam de tempo para maximizar o valor de investimento, o que significa que investir hoje pode não ser ótimo (num cenário onde os subsídios são excluídos).

Palavras-Chave: Energia Eólica; Opções Reais; Valorização; Processos Estocásticos; Espanha; Futuro Energia Renovável

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0 List of Abbreviations

AEP = Annual Energy Production

CAPEX = Capital Expenditures

CF = Cash Flow

DCF = Discounted Cash Flow

DECEX = Decommissioning Expenditures

ETIP = European Technology & Innovation Platform

EU - European Union

FOW= Floating Offshore Wind

GDP = Gross Domestic Product

GW = Gigawatt

IEA = International Energy Agency

INECP = Integrated National Energy and Climate Plan

KW= Kilowatt

LCOE = Levelized Cost of Energy

MW = Megawatt

MWh= Megawatt per hour

NPV = Net Present Value

OPEX = Operational Expenditures

PPA = Power Purchase Agreement

R&D = Research and Development

RES = Renewable Energy Sector

VW= Value of Waiting

WACC = Weighted Average Cost of Capital

1 Introduction

This dissertation investigates the topic of Investment models in the Renewable Energy sector, more specifically, it analyzes and looks to develop a Real Option Valuation Model for Wind Energy projects in Spain.

Two technologies were explored:

I. Onshore wind turbines
II. Floating Offshore wind turbines

Section 1.1 will provide insights regarding the dissertation's main research question, its relevance, and the expected contribution it will provide to the current literature. Finally, *Section 1.2* will explain the thesis' structure.

1.1 Research Objectives

1.1.1 Research Gap and Academic Relevance

Renewable energy, also known as clean energy, comes from the Earth's natural resources (such as sun or wind). This non-polluting type of energy has been quite relevant for many years now but has always been associated with higher costs and lower reliability. Innovation, however, has been ongoing, enabling costs to go down. Renewables like the wind have been booming, as they can now compete with non-renewable, fossil sources in terms of costs (NRDC, 2018).

With valuation being a critical aspect of these projects, significant amounts of studies were performed trying to find the best method. There has been a general consensus in the field about using real options to assess renewable energy investments' financial feasibility. This is due to the uncertainties and high learning curves associated with these investments. Either by developing variations of the Black & Scholes (Black & Scholes, 1973) or the binomial model (Cox, Ross & Rubinstein, 1979), researchers have been trying to build a framework to develop different strategies for different technologies (Gazheli & Bergh, 2018). Moreover, some studies aim to understand the impact of different support schemes (Boomsa et al, 2012), or develop a model to apply to specific markets (Zhang et al, 2016).

However, there are still doubts regarding which technology will have the brightest future. In addition, within wind power technologies, an interesting development is taking place with offshore wind energy receiving strong investments from some countries in the European Union. Spain, however, is one of the few who seem to keep investing practically solely on onshore technology (IEA wind TCP 2019 Annual Report). Therefore, the purpose of this dissertation is to analyze and understand the current situation in the Spanish market, while looking to develop a dynamic and flexible structure to identify the main financial differences between onshore and floating offshore wind technology. It will then look at future prospects.

This dissertation will, therefore, make an effort to (1) understand the main characteristics of the sector with focus on the Spanish market, (2) synthetize the main differences between each technology and (3) develop a structured and pragmatic model, capable of assisting in future investment decisions.

1.1.2 Research Question

This thesis focuses on strengthening the existing literature in one central topic: Valuing wind energy investments. Moreover, it provides possible explanations for the lack of offshore investment in Spain and yields recommendations for analyzing the financial differences and optimal timings for investing in each of the two analyzed technologies. As such, the following questions will be answered in the best possible manner:

- How to use Real Options to value and optimize the decision between investing in onshore and floating offshore wind turbines?
    - ❖ What are the main reasons behind the lack of installed offshore wind farms in Spain?
    - ❖ What are the future prospects for both technologies and optimal investment timing?
    - ❖ What (and how) are the key variables impacting the value of wind projects?

1.2 Dissertation Structure

This dissertation looks to complement the current academic's research through a pragmatic approach. The model developed is based on a thorough theoretical analysis, providing insights that could be helpful in future research.

Following this introduction, a total of 7 Chapters structure this thesis. Chapter 2 gives an overview of the current status of the wind energy sector (starting in *Section 2.1*) and reviews the literature about real options (*Section 2.4* and *Section 2.5*). It then looks upon the evolution of different variables affecting the sector, such as policy, costs, and production (*Section 2.6* onwards).

Chapter 3 describes the methodology used to develop the model. It includes the data collection process in *Section 3.1*, the model's structure, in *Section 3.2*, and the variables considered for valuation, in *Section 3.3*.

Chapter 4 provides the results obtained after the model is simulated. *Section 4.1* yields a detailed analysis of each variable's dynamics. *Section 4.2* analyzes the results found under the NPV methodology, while *Section 4.3* does the same for the Real Options method. *Section 4.4* compares the differences between both methods, emphasizing on the value of waiting. *Section 4.5* performs a sensitivity analysis.

Chapters 5 and 6 include research limitations and propose future recommendations, respectively, in order to add further value to this study.

Finally, the conclusion of the results is described in Chapter 7.

2 Literature Review

2.1 The Wind Energy Sector

There is no doubt that the world needs to reduce its CO2 emissions and environmental footprint. With it, comes a transition towards renewable energies and wind energy is already becoming an important source of electricity in leading countries. Not only are governments setting higher targets than ever to help the sector grow with support schemes, but private initiatives are also becoming more common through corporate power purchase agreements (PPA) with wind farms. In fact, given the lower levelized cost of wind energy in new farms (compared to any form of new fossil fired plants), together with performance gains, there is a shift from old subsidy schemes to auctions. As a result, some corporate funding PPAs are being reported in countries such as Spain. To further show the success of cost reductions and its impact of non-subsidized PPAs, it is worth mentioning that 44% of the total PPA funding in Europe was contracted in 2019. It is also important to state that the average cost of land-based projects achieved its peak in 2011. Offshore wind projects also made good progress, with recent subsidy-free auctions. Overall, in 2019, the global wind capacity was around 650GW, increasing by 60.4GW worldwide (IEA wind TCP 2019 Annual Report).

Wind energy is an abundant resource around the world, with its cost competitiveness developing the industry into a job creator, with around 366 thousand people being directly and indirectly employed in the (former) EU-28. It also generates a positive income on countries' Gross Domestic Product (GDP) and is resilient to economic crisis. In fact, the financial activity in the wind energy industry was 44.1 Billion Euros in 2019, with European wind energy companies having a commercial presence in more than 80 countries outside Europe. In terms of environmental impact, wind energy is the largest renewable contributor to CO2 emission savings in Austria, Belgium, Denmark, Ireland, Spain, and the United Kingdom (IEA wind TCP 2019 Annual Report).

Despite land-based wind power capacity being higher, with countries like Portugal and Spain setting goals to double its capacity by 2030, offshore wind power installations continue to grow at a fast pace, with more than 6.1GW of new capacity being added in 2019 (a growth rate above 30%). Moreover, almost 47% of the European Commission's funding granted to wind projects starting in 2019 was focused on offshore technology concepts. Offshore wind facilities can also increase biodiversity, with wind turbine foundations forming artificial reefs (enabling mussels and other sea life to grow) in Belgium, also contributing to the growing fish population in the Belgian North Sea (IEA wind TCP 2019 Annual Report).

Another relevant issue is the fact that 50% of the installed capacity in Europe will have reached the end of its operational life by 2030. Repowering will be necessary, with opportunities to increase productivity arising, and new investments being required (IEA wind TCP 2019 Annual Report).

2.2 Wind Energy in Spain

Wind power is consistently the second largest electricity generation source in Spain, accounting for 21% of total electricity generation in 2020 (which is equivalent to sustain 15.7 million homes). In fact, according to the Integrated National Energy and Climate Plan (INECP), by 2030 Spain will have achieved a 23% reduction in greenhouse gas emissions (as compared to 1990), a 42% share of renewables in energy end-use, a 39.5% improvement in energy efficiency, and a 74% share of renewable energy in electricity generation, as well as having a clear plan to make Spain carbon neutral by 2050.

The Spanish wind sector's new installed capacity represented 15% of all new wind capacity in Europe. Spain is fifth in accumulated installed capacity worldwide, and second in Europe (only behind Germany). Moreover, Spain has 1 203 wind farms, which represent an overall installed capacity of 25 704MW. Finally, the wind sector represents 0.31% of the Spanish GDP (3 584M EUR, an 800M increase from 2015), with the country being the third largest wind energy exporter in the world (a value of 2 181M EUR and only behind Denmark and Germany). Spain also employs around 24 thousand people in the sector and saves its consumers a net expense (after subsidies) of 72M EUR (Anuario Eolico AEE 2020, en español).

In addition, and including provisional data, we can observe that the impact of Covid-19 was somewhat reduced in wind generation in Spain, as the country was able to grow from 4 627GW in January 2020 (which represented 20.3% of all energy generated), to 7 076GW in January 2021, which represented 29.2% (REData, 2021)).

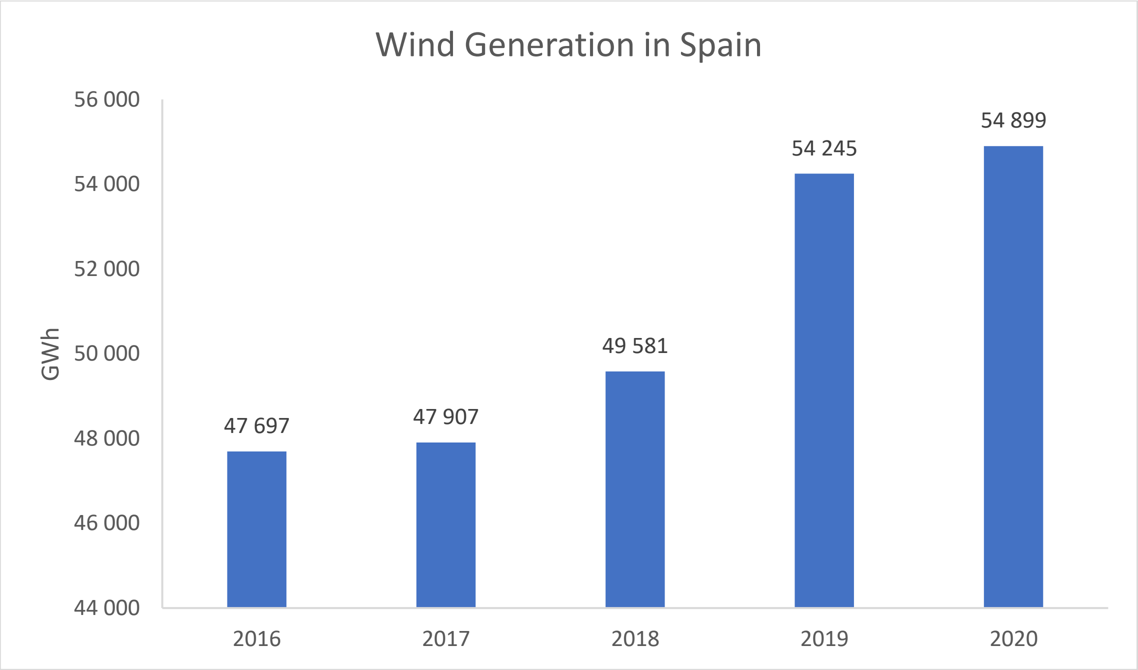


Figure 1 : Wind Generation in Spain

However, it is worth mentioning that while most European countries seem to be increasingly focusing on offshore wind farms, Spain is establishing itself as the leader in new onshore wind farms investments (with 2.8 Billion Euros invested in 2019). Consistent with this idea, is the fact that Spain only has one 5MW offshore wind turbine (despite some joint ventures to help other countries, like Portugal, with their supply needs). It therefore recognizes the limitations it has due to its higher costs (IEA wind TCP 2019 Annual Report).

Lastly, in order to better understand the type of wind turbines being used by Spain, it is crucial to look at the companies that are building said turbines. In fact, Siemens Gamesa is responsible for more than half (55%) of the installed capacity in Spain. The second largest player is Vestas with 18.7% (Anuario Eolico AEE 2020, en español).

2.3 Onshore vs Offshore Wind

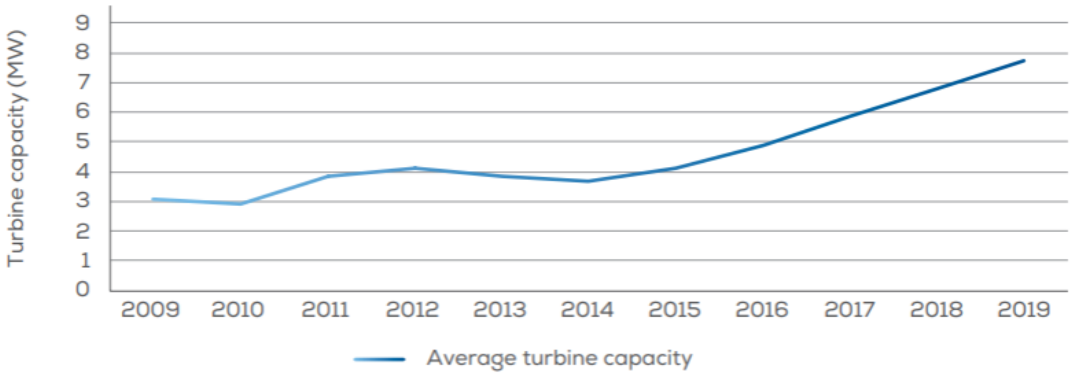
There are essentially 2 broad types of wind farms: onshore and offshore. Like the name suggests, onshore farms are the ones that operate on land, while offshore farms function in the sea.

The energy generating process for both types is similar: energy is generated by the rotation of blades caused by the wind, rotating at a speed between 7 to 12 turns per minute; a gearbox increases said speed to over 100 times; a high-speed shaft transmits the speed into a generator; the generator converts the mechanical power from the shaft into electrical power; the power is then placed in a transformer, that will enable it to be transported. For the transportation phase, their paths are different. While in onshore the current is transmitted through medium voltage cables to a substation (which then transforms the energy into high-voltage, and transports it to the distribution network), in offshore the electricity is transmitted through underwater cables (Greencoast, 2019).

Onshore wind energy has been, and still is the dominant force in the sector, with significantly cheaper costs, not only in infrastructure but also in transportation and maintenance. In addition, onshore wind projects can attract investment in the area. However, wind speeds are rather unpredictable, not only in speed, but also in direction (which affects the turbines' efficiency quite substantially). Moreover, some people claim these structures are dangerous to birds, and even create noise pollution (Greencoast, 2019).

Offshore wind energy is much more recent, with the first wind farm being only developed in 1992. These farms bring many advantages when compared to its counterpart. First, due to wind consistency, these turbines are more efficient than onshore turbines, with fewer being needed to produce the same energy. Second, they are built in the ocean, meaning they do not occupy land or disrupt any human (or bird) activity. Third, they can even help protect the marine ecosystem. But, because they are operated away from land, they tend to be much more costly in transportation, maintenance (due to stronger winds and waves) and infrastructure (Greencoast, 2019).

On the other hand, one of the key advantages of offshore wind farms is their added capacity. While onshore turbines have between 2 and 5 MW of capacity, offshore turbines have higher possibilities, with an average capacity of 7.8MW in 2019. In addition, this capacity is expected to increase, as companies are pushing to continue the evolution we can observe below:



Source: WindEurope

Figure 2 : Onshore Wind Turbine Capacity in Europe

Moreover, offshore wind farms have almost doubled in capacity, from 313MW in 2010, to 621MW in 2019 (WindEurope Annual Statistics, 2019). In addition, a fast-maturing technology is arising. Floating offshore wind (as opposed to bottom-fixed) enables farms being built in deeper waters (in fact, 80% of the offshore wind resource is not economically attractive for bottom-fixed technology). In fact, this technology offers both higher capacity factors and wind consistency. This characteristic is quite relevant in Spain, as its coast characteristics make it quite hard for bottom-fixed wind turbines to be developed (AEE, 2021). Floods bring more possibilities, but they also bring more cost advantages (which is the main issue regarding offshore wind). This is due to the fact that these structures require less operations being performed at sea, with the installation process being fully developed on land. Although quite new technology, the expectation is for floating wind farms to take a pretty important role, as the scale effect of these projects may enable cost competitiveness to increase if the right R&D is performed (WindEurope, 2019).

There are 4 types of floating offshore wind (FOW) turbines being developed across Europe: the semi-submersibles, which is a concept built around large columns and connected with bracings; the single point anchorage buoys, which have a single large cylinder with a low waterplane area; the tension leg platforms, which have a large, submerged volume; and barges which are built around a steel or concrete hull. There are around 34 concepts in the EU, with an installed capacity of 48.5MW and a technical potential of 4 000GW. In addition, FOW brings benefits in both social and environmental and economic, with the maximization of clean energy, the lower environmental footprint, job creation and synergies with bottom-fixed offshore wind (ETIP Wind, 2020).

2.4 Real Options

An option is a security giving the right to buy or sell an asset, subject to certain conditions, within a specified period of time. An "American option" is one that can be exercised at any time up to the date the option expires. A "European option" is one that can be exercised only on a specified future date. The price that is paid for the asset when the option is exercised is called the "exercise price" or "striking price." The last day on which the option may be exercised is called the "expiration date" or "maturity date" (Black & Scholes, 1973).

There are four main types of real options: the option to expand, to postpone, to abandon, or to suspend an investment temporarily. In cases where the firm has the possibility to either further develop, or wait until it starts developing a certain project, it is important to value this option, as it may turn a negative NPV project into a worthy one. On the other hand, the option to abandon or suspend a project becomes quite valuable in Research & Development projects, as it enables companies to limit their losses in the presence of negative outcomes. Also, there are 2 main drawbacks to using the traditional approach: the DCF assumption that future firm decisions are fixed, and the difficulty in finding an appropriate discount rate to calculate the NPV, when options are involved in the investment project (Schwartz, E., 2013).

The methods to estimate real options vary accordingly to their type. The most widely used European options include the Black & Scholes (Black & Scholes, 1973), the binomial model (Cox, Ross & Rubinstein, 1979) and Monte Carlo simulation. Several studies have showed that the 2 latter models converge towards Black & Scholes. For American options, the original method is the backward-induction binomial model. There have also been attempts to produce a Monte Carlo simulation approach, with some deficiencies that affect performance (Liu & Ronn, 2020).

2.5 Real Options in the Renewable Energy Sector

The Real Options Methodology has been widely used in the Renewable Energy Sector (RES). This is mainly due to the fact that other methods, such as the NPV, leave out risk and uncertainty associated with future rewards, one of the main strategic dimensions of the RES (Gazheli & Bergh, 2018). In addition, a renewable energy investment has some key features that make the NPV inappropriate to value projects in this sector: the investment is partially or completely irreversible; the investment costs of renewable electricity generation are usually high due to technological immaturity; there are many uncertain factors such as market development among others; the investment timing for these projects is discretionary (Zhang et al, 2016). This consensus around using real options extends to wind energy projects, as it is necessary to account for intermittence and uncertainty and the irreversible nature and flexibility enjoyed in such projects (Abadie & Chamorro, 2014). Therefore, it is reasonable to state that the investment environment of renewable energy simulates a stochastic scenario (Zhang et al, 2016).

2.6 The impact of policy on RES investments

One key aspect of RES investments is its political relevance. As such, subsidies play a big part in valuing a project. Its characteristics strongly affect both price and quantity risk. This aspect becomes increasingly relevant in Spain, due to its track record. In fact, due to the impact the previous financial crisis had in the country, in 2012 the Spanish center-right government halted all subsidies for new constructions (Reuters, 2012). However, the current center-left government does not seem to be willing to go in the same direction, with a new injection of 181 million euros being announced in September 2020. In fact, the president Pedro Sanchez has said that the public sector will invest 47 billion euros (out of 200 billion expected to be required) over the next decade (Reuters, 2020). In Spain, along several EU countries, a Feed-in-Tariff system is used, where energy generators receive a guaranteed payment over a fixed period of time. In addition, Spain also allows for a premium on market prices (Abadie & Chamorro, 2014). Finally, many papers focus on the impact different support schemes have on value. For example, one paper sets different scenarios, such as a constant Feed-In-Tariff, a premium on the market price, and a transitory subsidy (Abadie & Chamorro, 2014).

2.7 PPAs and the levelized cost of energy

Power Purchase Agreements are performance-based contracts that aim to create a fair and risk-controlled agreements between the purchase and sale of energy. PPAs can define every aspect of a project: the project's construction, operation and maintenance, interconnection and grid, government involvement, delivery of energy, and other third parties involved. In order to properly value energy projects, PPAs use an adaptation of levelized cost of energy (LCOE) model. For example, buyers can create terms to limit the annual purchase of energy, which affect the LCOE. In addition, PPAs create contractual limitations which, if violated, can enforce penalties to the seller. Moreover, the LCOE is calculated through the entire period of the contract and energy is purchased upon arrival, at a designated point of delivery. The LCOE also considers the risks of the project, such as country risks, or others. Therefore, buyers can reduce the LCOE by incurring more risk, with the allocation of risk being one of the primal purposes of a PPA. In short, while conventional LCOE models consider both capital and operational costs to be incurred in a project, PPAs address the aforementioned and energy produced, tax credits, and the weighted average cost of capital (Bruck, Sandborn & Goudarzi, 2018).

Despite the presented literature offering this new and complex way to estimate the LCOE, there are simpler (and perhaps better) ways to truly estimate the LCOE and make realistic comparisons between onshore and offshore wind farming. The LCOE can be estimated using 4 main parameters: CAPEX, OPEX, DECEX, AEP (Maienza et al, 2020).

These parameters can be easily identified and separated. CAPEX is defined as all investment costs to be incurred before the operations start. OPEX includes all the expenditures one has during the operational stage. DECEX are the costs of cleaning the area or repowering the wind farm (as these costs usually occur after the lifetime of the project, they will be neglected in this study). AEP is the annual energy production. All these parameters depend on the type of technology installed (Maienza et al, 2020).

Therefore, the LCOE can be calculated as (Corporate Finance Institute):

$$LCOE = \frac{NPV\ of\ all\ Costs}{NPV\ AEP}$$

The evolution of the LCOE is quite important for valuing these projects. New technologies have higher learning rates, enabling the costs to decrease at a higher pace as we increase installed capacity (ETIP Wind, 2020).

2.8 Onshore investment costs

Looking at the evolution of the investment cost for building an onshore wind turbine in the European Union, there is a clear reduction in the cost per kw, with it being improved from just over 2 500€ per KW in 2010, to less than 1 500€ per KW in 2018 and 2019 (IEA Wind, Task 26).

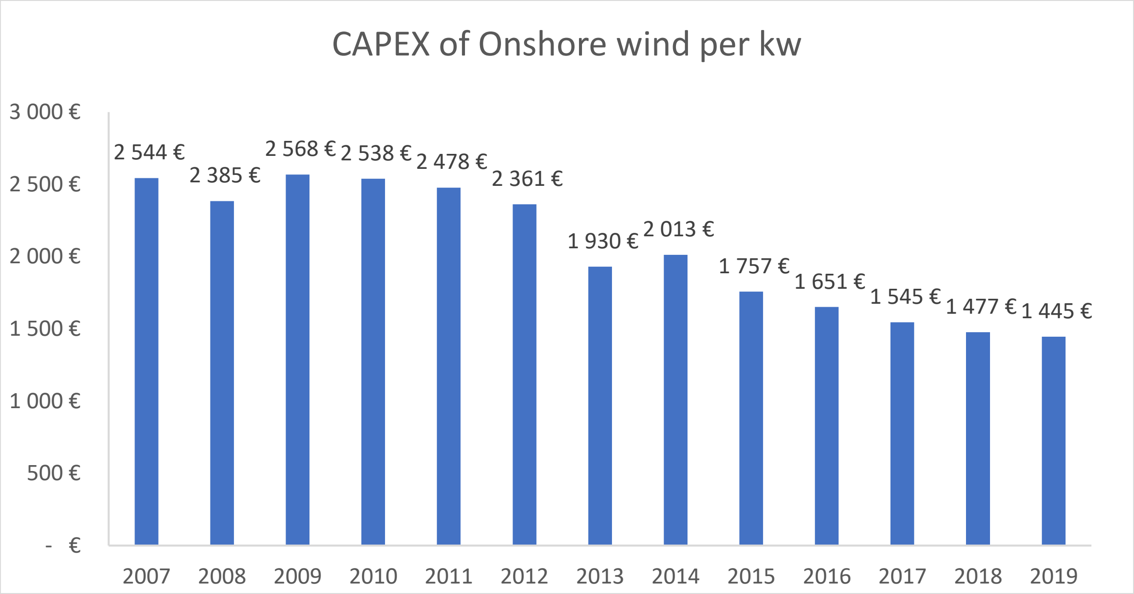


Figure 3 : Onshore Wind Investment costs

2.9 Onshore operating and maintenance costs

There is a similar trend in terms of operating costs per KW. A reduction from just over 30€ per kw a year, to around 23€ per KW a year can be observed (IEA Wind, Task 26).

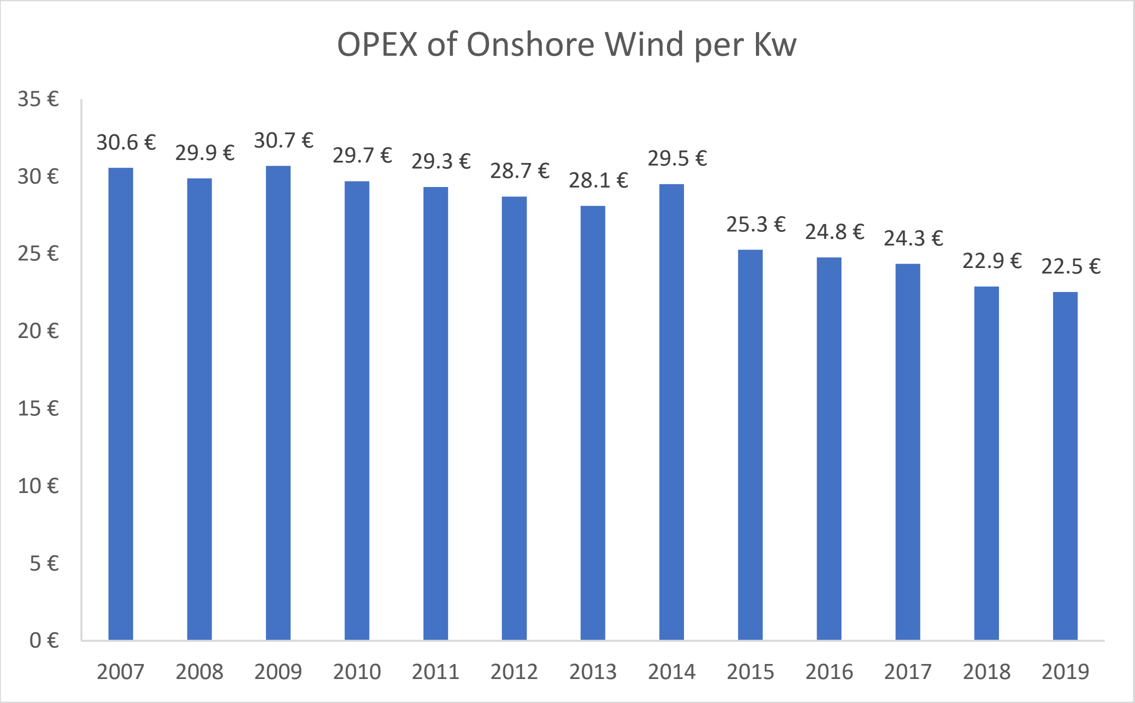


Figure 4 : Onshore Wind Operational costs

2.10 The LCOE of floating wind turbines

Floating offshore wind is a recent technology, which has by far the highest costs. However, FOW has benefited from R&D investment and the strong development made in bottom-fixed offshore wind energy (given the significant areas of overlap). Therefore, it is estimated that FOW has a strong speed of cost-reduction, which can be even higher than the 2 previous technologies (Wind Europe, 2018).

As expected, the current LCOE will be higher than onshore wind. However, the reduction prospects are enormous, with FOW benefiting from both investment costs and capacity factor being improved. Therefore, the expectation is for the LCOE to incur on an annual decrease between 6.6% and 10.10% until 2032 (InnoEnergy, 2020).

2.11 The annual energy production

An approximation of the AEP can be obtained using the following formula (DTU Wind Energy):

$$\text{AEP (Mwh)} = \text{Capacity (Mw)} * \text{Number of hours in a year (H)} * \text{capacity factor (\%)}$$

For the purposes of this dissertation and given that Siemens Gamesa is the largest player in producing wind turbines in Spain, a Siemens Gamesa 5.0 – 145 model was used, offering a capacity of 5MW. Regarding floating offshore wind energy, the first (and currently only) Iberian floating offshore wind turbines will be used , with a capacity of 8.4MW (Repsol, 2021). The approximate number of hours in a year is 8760 (DTU Wind Energy).

The average capacity factor of new onshore wind farms stands between 30% and 35% (WindEurope, 2019), with the average capacity factor for floating offshore wind farms being 45% (ETIP Wind, 2020).

2.12 The price of electricity

One of the key aspects of valuing a RES investment, is the price of electricity. Spain has had historically high prices when compared to the EU average. However, this trend appeared to have changed in 2018, with a decrease that puts the country's prices slightly below the EU average in the beginning of 2020 (Eurostat). It is worth mentioning that prices are quite volatile on a monthly basis (REE database).

3 Methodology

3.1 Data Collection

The data used to develop the model was collected from a variety of sources. Historical data about both electricity prices and energy output was retrieved from Red Eléctrica de España's official website. Historical onshore wind turbine costs were obtained through IEA Wind's Data Viewer (Task 26). It is worth mentioning that, despite Spain being one of IEA's members, the available data only pertains to the European Union as a whole, serving as the best proxy for the valuation. Finally, in order to gather information about offshore wind turbine costs, and because historical information is scarce, ETIP wind and InnoEnergy provided the main inputs to the model. These inputs consisted of current costs and future expectations and forecasts (essential to complete the model).

The valuation was performed on a yearly basis. This is consistent with the valuation performed by Zhang et al (2016) and explained by both the large lifetime expectancy of these investments, and the risk of seasonality in conducting a monthly analysis.

Finally, the model was conducted in Excel, with both backward induction and Monte Carlo Simulations being used to model uncertainties and correctly value the optimal investment decision. The model includes 11 possible investment periods (years), extending until the end of the lifetime of the project started in the last investment period. 5000 different paths were established to ensure a proper analysis free of path dependencies.

3.2 The real options model for renewable energy investment

Following Zhang's rationale (Zhang et al, 2016), one can see that the economic value calculated with the real options method (F) is the following:

$$F = V + VW$$

Where V is the NPV of the project, and VW the economic value of the flexibility.

Therefore, in a profit-seeking environment, investors have the option to wait for the optimal timing of the investment, within a valid period:

$$F = \underset{0 \leq ts \leq tv}{MAX} \left[\frac{\text{MAX}[V_{ts}, 0]}{(1 + WACC)^{ts}} \right]$$

Therefore, the NPV of the project is computed for all periods, and then discounted at the WACC. The highest NPV, meaning the period where the project generates higher value, is the stochastic optimal time to invest (*ts*). In addition, *tv* is defined as the last investment period.

Furthermore, Zhang's model defines the value of a project as the sum of all expected cash flows (CF) discounted at a certain rate. Using a simplified version of the model, one can compute cash flows in the following way:

$$CF = (Price\ of\ Electricity - LCOE) * AEP$$

Because the main goal of this dissertation is to understand the true value of each type of project, subsidies were excluded from the results (although the model could easily add them in future research).

Therefore, the model's main uncertainties are the price of electricity, the energy produced, and the LCOE. Since it was established that these uncertainties follow a stochastic process, the geometric Brownian motion (GBM) can be used to characterize them in the following way (Zhang et al, 2016):

$$dSt = \alpha Stdt + \sigma Stdz$$

where St is the uncertain variable (and dSt its variation over one period of time), α and σ are the drift and volatility parameters of such variable, respectively. In addition, dz represents the independent increments of a Weiner process ($\varepsilon\sqrt{dt}$, where ε is a normally distributed variable with zero mean and unit standard deviation).

The authors use a method that combines both backward induction and Least Squares Monte Carlo simulation, with the solution being comprised of 5 steps:

1. Denote W and N as the numbers of simulation path and decision point per path, respectively. Simulate the change paths of the uncertain factors using their discrete approximations. In this dissertation, 5000 paths were simulated (W=5000) and 11 years were considered as decision points (N=11).
2. Calculate the expected net present value of the project, for all paths and at each discrete decision point during the period of investment. The NPV is computed through the following equation:

   $$V_t = \sum_{i=t}^{t+L} \frac{CF_i}{(1 + WACC)^{i-t}}$$

   With *t* being the first year of investment (between 2021 and 2031) and *L* being the lifetime of the project (which will always be equal to 25 years).
3. Any path is solved by backward induction. At the final observation date of the investment period, we can obtain:

   $$F_{t,j} = MAX\{V_{t,j}; 0\}$$

   $$\Gamma_{t,j} = \begin{cases} 1, V_{t,j} \geq 0 \\ 0, Otherwise \end{cases}$$

   with *j* being the simulation path. *Γ* indicates whether the project is worth investing or not.

4. Evaluate if the optimal decision is to invest immediately or delay the investment. The comparison terms are the expected NPV from immediate investment, and the expected investment opportunity value from delaying the investment.

$$F_{t,j} = MAX\left\{V_{t,j}; \frac{E_t\left[F_{t+1,j}\right]}{1+WACC}\right\}$$

$$\Gamma_{t,j} = \begin{cases} 1, V_{t,j} \geq \dfrac{E_t\left[F_{t+1,j}\right]}{1+WACC} \\ 0, Otherwise \end{cases}$$

5. The induction continues until all exercise decisions of all possible paths have been determined. The optimal investment timing is the one with the highest frequency. The value is the computed by taking the average value of all paths.

$$t_j = inf\left\{t \middle| \Gamma_{t,j} = 1\right\} \qquad 1 \leq t \leq t_v$$

$$F = \frac{1}{W}\sum_{1}^{W} \frac{F_{t_j,j}}{(1+r)^{t_j}} \qquad j = 1,2,3 \ldots \ldots . . W$$

To summarize, the process starts by defining the number of simulations one wishes to run (a larger number of paths yields stronger results). After also defining the number of investment periods (or decision points), the project's value (NPV) is computed for each path and period. In step 3, the projects that have negative NPVs will be excluded. Step 4 directly compares the value of investing in one period, with the discounted value of investing in the next. This is made in order to understand the optimal investment timing in each path. Finally, step 5 will aggregate the decisions made in each path, taking the most common one as the optimal.

3.3 Parameter specification

All variables used in the construction of the model, as well as its notation and estimation procedure are presented below.

3.3.1 Price of electricity estimation

As one of the uncertain variables, the price of electricity follows a stochastic process, with its dynamic being represented as:

$$P(t+\Delta t) = Pt + \alpha . Pt . \Delta t + \sigma . Pt . dz$$

with both its drift and volatility being calculated using historical information of the past 5 years. Moreover, a floor and a cap were determined to keep prices under a desired range (between 45.71€ and 63.13€). This is determined by the new Spanish published regulatory revision for wind energy assets (EDP Renewables, 2020).

3.3.2 Annual Energy Production estimation

The AEP is an uncertain variable which differs from onshore to offshore projects, as it depends on both the installed capacity of the wind turbine and its capacity factor. The capacity used for onshore wind projects is 5MW, whereas 8.4MW was used for floating offshore wind projects. Capacity factors are 35% and 45%, respectively.

The AEP's dynamic is computed in the same way as the aforementioned price of electricity, following the same stochastic process for both types of technology:

$$AEP(t+\Delta t) = AEPt + \alpha.AEPt.\Delta t + \sigma.AEPt.dz$$

with drift and volatility being calculated using historical information of the total energy output per hour in Spain, divided by its installed capacity.

3.3.3 Onshore LCOE estimation

As previously defined, the LCOE can be estimated by computing the NPV of all costs and dividing it by the NPV of the AEP for the lifetime of the project. For simplicity, 2 different types of costs were used: CAPEX and OPEX.

Again, the dynamic of these 2 costs is present through the below stochastic process:

$$CAPEX(t+\Delta t) = CAPEXt + \alpha.CAPEXt.\Delta t + \sigma.CAPEXt.dz$$

$$OPEX(t+\Delta t) = OPEXt + \alpha.OPEXt.\Delta t + \sigma.OPEXt.dz$$

for both costs, historical information from the past 5 years was obtained to calculate drift and volatility. Since CAPEX is a cost made at the beginning, the analysis was made only for the 11 periods of investment (with the assumption being the investment will take place only once), whereas OPEX are incurred on an annual basis, and its evolution estimated as such. The discount rate, WACC, is fixed and assumed to be 9%

The LCOE is, therefore, a result of 3 uncertain variables. It is assumed that the LCOE will be the same across the lifetime of each project (as the dynamic will be already presented in its computation).

3.3.4 Offshore LCOE estimation

The LCOE for floating offshore wind projects is computed using the same formula as for the onshore LCOE. The key difference here is that the stochastic dynamic will be applied in the LCOE itself (due to lack of historical information), as presented below:

$$LCOE(t + \Delta t) = LCOEt + \alpha . LCOEt . \Delta t + \ \sigma . LCOEt . dz$$

For this particular variable, drift and volatility were obtained using forecasted values, rather than historical ones.

4 Results' Analysis and Discussion

The model applied in this dissertation was developed in order to understand how to compute the difference between investing in onshore (mature) wind turbines and floating offshore (immature), as well as the optimal investment timing for each technology. In this section, the results obtained are analyzed and explained in detail.

4.1 Initial Parameters and Variable Dynamics

4.1.1 Initial Parameters

Parameter	**Measure**	**Initial Value**
Price	Euros (€)	53.43
Drift rate of price	Percentage (%)	-4.54%
Volatility rate of price	Percentage (%)	19.9%
Price Cap	Euros (€)	63.13
Price Floor	Euros (€)	45.71
Number of Yearly Hours	Hours (h)	8 760
Declining Rate Energy Output	Percentage (%)	0.2%
Lifetime Wind Turbine (Onshore, Offshore)	Years (y)	25
Onshore Wind Turbine Installed Capacity	Megawatts (MW)	5
Onshore Wind Turbine Capacity Factor	Percentage (%)	35%
Offshore Wind Turbine Installed Capacity	Megawatts (MW)	8.4
Offshore Wind Turbine Capacity Factor	Percentage (%)	45%
Onshore Annual Energy Production	Megawatts per hour (MWh)	15 330
Offshore Annual Energy Production	Megawatts per hour (MWh)	33 113
Drift Rate AEP	Percentage (%)	1.9%
Volatility Rate AEP	Percentage (%)	7.8%

Onshore CAPEX	Euros (€)	1 444 593
Drift Rate Onshore Capex	Percentage (%)	-4.4%
Volatility Rate Onshore Capex	Percentage (%)	4.8%
Onshore OPEX	Euros (€)	22 540
Drift Rate Onshore Capex	Percentage (%)	-3.1%
Volatility Rate Onshore Capex	Percentage (%)	3.8%
Offshore Capex	Euros (€)	3 469 388
Offshore OPEX	Euros (€)	150 000
Drift Rate Offshore LCOE	Percentage (%)	-8.7%
Volatility Rate Offshore LCOE	Percentage (%)	11.4%
WACC (onshore, offshore)	Percentage (%)	9%

Table 1 : Initial Parameters

4.1.2 Price of Electricity Dynamics

In order to avoid misjudging the initial value for price, the average of the last 5 years was taken, giving a price of 53.43€.

Prices in Spain have been quite volatile over the years. Therefore, and given a volatility of 19.9%, it is natural that the price will have large shifts from one year to the other over one path.

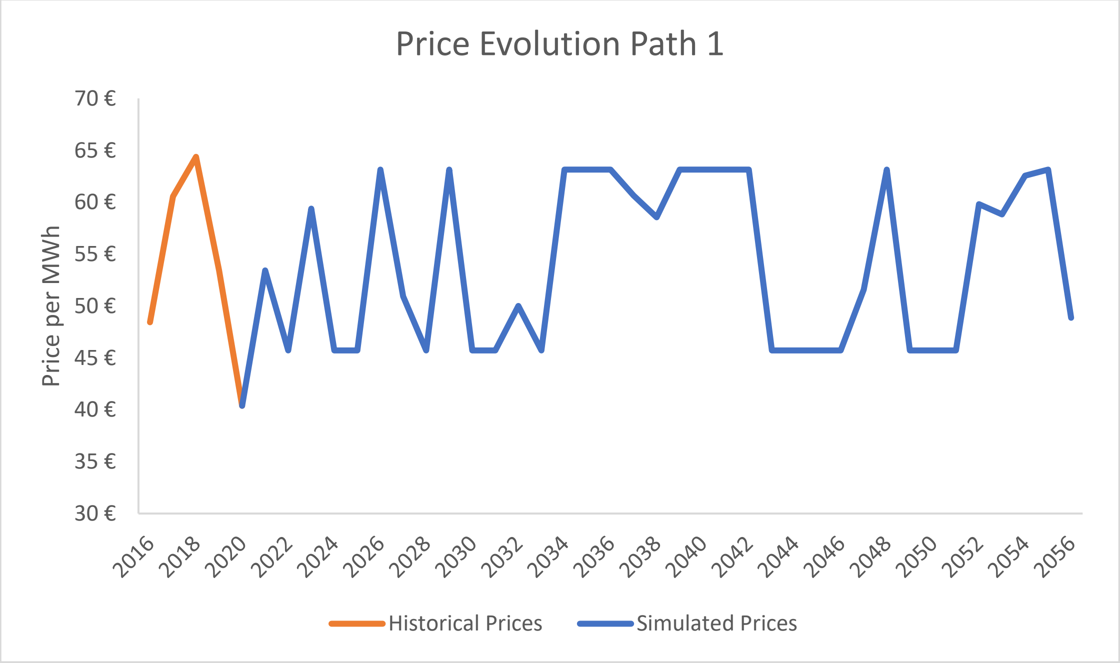


Figure 5 : Price evolution over one path

By looking at the average of all 5000 paths, it is possible to observe that the discrepancy from one year to the other almost disappears.

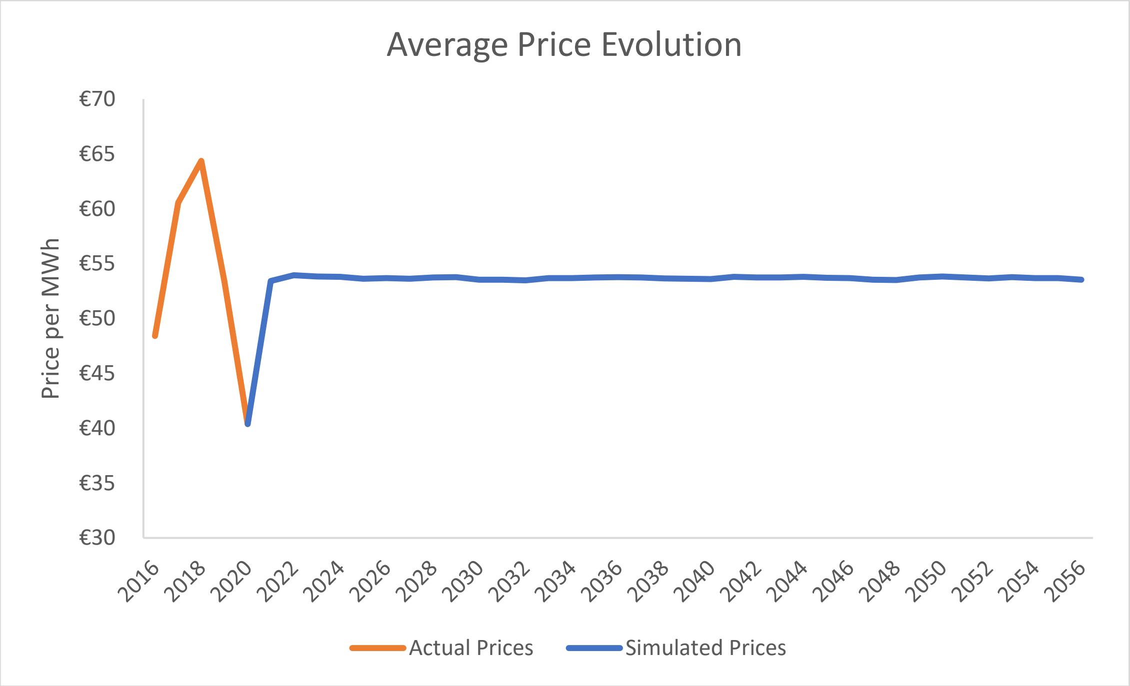


Figure 6 : Average Price evolution

As such, it can be said price variations will have a minor impact on value. This puts further emphasis on the other uncertain variables, which will be analyzed in detail.

4.1.3 Annual Energy Production Dynamics

The difference in the AEP from onshore to offshore arises upon setting the initial value for each. The onshore project's initial value is 15 330MWh, whereas the initial value for the offshore project is 33 130MWh. This difference, as already mentioned, is explained by the superior installed capacity of the offshore wind turbine (8.4MW, compared to 5MW) and its superior capacity factor (45%, as opposed to 35%).

Moreover, a volatility of 7.8% accounts for the difference in wind speeds and wind production efficiency over a 1-year period, with a drift 1.9% allowing for operational improvements and a declining rate of 0.2% accounting for the depreciation of the turbine’s quality over its 25-year lifetime. By simulating this process 5000 times, a sustained increase of the average AEP is obtained.

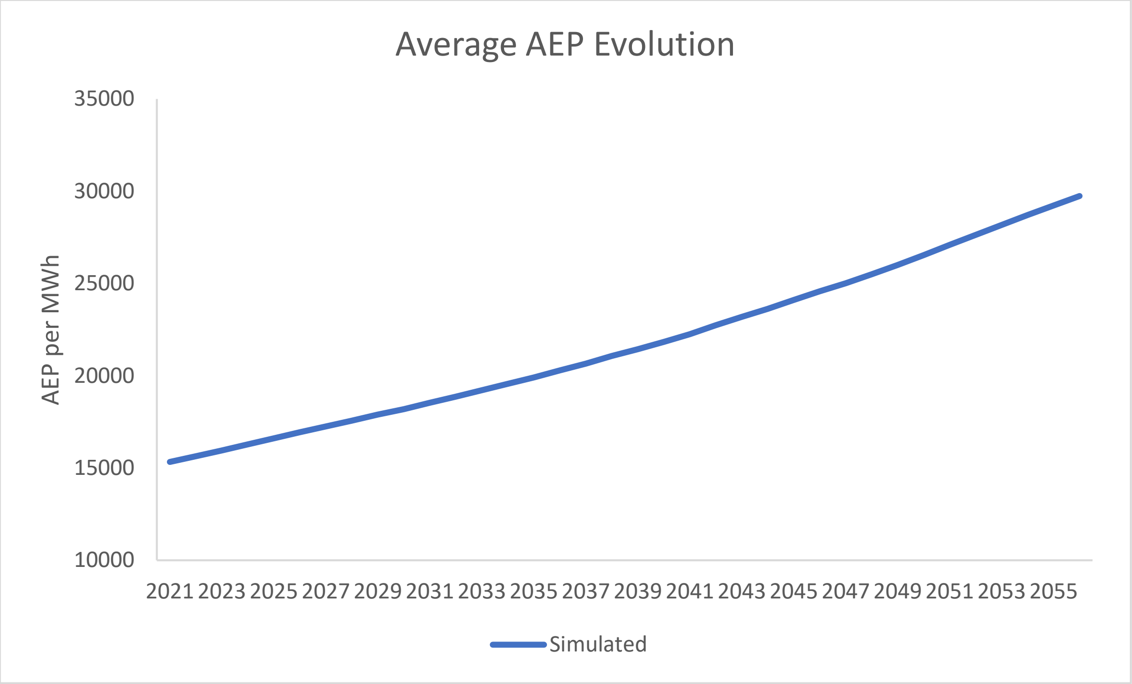


Figure 7 : Average Annual Energy Production evolution

4.1.4 Onshore LCOE dynamics

The onshore LCOE depends not only on the aforementioned AEP evolution but also on the CAPEX and OPEX evolution.

Firstly, CAPEX's initial value of 1 444 593€ per MW of installed capacity was used to obtain an initial value of 7 222 967€. A drift of -4.4% and a volatility of 4.8% enable a consistent reduction in investment costs (reaching a total of 4 602 647€ in 2031), as it is possible to verify in the below graph:

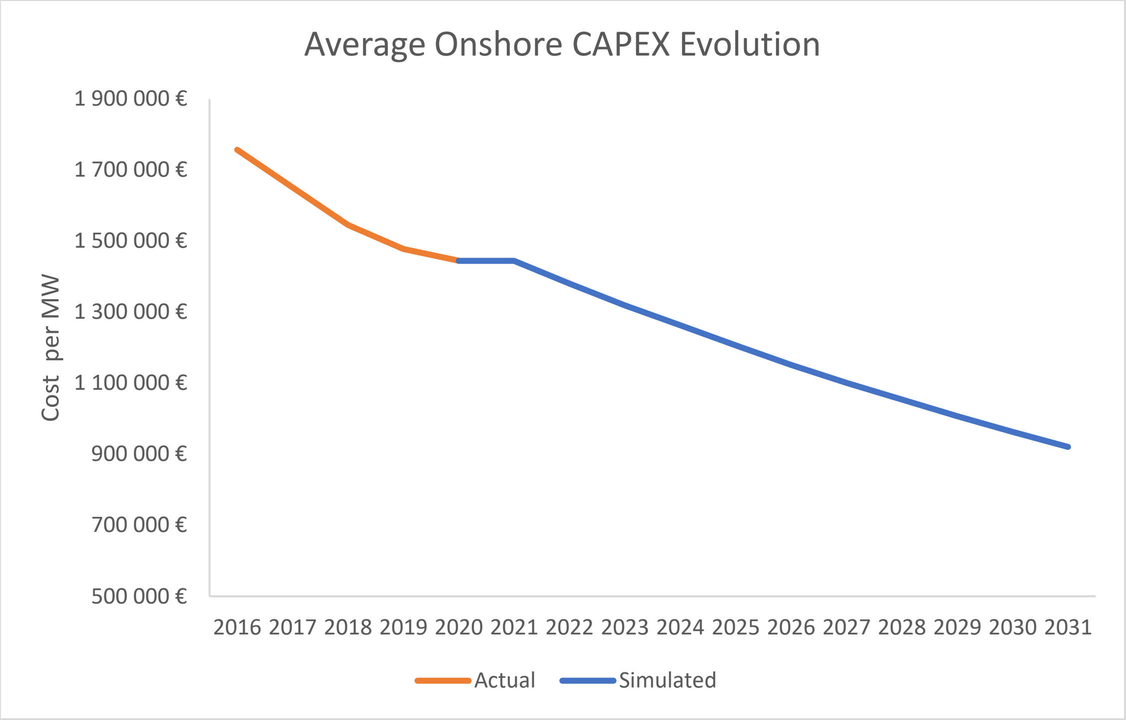


Figure 8 : Average Onshore Investment costs evolution

It is worth mentioning, that this evolution will have a big impact on the investment timing, as the evolution of investment costs is only observed if the investment is delayed.

With respect to OPEX, the process is similar. A drift of -3.1% and a volatility of 3.8%, enable the trend to be negative. This evolution, however, can happen on existing projects as operations are improved. Again, the average of the 5000 paths was calculated, with an average OPEX per MW of installed capacity of 22 540€ in 2021 being reduced to 7 412€ in 2056.

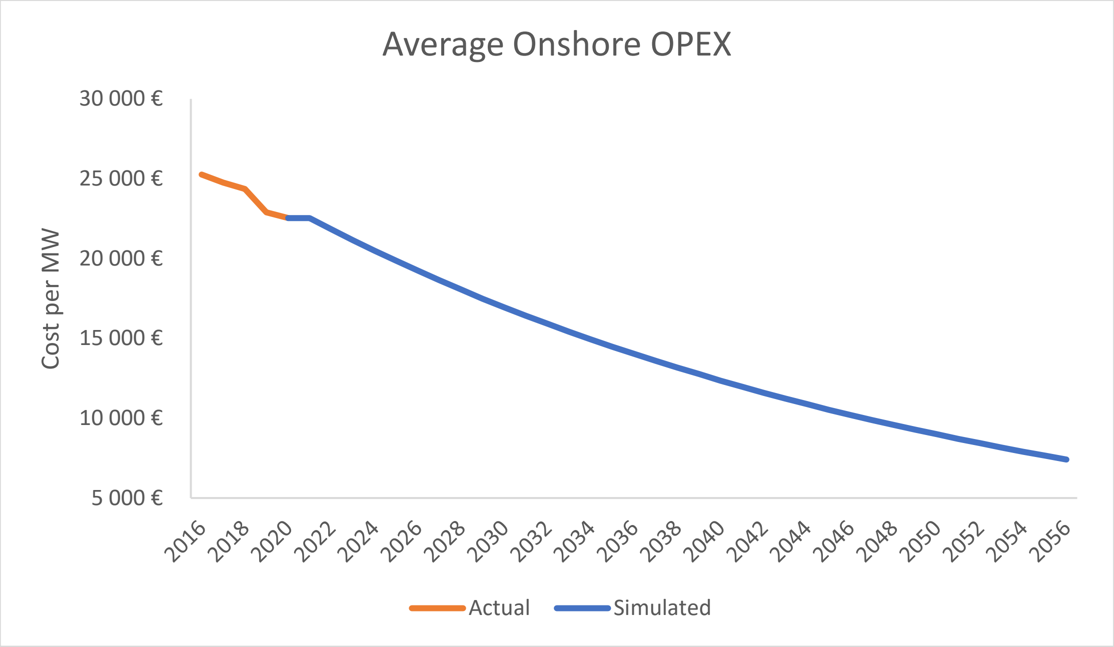


Figure 9 : Average Onshore Operational costs evolution

Having presented all necessary inputs to calculate the LCOE, it is now time to evaluate how it evolves over time. Like CAPEX, the LCOE's evolution only occurs when the investment timing is altered. As such, the average LCOE is improved from 47€ per MWh to 27€ per MWh. Because price has a floor of 45.71€, achieving an LCOE lower than the minimum price will guarantee positive cash flows (boosting the NPV, and minimizing price risk).

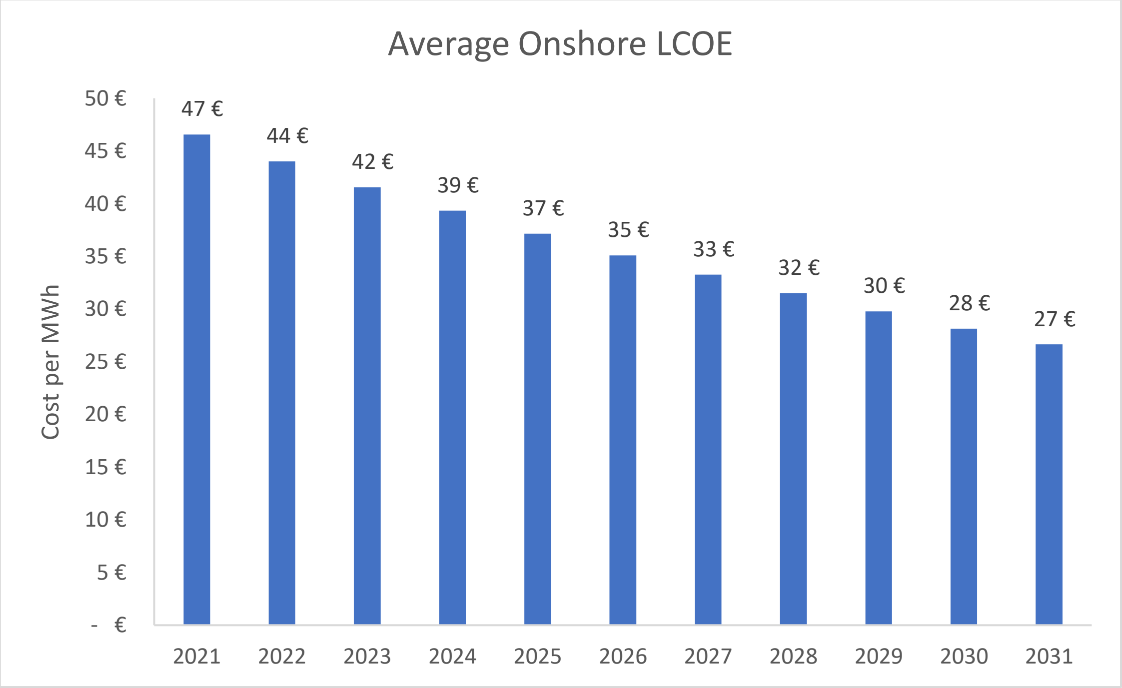


Figure 10 : Average Onshore Levelized Cost of Energy evolution

4.1.5 Offshore LCOE dynamics

As explained earlier in this dissertation, the lack of historical information forces a different approach to calculate the LCOE for floating offshore projects. The drift and volatility obtained reflect future experts' opinion and are applied directly to the LCOE. A drift of -8.7% and a volatility of 11.4% reflect the possibilities of efficiency improvement this technology has and the risk of being a recent project, respectively. An initial investment cost of 3 469 388€ per MW of installed capacity is more than double of the expense necessary to build an onshore project (naturally), but the largest difference pertains in the OPEX (150 000€ per MW of installed capacity, as opposed to 22 540€). Therefore, and because the floating offshore wind turbine used has an installed capacity of 8.4MW, the initial LCOE will be of 112€ per MWh, but its reduction across time will, most likely, be remarkable (reaching 45€ per MWh in 2031, possibly below the price floor).

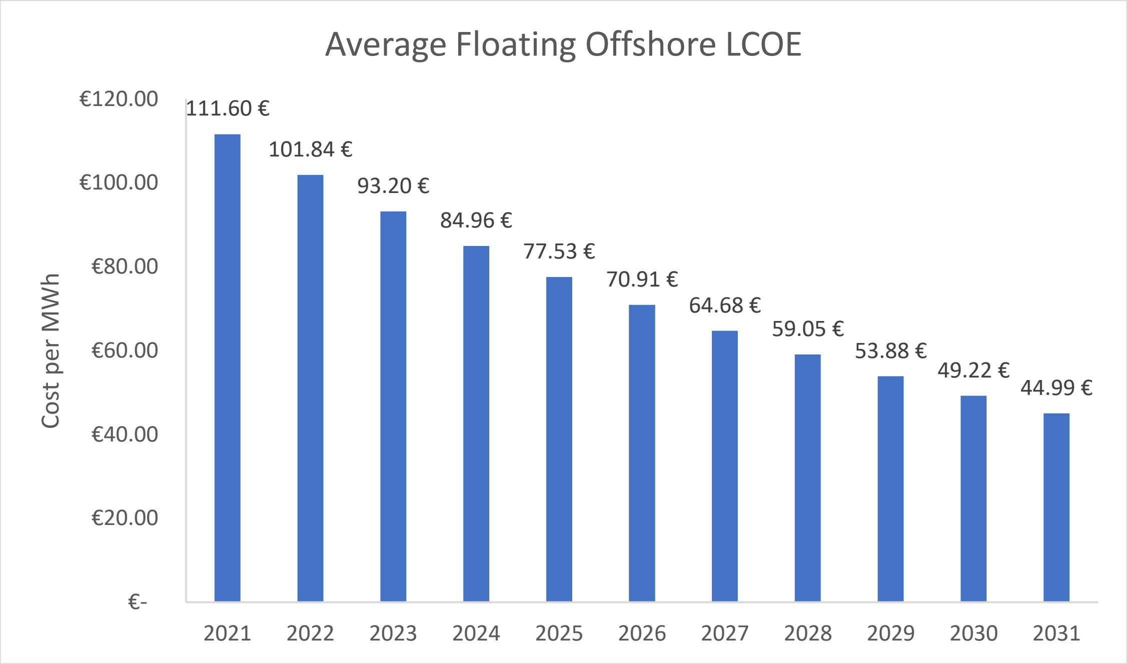


Figure 11 : Average Floating Offshore Levelized Cost of Energy evolution

4.2 NPV Valuation

Naturally, given the same price and lower costs per unit, the NPV for onshore wind projects will be much higher at an early stage. The NPV of investing in 2021 (attributing a value of 0€ to negative NPV scenarios) is, on average, 1 713 063€. It is also expected to grow over the next 10 years, with the NPV of investing in 2031 being 6 317 593€.

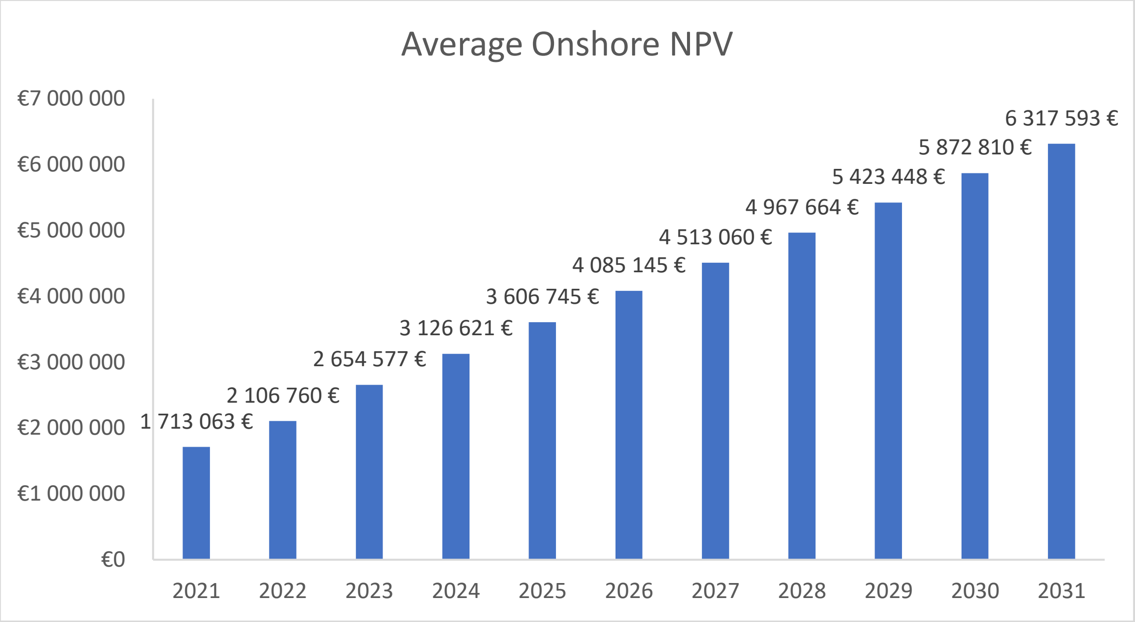


Figure 12 : Average Onshore Net Present Value

On the other hand, the value of floating offshore wind projects as a much steeper evolution. In fact, in most cases it is not worthy investing in these projects at an early stage (to be discussed later). Investing in this technology will only generate a 5000-path average, 248€ in 2021 (a residual amount). The outlook, however, is quite positive. Starting a project in 2031 will generate, on average, 6 791 185€ (a value superior to an onshore wind project).

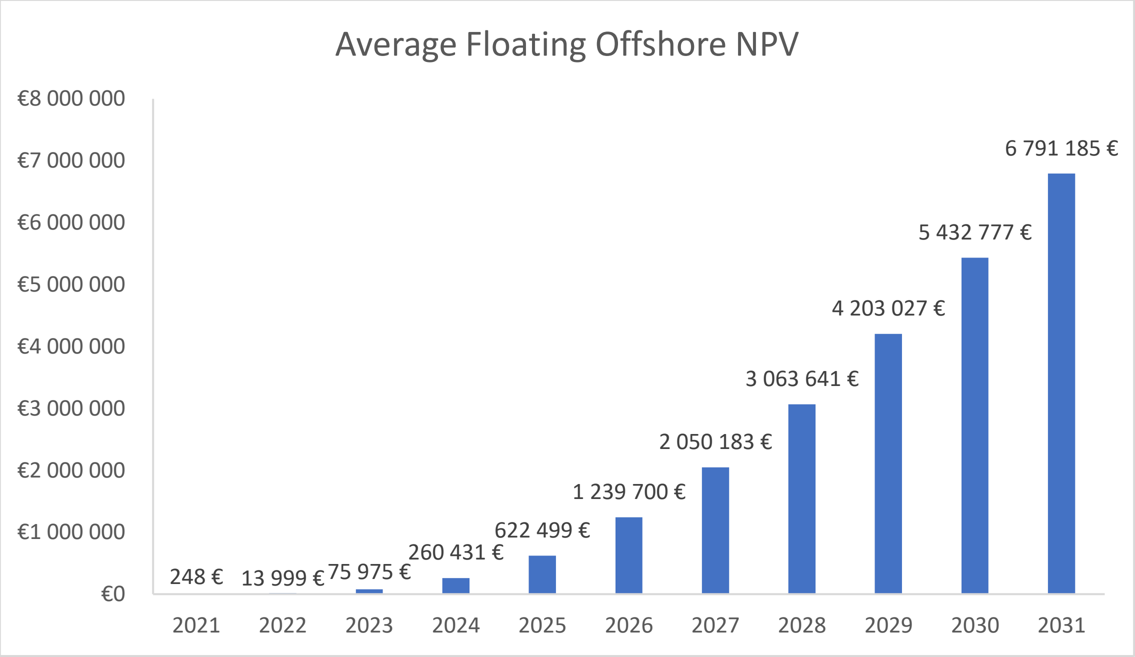


Figure 13 : Average Floating Offshore Net Present Value

To conclude the NPV analysis, it is worth looking at the optimal investment timing for each technology. As expected, given the developed nature of onshore projects, the decision to invest in 2021 is the optimal one, according to the NPV method. On the contrary, the optimal year of investment for floating offshore projects is only 2027. In fact, and without any government support, there is only one scenario (out of the 5 000 simulated), where the project would be worth undertaking in 2021, from a financial point of view. There are 1 246 scenarios where it is not worth investing throughout the period analyzed (as opposed to only 46 in onshore projects).

Investment Timing NPV	Onshore	Offshore
2021	3955	1
2022	314	24
2023	195	101
2024	135	252
2025	92	417
2026	71	521
2027	57	561
2028	44	543
2029	28	504
2030	13	456
2031	12	374

Table 2 : Investment timing decision – NPV model

4.3 Real Option Valuation

The primer objective of this thesis is to perform a real option analysis and identify investment timings. Having established this purpose, comparing NPVs do not tell the full story and may lead to misleading conclusions.

Therefore, as explained before, Zhang et al's (2016) method provides a structured way of performing the desired analysis. As expected, different results arise when using real options to identify the optimal investment timing. In the case of onshore wind projects, due to the fact the decline in the LCOE is still quite significant, the optimal period of investment becomes 2031. Nevertheless, there is still a high frequency of scenarios where it would be worth investing before 2031, which should not be disregarded. In addition, it comes with no surprise that the optimal investment timing for floating offshore wind projects is also 2031. Here, the frequency is much more dominant in this final period of analysis, which is expected given the strong evolution this technology is expected to have.

Investment Timing Real Options	Onshore	Offshore
2021	27	0
2022	42	0
2023	207	1
2024	336	4
2025	445	13
2026	593	48
2027	490	116
2028	501	201
2029	545	408
2030	650	734
2031	1118	2229

Table 3 : Investment timing decision – Real Options model

4.4 The value of waiting

As explained before, Real Option valuation is often more accurate and superior to the NPV methodology because it considers the economic value of waiting to invest. The value of waiting is considerably higher in the case of floating offshore projects, and it also represents a higher percentage of the total value. This occurs despite the fact the decision timing in onshore projects is delayed by 10 years (compared to 4 years in the floating offshore case).

Investment Value	Onshore	Offshore
NPV	1 713 063 €	1 222 457 €
Real Option Value	2 668 620 €	2 867 642 €
Value of Waiting	955 556 €	1 645 185 €
Value of Waiting (%)	36%	57%

Table 4 : Investment Value comparison

4.5 Sensitivity Analysis

This section looks to complement the results analyzed above. By changing the inputs of critical variables, one can better understand how the model works, hopefully answering some questions that may arise. With exception to the price (which is already confined to a relatively small range), all variables of uncertainty were explored.

4.5.1 Costs sensitivity

As said before, cost reduction is quite significant even for the most mature technology. However, this reduction may not happen in the way it has happened before. By taking an extreme scenario where both drift and volatility are set to 0, the NPV still increases but much less than before (from 1 494 249€, to 3 384 820€). As such, the value of waiting is much less than before, and both methods provide the same optimal investment period (2021). There is also an increase in scenarios where it is not worth investing in any period, from 46 to 325. Also, if the same inputs were assumed for floating offshore wind projects, it would not be worth investing in any period in the vast majority of cases.

Investment Value	Onshore
NPV	1 494 249 €
RO	1 774 208 €
Value of Waiting	279 958 €
Value of Waiting (%RO)	16%

Table 5 : Investment Value – Stable Costs scenario

4.5.2 WACC sensitivity

In the case of onshore wind technology, a case could be made that a WACC of 9% can be too high. In fact, this number is quite conservative. Using 6.75%, the most optimistic discount rate found (Grant Thornton, 2019) provides interesting results but no change in decision. The NPV still evolves quite considerably, but the low discount rate yields 4 795 cases where the project is NPV positive in 2021 (and only 10 paths where it is not worth investing in any year). However, the lower discount rate also reduces de opportunity cost of not investing. As such, the optimal decision timing, according to the real options method, continues to be 2031.

Investment Value	Onshore
NPV	3 640 161 €
RO	4 671 878 €
Value of Waiting	1 031 717 €
Value of Waiting (%RO)	22%

Table 6 : Investment Value – Low WACC scenario

4.5.3 Annual Energy Production Sensitivity

The AEP is the final key critical variable that should be further analyzed. It is quite interesting due to the fact it affects both revenue and cost. The initial assumptions yielded a constant increase in the average AEP over the years. However, this may not be the case. In fact, the evolution is mainly based on the fact that the capacity factor will be improved, which is not guaranteed. Moreover, a simplified method was used, one that only gives an approximation of the actual AEP. Due to these reasons, a scenario was taken where there is no drift or volatility in the yearly AEP. This, while extreme, can be realistic if wind speeds do not change with time. It would also mean that no technological improvements in both capacity factor and installed capacity would occur.

Looking at the results, the decision timing for onshore investments is unaltered. However, there is a substantial amount of paths where it is not worth investing in the case of offshore technology (1 789 out of 5 000). The evolution of the NPVs is similar, but in smaller quantities, with many scenarios not being able to recover the losses incurred where costs are too high. This is especially relevant for the case of floating offshore wind, where the starting point for the LCOE is extremely high. The results indicate the strong possibility of economies of scale in the business and explain why there is an effort to increase the amount of energy produced by wind turbines. Moreover, as in the previous scenario, the optimal decision timing does not change.

Investment Value	Onshore	Offshore
NPV	156 180 €	819 527 €
RO	1 251 176 €	1 328 975 €
Value of Waiting	1 094 996 €	509 448 €
Value of Waiting (%RO)	88%	38%

Table 7 : Investment Value – Stable Annual Energy Production scenario

5 Thesis Limitations

As one might expect, despite a thorough theoretical analysis that enabled building a strong and dynamic model, the conclusions taken from this dissertation rely on several assumptions that may or may not truly reflect the future outlook of the industry. Hence, the results should be examined considering said inputs, bearing in mind that the model was built to be flexible to different assumptions that may yield different results. The sensitivity analysis performed does address this issue, but with some constraints.

Secondly, there are some limitations regarding the estimation of the quantity of energy produced. Complex models are available, but it is quite difficult to find a simple and easy to apply model, with an approximation being taken. In addition, the formula used for the levelized cost of energy can be seen as incomplete (due to lack of data). These choices most likely affect the final results and should be taken into consideration in future research. Also, it fails to consider research & development investment necessary to improve the cost structure of each technology and the time it takes actually to build wind turbines.

Thirdly, databases used may not reflect the true cost of wind turbines in Spain. Lack of specific data forced the use of EU's general data for onshore wind turbines, which should yield close values, but may not be entirely accurate. Moreover, a technology as young as floating offshore wind meant some assumptions about future prospects were taken, based on expert sentiment. These sentiments may overvalue the behavior of the value of this type of projects, given some bias that could arise due to the relationship between experts and the industry.

Finally, government support and policy impact were not considered in the final version of this model. Uncertainty regarding the future outlook of Spanish policy and the difficulty to quantify the support for singular investments meant no subsidies were considered in the valuation. Nevertheless, this last limitation may not be as relevant as those as mentioned above, because (1) literature already exists to understand the relationship between renewable energy investments and support schemes, (2) the main goal of this dissertation consists in valuing both technologies with no external considerations.

6 Future Recommendations

The aforementioned limitations can and should be looked at as opportunities for further research. There is room for improvement with respect to the model developed. Firstly, using more complex formulas (such as Weibull's wind speed distribution) in specific locations can yield a much closer approximation to the actual AEP. Secondly, using a more developed formula for the LCOE could also improve the quality of results. This will be further strengthened if specific data of the actual costs firms are incurring is used.

Another research question that may arise upon reading this dissertation is related to the size of the project. Economies of scale can have a big impact in the development of a new technology such as floating offshore. It will definitely bring value to understand how one can introduce this nuance in the model, and the conclusions obtained from it.

As mentioned before, government subsidies were not considered for the purposes of this study. Given that the paper focuses on the Spanish market, adding subsidies as another variable will come closer to what investors face upon decision. On the other hand, this model can be looked from a governmental perspective, helping policy makers understand how and where to spend public funds. Spain can be a leading force in the floating offshore wind technology, but it cannot afford the mistakes of the past (mentioned in Section 2, more details in Ulazia & Arriola, 2018).

Finally, it would be interesting to introduce R&D costs into the model. Understanding the relationship between investment made today on innovation, and future cash flows can be crucial for both present and future decisions. It would, most likely, add value to both investors and policy makers.

7 Conclusion

This thesis investigates the topic of Real Options in Wind Energy Investments, providing an overview of the Spanish market in the process. It studies and looks to answer one central research question:

- How to use Real Options to value and optimize the decision between investing in onshore and floating offshore wind turbines?

Moreover, two sub-research questions are analyzed in

    - What are the main reasons behind the lack of installed offshore wind farms in Spain?
    - What are the future prospects for both technologies and optimal investment timing?
    - What (and how) are the key variables impacting the value of wind projects?

Before summarizing the key conclusions, an overview of each chapter will be provided.

Chapter 1 identified the main research gap, as well as the relevance of the topic at stake. One can easily understand the main motivations behind this topic, as wind energy investments will play a key role in the future.

Chapter 2 provided an extensive literature review about the state of the wind energy sector today, explaining in detail the three main technologies. It also reviewed key concepts in the topic of real options. The theoretical analysis finished with an overview of the evolution of some variables which are further analyzed.

Chapter 3 presented the data collection process. More importantly, it defined the methodology taken. It showed how to apply the real option method in the wind energy sector, defining the 3 main variables of uncertainty – price of electricity, AEP and LCOE.

In chapter 5 the main results were presented. After providing the initial values of each parameter, the dynamic of each variable was identified. Finally, a comparison between the NPV and Real Option's method was made, underlying the importance of using the latter. The optimal timing of investment was identified for each technology, under the assumptions taken. Moreover, a sensitivity analysis was performed to provide further insights on the importance of the assumptions, as well as the model's flexibility.

Chapter 6 explain this dissertation's limitations, with chapter 7 analyzing why these are opportunities for further research.

Regarding primary findings, it was discovered the high value of waiting for investment both technologies have. In fact, for a rather new technology such as floating offshore wind, this represents more than 50% of the project's current value. In both cases, high cost reduction curves cause 2031 to be the optimal year of investment. This variable was found to be the one with larger impact on investment timing, according to the sensitivity analysis performed.

In addition, the model explains how price caps and floors help stabilize the price of electricity on a yearly basis, making it a secondary concern when valuing wind projects. Despite not going into detail on the importance of size, it shows how a higher cost, higher capacity wind turbine may yield more value in the long run.

Furthermore, the model identifies huge potential in floating offshore wind energy. Its high learning curve (translating into a cost reduction), together with higher energy production make the case for this to be the technology of the future. In fact, it can solve Spain's offshore wind limitations (given it does not rely on its coast's characteristics).

Finally, it strengthens the argument that the NPV model falls short in understanding wind energy investments. Comparing both methodologies shows just how much economic value is left in the table by not considering the option to wait to invest.

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9 Annex – Sensitivity Analysis

9.1 Annex 1 - Stable Cost Scenario

Annex 1 shows a detailed analysis of the analysis performed when there is no cost drift nor volatility. Table 9.1.1 addresses the results of the Monte Carlo simulation. Figure 9.1.1 gives an overview of the average NPV over the years.

Investment Timing	NPV	RO
2021	4675	1272
2022	60	87
2023	89	343
2024	68	384
2025	70	349
2026	48	427
2027	44	161
2028	52	207
2029	43	227
2030	42	285
2031	37	953

Table 9.1.1 : Investment timing decision – Stable Cost scenario

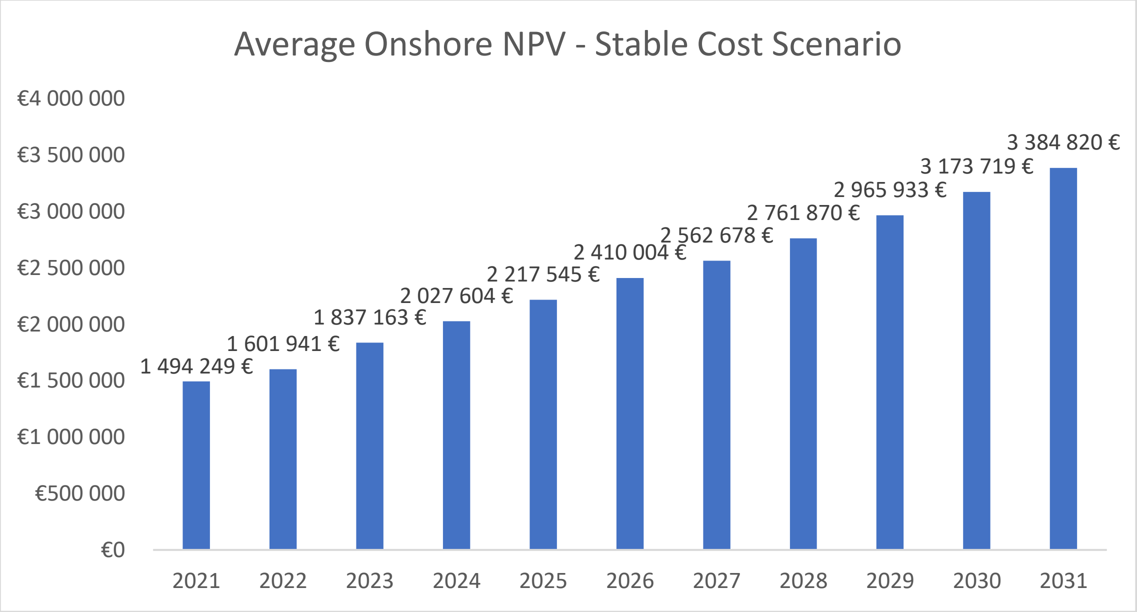

Figure 9.1.1 : Average Onshore NPV – Stable Cost scenario

9.2 Annex 2 – Stable Annual Energy Production Scenario

Annex 2 is focused on the evolution of the average NPV when both technologies see no AEP changes. Figure 9.2.1 is related to onshore wind projects, while Figure 9.2.2 concerns floating offshore wind projects.

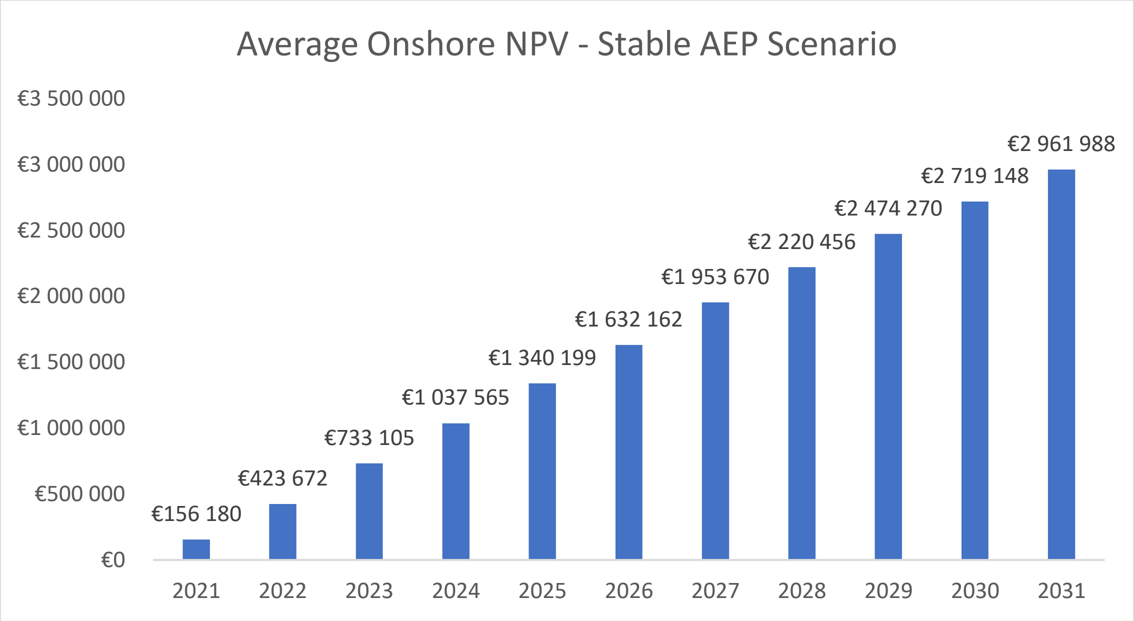

Figure 9.2.1 : Average Onshore NPV – Stable AEP scenario

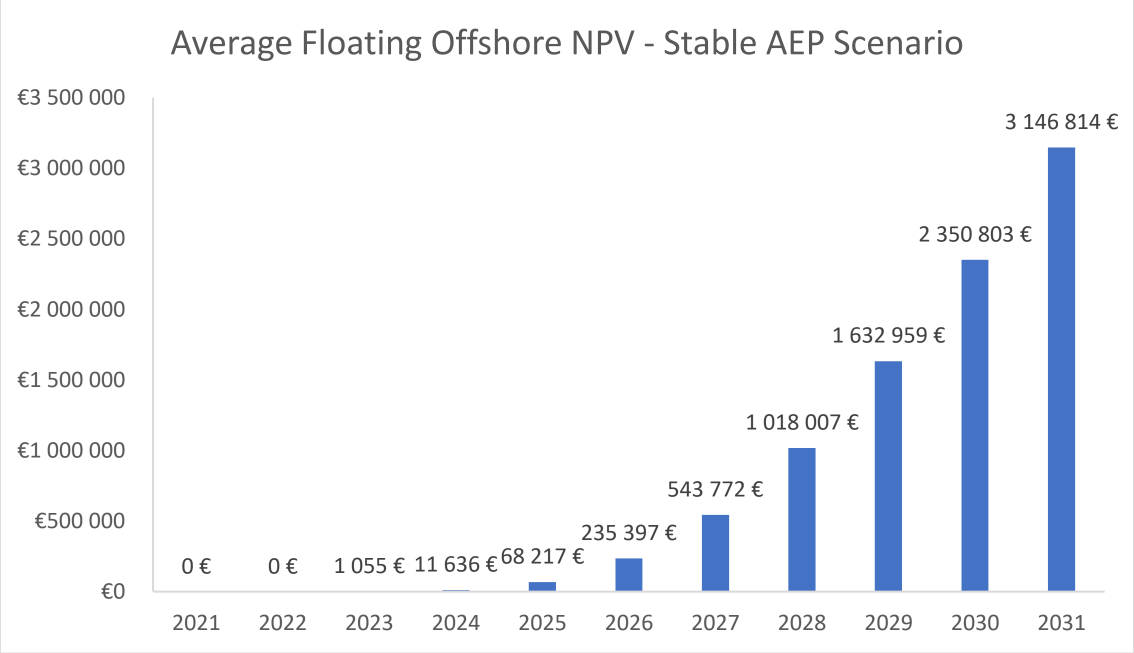

Figure 9.2.2 : Average Floating Offshore NPV – Stable AEP scenario

9.3 Annex 3 – Stable Annual Energy Production Scenario

Annex 3 presents the average onshore NPV of the 5000 simulated paths, in the low WACC scenario (Figure 9.3.1).

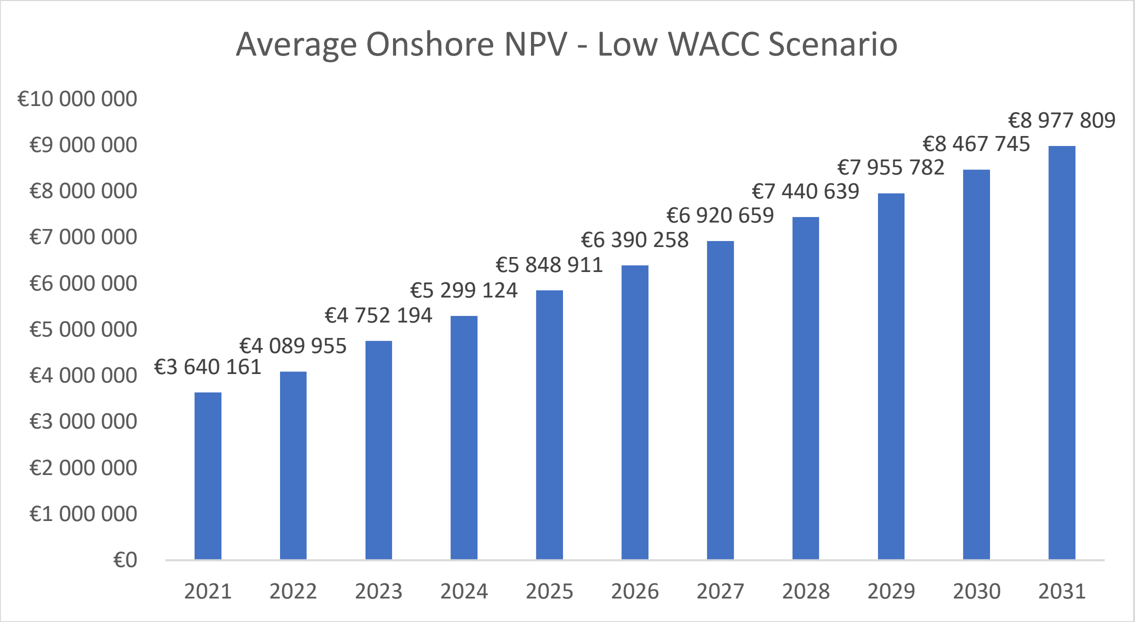

Figure 9.3.1 : Average Onshore NPV – Low WACC scenario