Evaluation of RES projects for electricity generation

Bartolomeu Fernandes*
Department of Production and Systems
University of Minho, Guimarães, Portugal
e–mail: bartolomeuafernandes@gmail.com

Jorge Cunha
Department of Production and Systems
University of Minho, Guimarães, Portugal
e–mail: jscunha@dps.uminho.pt

Paula Ferreira
Department of Production and Systems
University of Minho, Guimarães, Portugal
e–mail: paulaf@dps.uminho.pt

ABSTRACT

Renewable energy sources (RES) emerge as a necessary condition to achieve sustainable development. Traditional evaluation models relying mainly on discounted cash-flows fail to assess the strategic dimension of the investments in RES and do not allow for properly dealing with the risk and uncertainty of these particular projects. The diffusion of the renewable energy technologies are also affected by this features, so, the way investors evaluate their investments call for the use of more sophisticated evaluation techniques. Real options theory (ROT), gives the investor the ability to account for the value inherent in the flexibility to delay an irreversible investment into the future.

This paper presents an application of the ROT to a photovoltaic investment project for the particular case of the Portuguese electricity market conditions. Special attention is given to the combination of learning curves and ROT aiming to provide a new approach to the sustainable development and diffusion possibilities of renewable energy technologies.

INTRODUCTION

The use of renewable energy sources (RES) emerges as a necessary condition to achieve sustainable development. Energy shortage, global warming, and climate change forced an increase in the use of alternative sources of energy. Nay, the world's economy is affected by the prices of the raw materials and it is in turn affected by the constant instability of the fuel-based energy prices. For these reasons, RES have a fundamental role in providing universal access to energy, creating new business opportunities, reducing the external energy dependency and, at the same time, contributing to reduction of greenhouse gas emissions.

However, RES are not competitive when compared to other generation technologies. Partly, because of the fact of the investment costs often constitute a major barrier to their spread use [1]. Moreover, the overall benefits of renewable energy technologies are often not well understood and consequently they are often evaluated to be not as cost effective as traditional technologies. Consequently, in order to RES become competitive, the ensuring of adequate support schemes is necessary encouraging investments in this field [2].

However, a good support scheme may not be enough to encourage investments. The increase of the generation capacity in a liberalized market, requires taking into account future uncertainties [3]. Traditional evaluation models, relying mainly on discounted cash-flows, fail to assess the strategic dimension of the investments and do not allow for properly dealing with the risk and uncertainty of these particular projects. The diffusion of the renewable energy technologies are also affected by this features, so, the way investors evaluate their investments call for the use of more sophisticated evaluation techniques. Real options theory, gives the investor the ability to account for the value inherent in the flexibility to delay an irreversible investment into the future. In the RES projects field, this ability become particularly important, as these are often modular, normally require short construction times and exhibit learning curves with very steep slopes [4, 5].

An investment can be defined as the act of incurring in a cost in the present, in anticipation of getting a higher return in the future. Most investment decisions share three important characteristics [6]: a) the investment is partially or totally irreversible, i.e., the initial capital expenditure is, at least, partly a sunk cost; b) there is uncertainty about the returns provided by the actual investment, this is, the best one can do is assign probabilities to different possible outcomes; and c) the promoter of the investment has some freedom to decide the most appropriate time to make the investment, i.e., he may postpone the decision to obtain more information about the future. These three characteristics interact to determine the optimal decision of investors. However, the “traditional” approach (as reflected, for example, in the NPV criterion) has not recognized the quantity and quality of interaction between these three characteristics [6]. In fact, the NPV rule is based on certain assumptions, to some extent, simplistic. For example, or assume that investment is reversible, or, assuming that it is irreversible, corresponds to an all or nothing decision, i.e., if the company does not implement the investment project, loses the opportunity to do so in the future. Although some investments have these characteristics, most investments have not [6]. That is, the irreversibility and the possibility to choose the best timing to undertake the investment are important characteristics of most investments in reality. Moreover, traditional evaluation methods emphasize the financial return. That is, they tend to consider only tangible aspects, neglecting elements of intangible nature, such as future competitive advantage, future opportunities, or the flexibility of management.

One way of dealing with these aspects (namely, irreversibility, uncertainty and timing of investments) is to develop a similar reasoning to the investment in financial options. This approach is known as Real Options Theory (ROT) [7].

It can be said that a real option is the flexibility that a manager has to make decisions about real assets [8]. As new details emerge and the uncertainties on the cash flow are dying out, managers can take decisions that can positively influence the value of the project [6]. Some examples of decisions with which managers are faced are: What is the right time to invest, to abandon or temporarily stop a project? What is the possibility of modifying the operating characteristics of the project? Or, is there the possibility of exchanging an asset for another? In this sense, an investment project can be seen as a set of real options on a real asset - the project.

The remainder of this paper is organized as follows. Section 2 gives an introduction of the basic principles of the real options theory. In Section 3, the usefulness of the ROT approach in comparison with the tradition evaluation is illustrated, with an application to a photovoltaic investment. Section 4 concludes the paper presenting the main findings and some perspectives for further research.

REAL OPTIONS THEORETICAL BACKGROUND

To better understand the ROT reasoning/approach, it is important to provide a brief glance over the financial options. To start with it is necessary to distinguish between a call option and a put option. A call option is a contract that gives the buyer the right, but not the obligation, to buy something at a specified price in the future (and the seller of the call has the obligation to deliver the good or asset if the call owner exercises the option). A put option is a contract that gives the buyer the right, but not the obligation, to sell something at a specified price in the future (and the seller of the put has the obligation to take delivery of the good or asset should the put owner decide to exercise his option).

The something that can be bought (or sold) with the option is called the underlying asset. The specified price is called the exercise price and the future date is called the expiration date.

In the context of real options, one can define a real option “as the right, but not the obligation, to take an action (e.g., deferring, expanding, contracting or abandoning) at a predetermined cost, called exercise price, for a predetermined period of time – the life of the option” [9]. Therefore, an opportunity to invest is similar to a financial call option. If it is possible to find a call option like an investment opportunity, the value of that option would tell investors something about the value of the investment opportunity. So, it has to be established a relation between the investment project characteristics and the variables that are needed to value a call option, and this is shown in Table 1.

Table 1: Analogy of the call option and the project characteristics

Project characteristics	**Variable**	**Call option**
Present value of expected cash flows	S	Stock price
Present value of investment outlays	X	Exercise price
Length of deferral time	t	Time to maturity
Time value of money	r_f	Risk-free rate
Volatility of project’s returns	σ	Variance of stock returns

The value of a call option, CO, can be obtained using the Black-Scholes option pricing model, described in Equations 1, 2 and 3 [10]

$$CO = V = N(d_1)S - N(d_2)Xe^{-rt} \quad (1)$$

Subject to,

$$d_1 = \frac{\ln\left(\frac{S}{X}\right)+\left(r+\frac{\sigma^2}{2}\right)t}{\sigma\sqrt{t}} \quad (2)$$

$$d_2 = d_1 - \sigma\sqrt{t} \quad (3)$$

In equation (1) $N(d)$ is the cumulative normal distribution.

As can be seen, most of the data that are needed to evaluate a project using the DCF methods is the same data that will be used in ROT model.

EVALUATION OF A PHOTOVOLTAIC INVESTMENT

The Sun is our main source of energy, responsible for maintaining the various forms of life on Earth. This is practically an inexhaustible resource when compared with the scale of our existence on this planet.

The Sun annually provides to the atmosphere, a huge amount of energy (valuated in $1,5\ x\ 10^{18}\ kWh$) corresponding to about 10,000 times the world energy consumption observed during the same period. However, this source is considered too dispersed, with the resulting advantages and disadvantages. Among the disadvantages, it should be noted, without doubt, the need for major catchments surfaces for its use (for example, the Moura's photovoltaic power station for an installed capacity of $62\ MWp$, occupies an area of approximately 114 hectares). The great advantage is that it is an energy source fairly distributed [11].

In Portugal, the available potential is quite considerable, being one of the European countries with better conditions for exploitation of this resource. The average annual number of hours of sun ranges between 2200 and 3000 on the mainland, and between 1700 and 2200, respectively, in the Azores and Madeira (Figure 1). In Germany, for example, this indicator varies between 1200 and 1700 hours (Figure 2) [11].The use of solar thermal and photovoltaic is still far short of the potential of this resource, available in the country. In 2003 the estimated installed capacity of solar PV systems was about 2 MW, of which only 20% referred to facilities connected to the public grid.

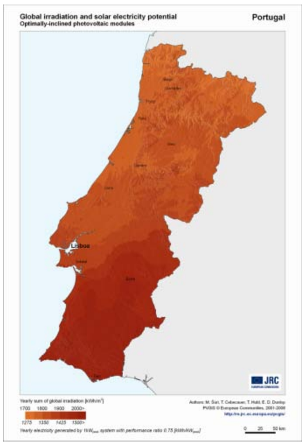

Figure 1. Global irradiation and solar electricity potential in Portugal [12]

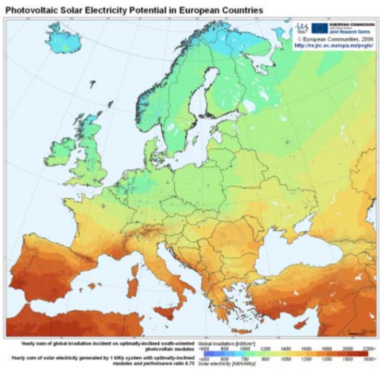

Figure 2. Photovoltaic solar electricity potential in Europe [12]

In an effort to promote economic development, reduce dependency on external sources and combat the forces of climate change, the Portuguese Government expanded the objectives to be reached in the Resolution of the Council of Ministers nº 63/2003, dated 19 October, for various sources of renewable energy. By 2010, the objective defined for electricity produced from RES has been set higher, going from an initial figure of a 39% share to 45%. These objectives are expected to be met by increasing all areas of energy supply, by the promotion of energy efficiency and the wise use of energy, by orienting the growth of energy consumption at a level lower than the growth of the country's wealth measured in monetary units by the GDP – Gross Domestic Product.

The opening of international competitive bids in Portugal brought about a boost of potential for renewable energy, such that industrial clusters were created, which drastically changed the previous paradigm where the creation of wealth for renewables was stunted. Here, wind energy made notable contributions, with its goals for production increasing from 3,750 MW to 5,300 MW, alongside some obligation were placed upon the winners of the state contract, aiming to create 2000 direct and 10000 indirect jobs in the sector and increasing national equipment production from 15% to 80%[13]. Solar energy has enormous potential for development in Portugal over the next decade. The complementarity with other renewable technologies, mainly due to being generated at times of peak consumption, leads to setting a target of 1,500 MW of installed power in 2020 through the implementation of many programs. The development of this capacity is strongly linked to the expected technological efficiencies progress and to the following costs reduction associated with these technologies, including solar photovoltaic and thermoelectric concentration [13].

This reality opens a window of opportunity for investors. So, to have good project evaluation methods to evaluate correctly this kind of investments is fundamental. However, before moving to the evaluation itself, knowing the particularities of an investment in photovoltaic is a requirement

Photovoltaic investment data

The investment studied in this work was based on the Portuguese Serpa Solar plant. This solar plant is located in the South of the country in Serpa, Alentejo, which is one of the locations with more solar irradiation potential, as shown in Figure 1.This solar plant is already in operation since 2007. However, one of the objectives of this work is to use data from a real case study to demonstrate how ROT may give a contribution to evaluation of these projects going beyond traditional evaluation techniques.

The source for most of the following data was Maso [15]. However, that document did not contain any information related to Operations and Maintenance (O&M) costs and the discount rate. In order to get that information Bensebaa [16] work was used. The author supports that the annual O&M costs should be 0,4% of the investment and the discount rate 7% for this type of projects.

Table 2. Technical and financial parameters of the project

Technical and financial parameters of the project	**Values**
Number of PV panels	52,000
Nominal Power	11 MWp
Power efficiency	11-14 %
Direct Capital Cost	3.83 €/W
Indirect Capital	1€/W
Investment	53,130,000 €
Electricity production (annual)	18 GWh
Feed-in tariff	0.32 €/kWh
O&M Cost (% of the investment)	0.4 %
Project life time	25 years
Discount rate	7 %

The traditional evaluation

To evaluate under the traditional approach, the NPV method was used. As mentioned earlier, this method is favored by nearly all the manuals for project evaluation, mainly for being the most consistent, from a theoretical point of view, in the context of project selection.

In order to reduce the complexity of the analysis, a simplistic approach was followed for the traditional evaluation, disregarding the financial data of the project, namely depreciation and taxes. However, for the intended comparative purposes this should not represent a major source of concern.

Taking into account the data presented in the Table 2, the cash flows of the project were obtained along with the required economic indicators. Table 3 summarizes all the financial forecast for this investment.

Table 3. Calculation of the project Cash-Flows and NPV

Operating Projections	Years			
	0	1	…	25
1. Revenues		5,760,000.00 €	…	5,760,000.00 €
2. O&M		212,520.00 €	…	212,520.00 €
Operating profit (1-2)		5,547,480.00 €		5,547,480.00 €
Investment	53,130,000.00 €			
Discount factor (7%)	1.00	0.93	…	0.18
PV	53,130,000.00 €	5,184,560.75 €	…	1,022,118.63 €
NPV	11,518,019.61 €			

According to these results, this project presents an NPV of 11.52 M€. This is relatively small value when compared to the amount of investment that had to be made (53 M€). Moreover, it is necessary to take into account that this is the best-case analysis, with no financial costs included in the analysis. Thus, the situation does not seem the most favorable to the investment. Yet, considering the decision rule of the NPV method, the project should be accepted.

Uncertainties

The analysed project has uncertainties that were not taken into account in the previous evaluation. Kaslow and Pindyck [17] identified the most important uncertainties related to energy production - utilisation and the attributes, which interact with them, as can be seen in table 5.

Table 4. Uncertainties related to the energy production (source: [17])

Uncertainty	Relevant resource attributes
1. Fossil fuels price	Operating costs
2. Environmental regulations	External costs
3. Demand	Location flexibility Modularity and Lead-time Capability Availability
4. Supply	Location flexibility Modularity and Lead-time Capability Availability
5. Initial Capital Cost and technological issues	Initial capital requirements Modularity and Lead-time Location flexibility
6. Market structure	Overall costs

The Real Options evaluation

To start valuing the option, it is necessary to identify the options that are embedded in the project. Given the uncertainties that were defined in the previous section, and the characteristics of the Portuguese electricity market (a RES a regulated and protected market), the variable that will most influence the evaluation results is the Initial Capital Cost and technological issues.

The initial Capital Cost uncertainty refers to the initial investment cost, as well as the additions to the installed capacity. The technological uncertainty relates to the risk that the installed resources can become economically obsolete, due to technological changes, before Capital Costs are fully recovered or the investment provides positive cumulative cash flow CF. Technology is an important driver of energy development, and technology costs change over time. In fact, one of the most important factors shaping the results of energy models are the assumptions they make about technology learning [18, 19].

Winkler et al. [20], presented in their work some learning ratios for photovoltaic. They showed that the range of learning ratios in the literature is for 17-68%. However, in their study they estimate a learning ratio of 25% for 2003 to 2025.

Nemet [22] summarized the learning curve model in three equations:

$$C_t = C_0 \left(\frac{q_t}{q_0}\right)^{-b} \tag{4}$$

$$PR = 2^{-b} \tag{5}$$

$$LR = (1 - PR) \quad (6)$$

Where C_t (in \$/kW) is the unit cost of technology, q represents the cumulative installed capacity, b is the exponent defining the slope of the power function, PR is the progress ratio and LR the learning ratio, [22]. The PR can be assumed as the reduced cost per unit, while the LR is the saved cost for an increase in cumulative output [22].
So, an investor has an opportunity to wait for the reduction of the initial capital cost. Thereby, the investor has an option to defer the investment.

To evaluate this option, the Black and Scholes [10] model was used. To use this model, most of the required data is the same one used in the NPV evaluation, namely:

- Present value of expected cash flows, S
- Present value of investment outlays, X
- Length of deferral time, t
- Time value of money, r_f
- Volatility of project's returns, σ

The use of ROT will be demonstrated for the photovoltaic project described before and under three different uncertainty cases: the learning curve effect, the market prices effect and the joint effects of learning curve and market price uncertainty.
In what follows, three cases will be analysed: the impact of learning curves, the influence of market prices volatility, and a combination of this two.

Case 1 – Learning Curves

The first case that will be analysed under the scope of the Real Options is the effect of the learning curves in this project.
As said in the previous section, the learning curves for photovoltaic technology can range from a minimum of 17% to a maximum of 68%, being 25% the most likely value. If the learning curve can be described by a triangular distribution, the values to calculate the volatility of the project returns can also be estimated. According to Evans et al. [23], the triangular distribution is a continuous distribution defined on the range $x \; in \; [a, b]$ with probability density function:

$$P(x) = \begin{cases} \frac{2(x-a)}{(b-a)(c-a)} \; for \; a \leq x \leq c \\ \frac{2(b-x)}{(b-a)(b-c)} for \; c < x < b \end{cases} \quad (7)$$

and distribution function,

$$D(x) = \begin{cases} \frac{(x-a)^2}{(b-a)(c-a)} \qquad for \; a \leq x \leq c \\ 1 - \frac{(b-x)^2}{(b-a)(b-c)} for \; c < x < b \end{cases} \quad (8)$$

where $c \in [a, b]$ is the mode.

Therefore, the value of the volatility of the project's return was obtained applying the Peng et al model [24]. To implement that model, it is important firstly to recognize that there are factors which influence the value of the NPV, like in this case, the learning curve. As so, , to carry out the simulations, all the relevant data must be included, such as investment as a function of the learning curve, revenues, O&M (because O&M are directly related to the investment O&M costs will decrease as investment decreases). NPV of the project will be set as output of project value in the model. A variety of different NPV will be obtained then from simulation, for each value of investment. The standard deviation of NPV is defined according to the following formula, and then the volatility σ of the project may be derived:

$$S_t = \sqrt{\frac{1}{N}\sum_{t=1}^{N}(NPV_t - \overline{NPV})^2} \tag{9}$$

$$\sigma^* = \frac{S}{|\overline{NPV}|} \tag{10}$$

$$\sigma = \frac{\sigma^*}{\sqrt{n}} \tag{11}$$

Where, $\overline{NPV}$ is the expectancy of the project's NPV and n is the duration of the project. In this case, NPV is considered as a factor of volatility. After calculating the, it is now possible to calculate the option value C_t of the project by using the Black-Scholes option pricing model.

In this case, the option that will be evaluated is the defer option. So, the decision rule will be:

- Invest, if the traditional NPV is higher than the option value
- Defer, if the traditional NPV is lower than the option value

This calculations where performed using the Monte Carlo simulation implemented in Excel®. For this case 1,000,000 simulations were done and the following results were obtained (Table 5) for the NPV with the corresponding value of the learning curve:

Table 5. Results of the simulations for case 1

	NPV	Learning Curve
Base Case	11,518,019.61 €	0%
Mean	32,090,599.51 €	37%
S_t	6,355,342.55 €	11%
σ^*	0.1980	---
σ (volatility)	0.0396	---

Figure 3 represents the histogram of the case 1 NPV, for each investment value, showing that NPV is triangular distributed.

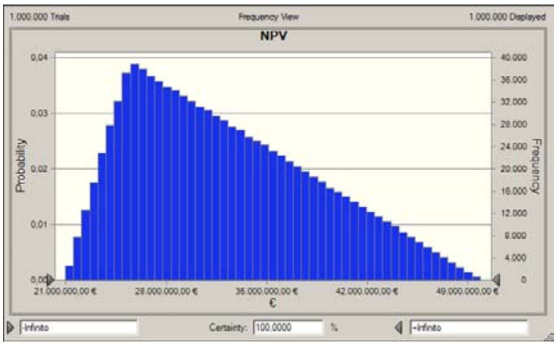

Figure 3. Case 1 NPV histogram

With the calculation of the volatility, all the necessary data to apply the option pricing model were obtained. The following table shows the real options input data and the option valuation.

Table 6. Real Options Input data

Real Options Input Data		
Variables	Project characteristics	Value
S	Present value of expected cash flows	64.65 €
X	Present value of investment outlays	53.13 €
t	Length of deferral time	25
rf	Time value of money	7.00%
σ	Standard deviation of project returns	5.77%
		Values in M€

Table 7. Option valuation

Black-Scholes Formula	
Option value	51.29 €
d1	1.44367861
d2	1.245678610
Expanded NPV = (option to defer + NPV)	63.11 €
	Values in M€

It can be seen that the value of the option is much higher than the NPV of the traditional evaluation. So, by evaluating this project using the ROT a new NPV value can be obtained. That NPV is called “Expanded NPV” and it contains the value to invest now and the value to defer the investment. In this case and considering, strictly, the decision rule, the investor should defer the investment and wait to the resolution of the uncertainty. However, since this project has already a positive NPV, it would not be surprisingly that the investor would chose to invest now, earning something rather than loose a good investment opportunity, given that, in the next period, other sources of risk could offset the advantage of deferring the investment.

Case 2 – Market Prices

The second case that will be analysed in this work is the effect of the photovoltaic market prices in this investment project. In fact, this case can not be verified in real projects in Portugal because the photovoltaic market is still regulated and based on protected fee-in tariffs. However, the objective of this case is, mostly, to give indications about what would be the investment decision if the electricity price was defined in a free market environment.

To calculate the uncertainty of the market prices, obtaining the historical data of the selling price of photovoltaic electricity would be necessary. To give more realistic results, that data should be hourly based, as prices differ between peak hours and off-peak hours. Peak hours price is relatively higher than off peak price. The peak hours usually occur during the day while the off-peak hours occur mainly during the night. So, the photovoltaic selling price is mostly affected by the peak hour price as this type of RES can only produce during the day. However, since it was extremely difficult to obtain the data hourly based, the average monthly prices were used as a first approach. That data was obtained in the *Operador del Mercado Ibérico de Energía* (OMEL) database from July of 2007 to June of 2011. This data was described by a lognormal distribution. The probability density and cumulative distribution functions for the log normal distribution are:

$$P(x) = \frac{1}{S\sqrt{2\pi}x} e^{-(\ln x - M)^2/(2S^2)} \qquad (12)$$

$$D(x) = \frac{1}{2}\left[1 + erf\left(\frac{\ln x - M}{S\sqrt{2}}\right)\right] \qquad (13)$$

Where $erf(x)$ is the erf function.
The volatility was obtained, and the calculation of the option value was done following the same method as in case 1, having the same decision rule.

Table 8. Results of the simulations for case 2

	NPV	Revenues
Base Case	11,518,019.61 €	5,760,000.00 €
Mean	-45,378,941.57 €	877,642.33 €
S_t	3,340,315.60 €	286,634.21 €
σ^*	0.0736	---
σ (volatility)	0.0147	---

Table 9. Real Options Input data

Real Options Input Data		
Variables	Project characteristics	Value
S	Present value of expected cash flows	64.65 €
X	Present value of investment outlays	53.13 €
T	Length of deferral time	25
Rf	Time value of money	7.00%
Σ	Standard deviation of project returns	1.47%
		Values in M€

Table 10. Options valuation

Black-Scholes Formula	
Option value	55.41 €
d1	3.65914952
d2	3.585649520
Expanded NPV = (option to defer + NPV)	66.93 €
	Values in M€

In this case and considering the decision rule, the investor should defer the investment and wait to the resolution of the uncertainty, as one would expect. The price of the electricity has a big influence in the financial results of photovoltaic investment projects.

Case 3 – Learning Curves and Market Prices

The third case that will be analysed in this work is the combination of the two previous cases. This case is important to give indications about what would be the investment decision if the value of the investment decreases but the price of the energy is defined by the market.
The volatility was obtained, and the calculation of the option value was done with the same method as in the two previous cases. In this case, the option that will be evaluate is the defer option. So, the decision rule will be the same as in the previous case.

This calculations where performed using the Monte Carlo simulation implemented in Excel®. As previously, 1,000,000 simulations were done and the following results (Table 11) for the NPV, with the respective value of the learning curve, were obtained:

Table 11. Results of the simulations for case 3

	NPV	Revenues	Learning Curve
Base Case	11,518,019.61 €	5,760,000.00 €	0%
Mean	-24,940,443.06 €	881,615.65 €	37%
S_t	5,952,057.89 €	288,096.10 €	11%
σ^*	0.3268	---	---
σ (volatility)	0.0568	---	---

Figure 4 shows the contribution of the learning curve and the average monthly prices to the deviation of the NPV. It can be seen that the learning curve has a contribution of 80,1% and the monthly prices 19,9 %. So the learning curve, namely the investment value, has an important influence in the results of photovoltaic projects.

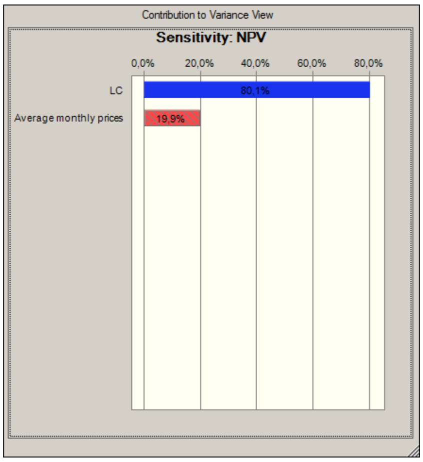

Figure 4. Sensitivity analysis of the NPV, case 3

With the calculation of the volatility, all the necessary data to apply the option pricing model were obtained. The following table shows the real options input data and the option valuation.

Table 12. Real Options Input data

Real Options Input Data		
Variables	Project characteristics	Value
S	Present value of expected cash flows	64.65 €
X	Present value of investment outlays	53.13 €
T	Length of deferral time	25
Rf	Time value of money	7.00%
σ	Standard deviation of project returns	5.68%
		Values in M€

Table 13. Options valuation

Black-Scholes Formula	
Option value	48.32 €
d1	1.0794872
d2	0.795487200
Expanded NPV = (option to defer + NPV)	59.84 €
	Values in M€

In this case and considering the decision rule, the investor should defer the investment and wait to the resolution of the uncertainty.

CONCLUSIONS

The traditional DCF methods may fail in the evaluation of projects that are characterized by uncertainty and high financial risks. Those methods do not take into account the possibility of variations on cash flows, according to market changes or sensitivity of investors. Those changes are extremely important. A project that seems to be a good one can be turned into a bad one, only by the uprising of the prices of raw materials, or a sudden crisis in financial markets. Sometimes, traditional methods provide misleading information and that is the major drawback of those methods. Although, the ROT approach does not give the answer to all the issues in project evaluation, it can provide more accurate information to the decision maker, giving the possibility of better decisions. Curiously, by incorporating risk in the analysis, this is done with less risk. In other words, the results obtained are more precise. Nevertheless, ROT is often difficult to apply in practice. In fact, uncertainties are extremely difficult to model with precision and require sophisticated techniques, like simulation tools. Also, the equations that are used in ROT require a great mathematical knowledge and can be arduous to apply. Even the line of thought that should be followed in order to use ROT is different from the one that is needed in DCF methods. This rupture of thinking is as difficult as applying the methodology. In spite of all that, not only on energy sector, but also in major public investments, like airports, seaports or railways, ROT can be an important tool to better evaluate (or assess) the value of investments.

RES projects have particular characteristics that imply selecting methods capable to assess their correct value taking into account these particularities. Namely, these projects have high initial costs, low marginal costs, high financial risk and uncertainties. These uncertainties are caused by their natural sources variability, the possible changes in the support schemes and by their learning curves exhibiting very steep slopes. These project's interest is also indirectly affected by the fossil fuel prices and consequently by the prices of the electricity and, as so, the markets uncertainty also affects these kinds of projects.

Taking into account the exposed reasons, ROT seems to be an evaluation method that can provide a more realistic value of a RES investment project. However, there seems to exist a lack of application of this technique to this field and, as so, the authors frequently resource to the simulation of the application. Real Options proved that can produce better results than other methods. To the authors' best knowledge this technique was not frequently applied to other RES projects, beyond wind power and hydropower.

Regarding the case of a photovoltaic investment, the evaluation under the ROT provides some interesting conclusions. The mere fact that this technology has learning curves with very steep slopes makes a project that is not profitable in a given year, to become profitable one year later. Therefore, the evaluations that can be done to similar projects must consider those issues.

Although, the evaluation undertaken in this work does not use a detailed financial investment data, it can be regarded as being done for the best case. The major conclusion is that, in all cases analyzed, the investor should wait for the resolution of the uncertainty and then evaluate the project again. Also, it was found that the impact of the learning curves in the financial results is higher than the impact of the market prices. However, both of these issues are extremely important and must be considered in the evaluation of projects like this one.
Another factor that can not be overlooked is the use in the model of market prices are not hourly based, and according to authors conviction the results would be different if the hourly values were used instead of monthly averages.

Considering the presented cases, although the decision given by ROT was to defer the investment, this does not, necessarily, mean that the investor would defer it. In fact, as the NPV of the base case is positive, if the investor defers the investment, he might lose the opportunity of generate a profit in the present. What the application of ROT allows is the investor to know what the postponing of the investment is worthing. Another conclusion that can be drawn refers to the fact that this technique can provide better knowledge of the potential and better evaluate these new technologies.

An opportunity of investment in this area has been growing in Portugal, so if investors have more accurate methods to evaluate those opportunities they may be more receptive to investment and thus help in the revitalization of the Portuguese economy. Real Options theory is one of those accurate methods.

FURTHER WORK

Despite the great theoretical advantages of ROT approach that were pointed out, to the authors' best knowledge, this approach has not been much applied (or used in real situations).

So, an important step in would be the development of a software that could turn RO more "user friendly". The training of managers in order to raise awareness of the potential of this approach is a great way to the spread of ROT. This technique can be applied to almost all types of investments in different sectors. However, the absence of applications has been an obstacle to their use.

Although the photovoltaic market, in Portugal, is still regulated, it is important to predict what would happen when the deregulation occurs. So, the development of a Real Options model to apply in a deregulated market will be a very important step in. In that case, other types of uncertainty will be present and therefore it will be necessary to compute those uncertainties. Thus, some interesting insights of the markets will be provided.

AKNOWLEDGEMENTS

This work was financed by: the QREN – Operational Programme for Competitiveness Factors, the European Union – European Regional Development Fund and National Funds-Portuguese Foundation for Science and Technology, under Project FCOMP-01-0124-FEDER-011377 and Project Pest-OE/EME/UI0252/2011.

REFERENCES

1. Menegaki, A., *Valuation for renewable energy: A comparative review.* Renewable and Sustainable Energy Reviews, 2008. **12**(9): p. 2422-2437.
2. Haas, R., et al., *A historical review of promotion strategies for electricity from renewable energy sources in EU countries.* Renewable and Sustainable Energy Reviews, 2011. **15**(2): p. 1003-1034.
3. Muñoz, J.I., et al., *Risk assessment of wind power generation project investments based on real options.*, in *IEEE Bucharest Power Tech Conference*2009: Bucharest, Romania.
4. Martínez-Ceseña, E.A. and J. Mutale, *Application of an advanced real options approach for renewable energy generation projects planning.* Renewable and Sustainable Energy Reviews, 2011. **15**(4): p. 2087-2094.
5. Kumbaroğlu, G., R. Madlener, and M. Demirel, *A real options evaluation model for the diffusion prospects of new renewable power generation technologies.* Energy Economics, 2008. **30**(4): p. 1882-1908.
6. Dixit, A.K. and R.S. Pindyck, *Investment under uncertainty*1994, New Jersey: Princeton University Press.
7. Trigeorgis, L., *Real options and interactions with financial flexibility.* Financial Management, 1993. **22**(3): p. 202-224.
8. Santos, E. and E. Pamplona, *Teoria das Opções Reais: uma atraente opção no processo de análise de investimentos.* Revista de Administração da USP - RAUSP, 2005. **40**(3): p. 41.
9. Copeland, T. and V. Antikarov, *Real Options: A practitioner's guide*2003, New York: Cengage Learning.
10. Black, F. and M. Scholes, *The Pricing of Options and Corporate Liabilities.* The Journal of Political Economy, 1973. **Vol. 81**(No. 3.): p. 637-654.
11. DGEG. *Energia Solar*. 2010 [cited 2011 31-05-2011]; Available from: www.dgge.pt.
12. Šúri, M., et al., *Potential of solar electricity generation in the European Union member states and candidate countries.* Solar Energy, 2007. **81**: p. 1295-1305.
13. MEID, M.d.E., da Inovação e do Desenvolvimento. *Energia*. [cited 2011 2011-05-31]; Available from: http://www.min-economia.pt/innerPage.aspx?idCat=51&idMasterCat=13&idLang=1.

14. Szabó, S., A. Jäger-Waldau, and L. Szabó, *Risk adjusted financial costs of photovoltaics☆.* Energy Policy, 2010. **38**(7): p. 3807-3819.
15. Maso, P.d., *Serpa Solar Plant*, in *PARTNERING FOR ENERGY AND ENVIRONMENTAL STEWARDSHIP*2007: Peniche, Portugal.
16. Bensebaa, F., *Solar based large scale power plants: what is the best option?* Progress in Photovoltaics: Research and Applications, 2011. **19**(2): p. 240-246.
17. Kaslow, T. and R. Pindyck, *Valuing flexibility in utility planning.* The Electricity Journal, 1994. **7**(2): p. 60-65.
18. Innovations, E., *Energy innovations: a prosperous path to a clean environment.* Washington, D.C., Alliance to Save Energy, American Council for an Energy Efficient Economy, Natural Resources Defense Council, Tellus Institute, Union of Concerned Scientists., 1997.
19. OECD, I., *Energy technology perspectives: Scenarios and strategies to 2050.*, in *International Energy Agency & Organisation for Economic Cooperation and Development.*2006: Paris.
20. Winkler, H., A. Hughes, and M. Haw, *Technology learning for renewable energy: Implications for South Africa's long-term mitigation scenarios.* Energy Policy, 2009. **37**: p. 4987-4996.
21. UNEP, U.N.E.P., *Changing Climates:The Role of Renewable Energy in a Carbon-Constrained World. By Christensen, J., Denton, F., Garg, A., Kamel, S., Pacudan, R., Usher Roskilde, E.*, 2006.
22. Nemet, G.F., *Beyond the learning curve: factors influencing cost reductions in photovoltaics.* Energy Policy, 2006. **34**: p. 3218–3232.
23. Evans, M., N. Hastings, and B. Peacock, *Statistical Distributions, 3rd edition*2000, New York: Wiley.
24. Peng, R., N. Zheng, and H. Chen, *The Calculation of Volatility in Real Option Investment Decision-Making Model Using System Dynamics Models.* International Conference on Management and Service Science (MASS), 2010: p. 1-4.