Real Options applications to assess the impact of public funding on R&D projects from a double perspective: the private company and the funding body

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Doctoral Thesis: *Real Options applications to assess the impact of public funding on R&D projects from a double perspective: the private company and the funding body.*

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To Abengoa Research for allowing me to prove my beliefs.

Preface

This doctoral thesis is born as a response to a challenge posed in my previous company, Abengoa Research, in which I was definitely decided to prove the valuation of Research and Development (R&D) Projects should be assessed with Real Option Valuation (ROV) and not with the well-know and widely spread Net Present Value (NPV).

Before reaching there, I have an Engineering background and experience. However, in 2010 I decided to start a MBA in Copenhagen finding Corporate Finance is my passion. The feel of quantifying money, time and even actions was a complete new area of curiosity and investigation.

After joining Abengoa Research in 2014, I proposed to Manuel Doblaré, CEO of such company, to undertake this doctoral thesis to prove the company we should think out of the box when assessing R&D. It has taken me about three years and a half to do all the investigation, set my new mindset, prepare articles, have enriching discussions with my tutors, many and many hours of English editing and great doses of patience to wait journals' response.

Finally, I am here today to present my doctoral thesis as my last contribution to R&D. I have joined a Yieldco company in which I have extrapolated Corporate Finance and Engineering to a next level.

I would like to thank my tutors their availability and flexibility to change their initial mindset to a new paradigm in the Engineering.

Index

List of tables

List of figures

Acronyms

Concentrated Solar Power	CSP
Discounted Cash Flow	DCF
European Commission	EC
Feed-in Tariff	FiT
International Energy Agency	IEA
Megawatts electric	MWe
National Renewable Energy Laboratory	NREL
Net Present Value	NPV
Photovoltaics	PV
Real Option	RO
Real Option Analysis	ROA
Real Option Valuation	ROV
Renewable Portfolio Standard	RPS
Renewable and Sustainable Energy Reviews	RSER
Research & Development	R&D
Return on investment	ROI
Small and Medium-sized Enterprises	SMEs

Chapter I. Introduction

Technically, the RO method is more appropriate for valuation of R&D projects than DCF, because plans are options, not assets

For many decades, Net Present Value (NPV) has been the main tool used by companies to assess the future economic revenues of projects and their consequently attractiveness. To some extent, this tool made sense as projects seemed to be predictable: for instance, a shoe factory would produce shoes, at a higher or lower yield, with some uncertainty on inputs' price or demand, but the factory itself would be easy to model. If some hypotheses are met, such as the input total cost below or the demand above a certain threshold, the factory would work. No more decisions are relevant and NPV perfectly catches the rationale of the economics underlying this project.

As NPV usage became extensive, it was extrapolated to less predictable project returns in which the economic rationale would not apply. In these cases, an error was introduced into the valuation allowing companies to make not-optimal decisions. One of the most representative cases of this idea are the Research and Development (R&D) projects. Contrary to the shoe factory case, a R&D project presents many options the company can take during the lifetime of the investment. By nature of these R&D projects, the initial investment is decided many years in advance the demand is forecasted or even if the technical success of the project is proven. During the development of the technology or product, additional information is usually gathered from market perspectives and potential future suppliers or customers. However, there is an increasing risk in parallel of another company launching to the market a better technology or product, becoming the initial investment less attractive, useless or even obsolete.

Therefore, R&D projects present the so-called flexibility by which managers (ie. the company) can decide either to continue the investment as planned, to cancel the project, to slow-down the pace of investment to get more information about the market demand or even to speed up the process to reach the market before a competitor does. However, none of these options can be included into a NPV project valuation. Although NPV is beloved by financial executives, it presents the following flaws:

NPV only accounts for market risk (ie. demand) and “simulates” private risk (ie. technical success) by adding subjective probabilities to the different scenarios.

NPV always assumes the same discount rate for all the life of the project; whereas as the investment grows, the technical uncertainty should decrease.

Based on the risk principle, as the downside risk increases, the upside potential also increases. But if the discount rate is increased, the upside potential is ignored even more. This inherent bias may result in rejection of potentially highly successful projects because of their higher uncertainty.

Finally, the additional value created because of contingent actions is not captured.

Then, NPV systematically underestimate the value of R&D projects.

On the other hand, a financial option is the right but not the obligation to trade products at a specific time for a predetermined price. These products are contracts between two parties, typically consumers and sellers. Real Options (RO) is the extension of that financial theory but for real assets assessments. Therefore, a RO can be defined as the right but not the obligation to make an investment decision concerning real assets, for instance defer its development, build a prototype, abandon the project, alter its scale, switch to another technology, etc. These possible actions are known as managerial flexibility, and it enhances the value of the projects.

Despite the previous clearly disadvantages, NPV is still widely spread because is more intuitive and easier to expand. To some extent, RO seem a black box to those executives with lower mathematical background. Nonetheless, after 1994, RO were simplified to reach a wider audience. Actually, the evolution of financial options began in the early 70s due to growing dissatisfaction with discounted cash flow (DCF) methods at the same time significant breakthroughs in options theory were developed by Fisher Black, Myron Scholes and Robert Merton who were the first to price their value. Later on, Cox introduced the pricing formula for binomial trees. Decision trees only capture the substantial value of the option to abandon; however, RO captures the value from the management of market risk (risk that cannot be diversified) who adapt the project to the market circumstances. However, other approaches have been taken for getting the valuation of RO. For instance, Amran and Kulatilaka use partial differential equations to express mathematically the value of an option and its dynamics. Finally, another approach is to simulate the uncertainty with Monte-Carlo. One of the main critics towards RO is their supposed exaggerated value of projects. Although the real problem is that NPV is undervaluing those projects because its ignores the managerial flexibility, which reduce losses and maximize benefits.

In summary, the traditional technique of NPV presents several important limitations to value R&D projects, such as the use of a static risk-adjusted discount rate, the underestimation of the impact of economic uncertainty (Borissiouk & Peli 2001), and the failure to consider the value of the flexibility. In this respect, the Real Option Analysis (ROA) allows us to overcome these limitations, particularly when the uncertainty conditions that characterise the current context are considered (Zhang et al. 2014) because the ROA values the flexibility which implies that managers can readjust their R&D projects in the face of the potential impact of both external and internal factors (Borissiouk & Peli 2001; Santos et al. 2014).

This doctoral thesis deeply explores these considerations and limitations of NPV presenting a R&D project valuation in the specific case of Concentrated Solar Power. By using Real Option Valuation (ROV), two perspectives are provided of: the private company and the public institution.

As regards the private company perspective, the use of renewable energy for electricity generation has been assessed as beneficial throughout the cycle of high and low oil prices (Krozer 2013). According to Krozer, the growing renewable energy use has not increased consumers' electricity prices except in the countries that hardly used it and it had a calming effect on the prices in the countries that are large renewable energy users. Therefore, although uncompetitive during low oil prices, the use of renewable energy is attractive during high fossil fuel prices. An anti-cycling policy that anticipates high fossil fuel prices through enforcement and support of renewable energy during low prices is socially beneficial.

The subsequent issue would be to determine if public R&D financing is complementary to private R&D spending or it becomes a substitute which tends to crowd it out. Currently, there are some policies like feed-in tariff (FiT), renewable portfolio standard (RPS), tax rebates and direct subsidies or grants directly given to companies to promote R&D investment. The use of grants to encourage private R&D financing has been already discussed in previous works (David et al. 2000), with the positive conclusion that it amplifies the effect of private R&D rather than crowding it out (Ali-Yrkkö 2004). Results confirm that the public funding of R&D expenditure through subsidies have a positive impact on the decision to conduct R&D internally (Afcha et al. 2014). Moreover, some results establish that receiving a positive decision to obtain public R&D funds increases privately financed R&D. Ali-Yrkkö (Ali-Yrkkö 2004) suggests that this additionally effect is bigger in large firms rather than in small firms.

Furthermore, some scholars have already investigated the optimality of the modulation of public R&D financing (Marino et al. 2010) to strike a balance between crowding-in effects and crowding-out effects that typically plague public policies. Policy makers are assigned the tasks of the modulation of public intervention. From the point of view of those policy makers, there is literature and work providing tools and evidences to serve the needs of the energy policymaking community (Siddiqui et al. 2007). The perspective of policy makers and funding agencies (Eckhause et al. 2014) has been already taken into account to determine the optimal funding strategy in several R&D areas. However, there is a lack in the literature from the point of view of private companies to determine if a grant will have a positive impact or, on the other hand, could be even not beneficial for the firm.

It seems clear that if a public R&D policy replaces private investment, the policy is not appropriate. On the other hand, as well as there is an upper limit that should not be exceeded by the policy makers, there might be a lower limit that companies should not accept, because in most of the cases these direct subsidies restrict management choices to defer, abandon or modify the scale or technology of the project. Real Options Analysis (ROA) allows an investor to define the optimal time to invest or to estimate the value of project uncertainties, because RO methodology enables to assess management flexibility of a project (Santos et al. 2014). Contrary to the common belief derived from NPV valuation techniques, not all the subsidies are attractive for companies. From the NPV standpoint any additional income (due to grants) is always positive for the project valuation as the drawback imposed by the public institution (always implies a reduction of the managerial flexibility as further explained) cannot be included into the calculation. This first case will explain why companies should require a minimum grant to accept, considering the value lost due to flexibility reduction.

So, by considering the private company perspective, the first goal of this doctoral thesis is to assess the loss of flexibility imposed to management, and therefore the resulting need to determine the lower limit of a grant from which companies should not accept public R&D funds. For this purpose, this study will analyse an investment in a Concentrated Solar Power (CSP) R&D project through the application of NPV traditional method, then the project is valuated with RO methodology, in order to assess the loss of flexibility associated with the fact of accepting a grant.

Specifically, the methodology employed consisted of the use of ROV to asses, at the end of each year, the economic sense it would have to continue with the R&D, to postpone it one year or even to abandon it. Companies have realized that R&D project management differs from traditional projects. The main uncertainty in the latter is the market risk that might affect future cash-in. However, an R&D project is affected not only by market evolution, but also by its technical success and the potential emergence of substitutes during the development of the product. Therefore, R&D requires a specific management framework to handle its risks and decisions to be taken during its lifecycle. In this sense, a new approach was developed to manage R&D projects, known as stage-gate methodology. This framework allows companies not to commit all the resources for a project at the very beginning, but it establishes several gates the project would pass or not depending on the technical success and the market evolution. If a project seems to be viable and the market perspectives are reasonable good, according to stage-gate methodology, the company should release more funds to continue the development. This tool ensures the company does not devote too many resources to a project about to fail or which will not be profitable in the future. Thus, the managerial flexibility is quantified (ie. the difference between the traditional NPV technique and the ROV). Grants not balancing the loss of flexibility are clearly a value destroyer. The specific example of this article presents a new solar tracker in 1998 with a subsidy granted by the European Commission; imposing deadlines to its finalization and not allowing the abandon option. With those limitations, a minimum grant of 17.25% is required, much lower than the 50% provided by the EC for that project. The question here is if the public institution excessively funded the project.

In order to complement the ROV from the private company perspective, this doctoral thesis considers also the public institution perspective. In this sense, private R&D investment in renewable energy technologies is often associated with market failure from the economic perspective (Gillingham & Sweeney 2010). This designation is employed to describe a situation in which there are no conditions to reach an efficient allocation of resources (Stiglitz 1988). Thus, companies that invest in this type of project do not realise the full potential benefits that said projects could generate. Specifically, these projects positively impact society as society benefits from a less polluted environment, for instance. In fact, society demands greater investment by private companies in renewable energy R&D projects that would naturally be carried out by companies under perfect market conditions.

One of the main reasons justifying the use of public funding for private R&D investments is precisely to overcome this market inefficiency in order to reach the socially optimal level of development (Stiglitz 1988). In this way, public funding can help companies to receive some of the potential benefits that are generated by their R&D projects, as well as encouraging R&D projects that, due to their high cost and risk, would not be undertaken by companies despite being socially valuable projects (Hall 2002).

When public funding for private R&D investment is considered, specifically by means of public subsidies, one of the questions that has attracted the attention of researchers regards the effect of these public subsidies on private R&D investment (David et al. 2000; Ali-Yrkkö 2004; Afcha & León López 2014). In particular, the specialized literature has distinguished two types of effect: the crowding-in effect, which implies that public subsidies to R&D projects tend to stimulate private R&D investment and therefore have an additive effect; and the crowding-out effect, which, on the contrary, implies that public subsidies to R&D

investments tend to reduce private investment with the result that public funding would negatively displace private R&D investment.

More specifically, the main drivers for public institutions are the widest promotion of private R&D investments using the lowest public funding. There is a risk, the so-called crowding-out effect, by which above a threshold, more public funding reduces the private investment -ie. the public institution has granted excessively. This section fully explains to public institution how a grant could be equally attractive for companies by reducing the nominal grant but enhancing the flexibility embedded (at no cost for the Institution). As shown by Zúñiga et al. (Zúñiga-Vicente et al. 2014), the empirical evidence of this effect is inconclusive: they found differences that may be due to factors such as the countries and industries considered, or the empirical approach conducted. In their wide literature review, these authors highlight that most studies have not considered the amount of the subsidy granted to the firm in their empirical assessments. Various factors, however, support the existence of a level of inflection in the subsidy amount that reduces private R&D investment (for instance, the rising of specialized workforce costs (Wolff & Reinthaler 2008; Mohnen et al. 2008); the reduction of inflection in the efficiency of these subsidies for larger projects (Aschhoff 2009; Irwin & Klenow 1996; Setter & Tishler 2005; David et al. 2000); or that these projects stop having the desired level of efficiency in relation to the social benefits that justify the existence of these subsidies).

Thus, the second goal of this doctoral thesis is, by considering the public institution perspective, to fill the gap in the existing literature by establishing a reference for policy makers and funding bodies to determine the maximum amount of public subsidies to be given to private R&D investment in order to accelerate companies' R&D activity while reducing the crowding-out effect on private investment. In order to do so, this paper applies the ROA to the case of an R&D project in solar thermal power carried out by a consortium of European companies.

Similar to the analysis carried out from the private company perspective, a Real Options Analysis is performed to determine the value of flexibility such public institutions could provide (such as longer periods). By taking into account this added value, the nominal grant can be reduced and therefore the crowding-out effect risk decreases whereas the public institution has more resources to grant additional projects and companies. Furthermore, the numerical case applied to illustrate this rationale is the same as the case employed in the analysis from the private company perspective; then all the background is shared. However, as in the private company perspective the focus was set on the company and how much should be the minimum grant to accept the project; in the public institution perspective, the focus is switched to the public institution and which alternative it has to promote an equally attractive project but minimizing the risk of crowding-out (ie. decreasing the private R&D investment). The use of the same case for both perspectives is intentional to further enrich the work by providing the two points of view of the same numerical example.

Traditionally, public subsidies to R&D programs, such as the European Commission's Horizon2020 program (EuopeanCommision 2014), restrict the flexibility of companies when deciding whether to continue their project. We did not confirm the anticipated results in this study; the decision to abandon a project, if this were the case, would imply the partial repayment of the public subsidy – if the funding body considers the project has not reached a minimum level - which, in turn, would reduce the probability of being granted future subsidies as a consequence of the reputation loss of the company towards the funding body. Likewise, since the probability of a crowding-out effect can be expected to increase with the subsidy size (Siddiqui et al. 2007), other things being equal, the proposal of this paper also contributes to reducing the probability of said effect because it justifies the reduction of the public subsidy to private R&D investment. Hence in restructuring classical grant schemes by giving firms options, these companies could decide to undertake projects a few years earlier and accept lower levels of grant funding. Thus, a more flexible scheme could reduce the crowding-out effect, deferring the inflection point where grants are less efficient for attracting private investors.

Therefore, the main contributions of this doctoral thesis are, firstly, to assess the loss of flexibility imposed to management, and therefore the resulting need to determine the lower limit of a grant from which companies should not accept public R&D funds. Previous studies about R&D projects in renewable energy valuation have not considered the loss of flexibility imposed by grants (Santos et al. 2014; Martínez-Ceseña et al. 2013; Tsui 2005; Hodota 2006; Trang et al. 2002). In this respect, this doctoral thesis contributes to strength the RO framework to assess energy R&D projects and so, allowing investors to be more conscious about costs involved in government grants. Also, ROA has been used to policy evaluation (Siddiqui et al. 2007; Yu et al. 2006; Boomsma et al. 2012; Lee et al 2011; Lin et al. 2013; Reuter et al. 2012; Monjas-Barroso et al. 2013; Zhang et al. 2014). In this sense, policy makers will have a new point of view when defining public R&D: the jeopardy of managerial flexibility. A very restrictive grant policy would negative impact in the development of projects whereas allowing some actions to the companies would increase the projects' value without representing an extra cost to governments.

Secondly, this doctoral thesis contributes to fill the gap in the existing literature by establishing a reference for policy makers and funding bodies to determine the maximum amount from public subsidies to be given to private R&D investment in order to accelerate companies' R&D activity while reducing the crowding-out effect on private investment. In particular, this doctoral thesis contributes to the specialized literature by proposing an assessment system based on ROA that justifies the reduction of the amount of public subsidies for private R&D investment by showing that companies could prefer a lower public subsidy for their R&D investment, but that the public subsidy allows them greater flexibility by permitting options such as abandoning or deferring the R&D project.

The reminder of this doctoral thesis is structured as follows. The second chapter presents, on the one hand, a review of the literature regarding RO and specifically applied to R&D projects and, on the other hand, and in a complementary way, a review of literature related to the main factors that can impact the relationship between public subsidies to R&D and private R&D investment, as well as the specific influence of the subsidy size on the R&D activity of private companies. The third chapter describes the methodology employed in this work in order to reach our two goals, whereas the fourth and fifth chapters present, respectively, the results of the empirical studies carried out, as well as the discussion of the results. Finally, the sixth chapter presents the main conclusions of this doctoral thesis, indicating limitations to the current research and further research to this work.

Chapter II. Theoretical framework

This chapter presents the theoretical framework of this doctoral thesis. Firstly, a review of literature regarding RO is presented, by considering in particular the evolution of the RO theory, its application to R&D projects, and its consideration for the policy evaluation of renewable energy projects. Secondly, the previous literature review is complemented with the rationale for R&D grants, by considering specifically the reasons to subsidize R&D projects, the main factors that can impact the relationship between public subsidies to R&D and private R&D investment, as well as the main effects on companies.

2.1. RO Theory

A financial option is the right but not the obligation to trade products at a specific time for a predetermined price (Ross 2003). These products are contracts between two parties, typically consumers and sellers. RO is the extension of that financial theory but for real assets assessments. Therefore, a RO can be defined as the right but not the obligation to make an investment decision concerning real assets (Menegaki 2008), for instance defer its development, build a prototype, abandon the project, alter its scale, switch to another technology, etc (Martínez-Ceseña et al. 2011). These possible actions are known as managerial flexibility, and it enhances the value of the projects. There are two options studied in this paper: one is the defer option, giving the manager the ability to wait for investing the money. The value of this time of waiting comes as a result of the more information about the investment obtained or the resolution of an uncertainty (such a new law or regulation in process) (Dixit et al. 1994). The second one is the abandon option, which reflects in a more realistic manner the reality of the project; if the evolution of the market or the technical success is not as expected, the company can stop investing in a non-profitable project.

In other words, RO account for management flexibility which delivers a significant value contribution in the presence of uncertainty. Technically, the RO method is more appropriate for valuation of R&D projects than DCF, because plans are options, not assets. For a real option, the underlying security is the present value of the business plan (Boer 2004). Special features of energy R&D projects suggest ROA to be more suitable than traditional methods like NPV to assess their economic valuation, as shown by Santos et al. (Santos et al. 2014).In most cases, energy R&D projects are irreversible because associated investments are partially or completely irreversible. Therefore, the assets of these projects cannot be used in other activities or different companies. Besides that, there is a high level of commercial uncertainty, especially in the liberalized electricity market (Kumbaroğlu et al. 2008). Moreover, investment can occur in a flexible time. Finally, by designing the project, investors have several generation technologies that are associated with different uncertainty levels. Therefore, ROA has been recommended to be more appropriate than traditional NPV for judging R&D projects (Hartmann et al. 2006).

Myers (Myers 1977) was the first who recognized the analogy between financial options and real world investments, being the one who coined the expression "real option", based on the resemblance between R&D investments can be valued similar to financial options. Mapping an investment opportunity onto a call option (Olilla 2000) implies the stock price would be equal to the present value of the project's operating assets to be acquired (or developed); the exercise price is the expenditure required (or the R&D investment), the time to expiration would be the length of time the decision may be deferred, the risk-free rate of return equals the time value of money and finally the variance of returns on stock, the riskiness of the projects assets.

The evolution of financial options began in the early 70s due to growing dissatisfaction with DCF methods at the same time significant breakthroughs in options theory were developed by Fisher Black, Myron Scholes (Black et al. 1973) and Robert Merton (Merton 1973) who were the first to price their value. Later on, Cox introduced the pricing formula for binomial trees (Cox et al. 1979). Decision trees only capture the substantial value of the option to abandon; however, RO captures the value from the management of market risk (risk that cannot be diversified) who adapt the project to the market circumstances. However, other approaches have been taken for getting the valuation of RO. For instance, Amran and Kulatilaka (Amram et al. 1999) use partial differential equations to express mathematically the value of an option and its dynamics (Fernandez et al. 2011). Finally, another approach is to simulate the uncertainty with Monte-Carlo.

2.2. Application of RO to R&D projects

The problem with DCF is the mind-set that has developed around it. For example, the Japanese approach to R&D valuation is not consistent with DCF thinking, because growth and market are more important than return on investment (ROI) (Faulkner 1996). Despite of that, DCF is still commonly used in R&D valuation. However, there are several cases in literature in which RO are applied to R&D projects. For instance, Tsui (Tsui 2005) applies the RO theory to fuel cell vehicles, Hodota (Hodota 2006) to an intelligent transportation system, and Trang (Trang et al. 2002) to the pharmaceutical industry. All of them valuate the project with DCF that implies no flexibility. Over that value, normally a decision tree is considered, increasing the value due to the abandon option. Finally, RO provide the higher value because it accounts for all the potential flexibility related to the project.

In the field of renewable energies, Venetsanos et al. (Venetsanos et al. 2002) proposed a framework for the appraisal of power projects under uncertainty within a competitive market environment. This framework includes these stages: uncertainty and resource attributes, RO identification of the project and evaluation of the project value. Using a Black-Scholes model, ROA provided a positive option value of a wind project and DCF gave a negative value. Amran and Kulatilaka (Amram et al. 1999) define a methodology to value RO based on four steps: (i) frame the application by identifying the possible decisions that could be taken and when they might be made; (ii) implementation of the option valuation model (in this paper, a binomial lattice is approached); (iii) review the results and compare them against other methods (in this case, against NPV); and (iv) redesign the option model valuation to produce better results. In this work, a recommendation to policy makers is done.

ROA has been used to evaluate renewable energy technologies in the face of uncertain fossil fuels (Davis et al. 2003). In fact, most of recent papers have considered these external uncertainties (market price of fuel or electricity), because it is the easiest type of uncertainty to handle in RO models, with the added advantage of not having interactions with the performance of the project. However, renewable energy projects have at least one internal uncertainty: wind speed, water flows, solar radiation, new equipment efficiency, etc. (Martínez-Ceseña et al. 2013). Specially, RO research about wind or photovoltaic projects is beginning to address these internal uncertainties (Fleten et al. 2004; Sarkis et al. 2008; Ashuri et al. 2011). So, for instance, in hydropower projects the most frequent uncertainty is the water flow (Hedman et al. 2006; Zhang et al. 2005; Kjærland 2010).

Santos et al. (Santos et al. 2014) applies RO to a mini-hydro power plant and Martínez and Mutale (Martínez-Ceseña et al. 2011) describe the case of a hydropower plant comparing between three different valuation methods: the first is using DCF; secondly what the authors call typical RO (including only the option to deferral the project); and finally the advanced RO in which also the time and design of the project are options. In absence of all flexibility, RO behaves as DCF; but if there is some flexibility, RO would increase the project's value. Therefore, the minimum value in RO equals the optimal DCF.

Siddiqui and Fleten (Siddiqui et al. 2010) analyse how a firm may proceed with staged commercialization and deployment of alternative energy technologies. It is remarkable the work carried out by Karamitsos (Karamitsos 2009) because the company perspective is considered, not in terms of analysing grants but on comparing methodologies to evaluate R&D projects in the power sector.

2.3. RO in policy evaluation of renewable energy projects

Unlike fossil energy that is consolidated in the current environment, renewable energy is in an important stage of its development and it needs the support of policy. Environmental policies are associated to uncertainties such as carbon, fuel or electricity prices or natural resources. For this reason, RO is an effective tool to evaluate energy projects. Thus, the RO theory has been used by some authors to analyze the policy evaluation of renewable energy in several countries.

In this research line, Kumbaroglu et al. (Kumbaroğlu et al. 2008) designed a model to guide policy planning in relation to renewable energy projects in Turkey and concluded that the diffusion of renewable energy technologies occurs only if there are targeted policies. Lee and Shih (Lee et al. 2010) applied RO into renewable power generation in Taiwan, and they proposed a model that is useful to quantify the policy value on different renewable energy development policy. Also, in the case of Taiwan and for wind energy technologies, Lee and Shih (Lee et al. 2011) constructed a model based on the binomial RO method that helps reduce policy implementation costs and facilitate an estimation of benefits brought by specific policies. For the cases of wind power and pumped storage in Germany and Norway, Reuter et al. (Reuter et al. 2012) employed a RO model to investigate the specific characteristics of renewable technologies and their associated uncertainties by taking into account market effects of investment decisions. Monjas and Balibrea (Monjas-Barroso et al. 2013) conducted a comparative study on an investment project on renewable energy in Denmark, Finland and Portugal, based on RO. This study assessed how the ROs affect the expanded net present value of the project and also evaluated the public incentives in these countries for wind energy. Lin and Wesseh (Lin et al. 2013) studied the feed-in tariff for solar power generation via RO in China. An important conclusion of this study is that solar energy technologies in China have a significant amount of value that cannot be detected when the hidden costs of non-renewable energy are not reflected through prices. Boomsma et al. (Boomsma et al. 2012) analyzed both feed-in tariff and renewable energy certificate trading under a RO approach in a case study based on wind power in Norway. So, while feed-in tariff encourages earlier investment, renewable energy certificate trading creates incentives for larger projects when the investment has been undertaken. Yu et al. (Yu et al. 2006) evaluated the use of feed-in tariff in the wind energy sector in the Spanish market. By using a RO analysis, these authors conclude that both the values and operation risk of wind generation assets are changed by the switchable tariff. Recently, Zhang et al. (Zhang et al. 2014) have proposed a RO model to evaluate the unit decision value and save-path rate for renewable energy development and they applied this model to the case of the solar photovoltaic power generation in China.

The studies above mentioned have contributed to the specialized literature about the use of RO in policy evaluation of renewable energy projects. In this research line, our study aims to do a contribution to this literature by considering the cost for companies as a consequence of the loss of flexibility that is due to the grant of a subsidy to develop an R&D project. An example relative to a renewable energy technology is presented, using for its analysis the RO theory. In this sense, the cost of this loss of flexibility should be considered both by companies when they develop an investment project and by policy makers when they design a subsidy policy for renewable energy projects.

2.4. Rationale for R&D grants: motivation, limitations and effect on companies

This section describes the main goals sought by Governments and public bodies when subsidising private R&D investment. Furthermore, a set of limitations to this process is described.

2.4.1. Reasons to subsidise R&D investments

There are several justifications for the subsidisation of R&D investment, first and foremost being the uncertainty surrounding the technical and economic success of an R&D project and its potential benefits (Dasgupta & Maskin 1987). In fact, government R&D expenditures are funded through public agencies because it may generate social benefits beyond the direct provision of government services. A further objective is pursued with this spending: generating social benefits in the form of knowledge and "training" spillovers (David et al. 2000). Second, a company will never be able to appropriate all returns of a successful R&D project because the developed knowledge can quickly and easily diffuse into the public domain (Arrow 1962). These are positive externalities to society that are not remunerated to firms. Third, firms take the risk that the knowledge created in their R&D programme will be available to other companies (free riders), taking advantage of the progress of R&D programmes from competitors (Arrow 1962). Fourth, external funding for R&D projects is relatively scarce. Managers are reluctant to reveal all the features of company projects to external parties, including investors, due to the strategic nature of R&D activities and to avoid disclosing critical information to competitors (Ughetto 2008). Investors are discouraged from supporting R&D projects because they face problems of information asymmetry, such as adverse selection and moral hazard (Stiglitz & Weiss 1981). R&D investments are more risky and their assessment is less reliable for external parties (Czarnitzki et al. 2011). In subsidising R&D projects, both firms and investors are compensated for several reasons: the uncertainty of the project, the spillover benefits R&D expenditures provide to society, and the increased risk and reduced cost of capital. Therefore, because subsidies are a necessary tool for the development of knowledge in society, this paper contributes to optimising how they are awarded.

2.4.2. Limiting factors

The main factors regarding the equilibrium between public R&D subsidies and private R&D investment are reviewed below. Probably the most important issue, one which also deeply affects this work, is the effect of the size of the grant given to firms and its effects on firms' R&D activity.

2.4.2.1. The equilibrium between public R&D subsidies and private R&D investment

The results of studies on the relationship between public R&D subsidies and private R&D investment are highly heterogeneous due to, among other reasons, the differences between each analysed industrial sector, the country to which the firms belong, and the methodology employed (Zúñiga-Vicente et al. 2014). In the specialised literature, it is nevertheless possible to distinguish some factors that have been frequently considered, such asthe size of the firm, the economic context, the type of incentive, and the recurrence in the public funding. As it is most likely the most important issue, the size of the grant will be discussed separately in following subsections.

2.4.2.2. Size of the firm

As regards the size of the firm, Busom (Busom ∗ 2000) found in a sample of Spanish companies that smaller firms are more likely to apply for and be granted a subsidy. This is probably aligned with the public agency's goals, which may be to incentivise R&D investment in small and medium enterprises (SMEs). In the same sense, in another study on Spanish firms, González & Pazó (González & Pazó 2008) concluded that subsidies have a greater effect on inducing new R&D activities in smaller firms. Meanwhile, Ali-Yrkkö (Ali-Yrkkö 2004) concluded that receiving a positive decision to obtain public R&D funds increases privately financed R&D and that this effect is also bigger in large firms than in small firms, although the results of Lööf & Heshmati (Lööf & Heshmati 2005) show that there are additive effects of public R&D financing on private research expenditures only for small firms. Duguet (Duguet 2003) considered a sample of French firms and found that the probability of being awarded a subsidy increases with the debt ratio and the importance of privately funded R&D, as well as with the size of firms. Görg & Strobl (Görg & Strobl 2007) conducted their study on Irish firms and concluded that for small domestic plants, grants serve to increase private R&D spending. In their study of a sample of Turkish firms, ÖzceliK & Taymaz (Özçelik & Taymaz 2008) found that smaller R&D players benefit more from R&D support and therefore with better performance research, which suggests again that public R&D support is likely to play a more important role in stimulating private R&D in small firms. Moreover, regarding Belgian firms, Meuleman & De Maeseneire (Meuleman & De Maeseneire 2012) found that obtaining an R&D subsidy provides a positive signal about the quality of small and medium-sized enterprises and results in better access to long-term debt. They further found that investors and banks may require firms to obtain an R&D subsidy as a condition for receiving funds.

2.4.2.3. Economic context

In relation to small and medium-sized enterprises but also considering the influence of the economic context in their study, Hud & Hussinger (Hud & Hussinger 2015) analysed the impact of public R&D subsidies on the R&D investment of German companies during the latest economic crisis. They found an overall positive effect of R&D subsidies on R&D investment attitude from companies, although there is evidence of a crowding-out effect during the 2009 crisis. Furthermore, when the German economy started to recover in 2010, the subsidy effect was smaller than in the pre-crisis years. Wiser & Pickle (Wiser & Pickle 1998) also considered the influence of the economic and political context in which companies develop the power plant financing process for renewable energy projects. They conducted five case studies showing policies that do not provide long-term stability or that have negative secondary impacts on investment decisions will increase financing costs and therefore could dramatically reduce policy effectiveness. This work specifically highlights that the importance of policy stability to renewable energy developers and financial investors should not be underestimated. In fact, changes in renewable energy subsidies have tended to be abrupt and therefore disruptive to developers and investors.

2.4.2.4. Type of incentive

The effect of the type of incentive on the relationship between public R&D subsidies and private R&D investment has also been considered by specialised literature. In this vein, Guellec & Potterie (Guellec 1997) analysed whether tax incentives and direct subsidies stimulate business-funded R&D in 17 OECD countries. They found that although tax incentives and direct subsidies stimulate private R&D investments in the short run, direct subsidies are more effective than tax incentives in the long term. In a later study also considering figures from 17 OECD countries, Guellec & Potterie (Guellec & Van Pottelsberghe De La Potterie 2003) concluded that both direct government funding of R&D performed by firms and R&D tax incentives have a positive effect on business financed R&D and that they are more effective when they are stable over time. Another important conclusion of Guellec & Potterie (Guellec & Van Pottelsberghe De La Potterie 2003) was that direct government funding and R&D tax incentives are substitutes. Thus, the increased intensity of one reduces the effect of the other on private R&D. More recently, Abolhosseini & Heshmati (Abolhosseini & Heshmati 2014) compared feed-in-tariffs, tax incentives and tradable green certificates as the main mechanisms used by governments to finance renewable energy development programmes. They concluded that tax credits constitute an attractive mechanism for private investors because they directly increase investor liquidity. On the other hand, while feed-in-tariffs are a suitable mechanism as a policy to develop renewable energy sources when low investor risk is preferred, tradable green certificates constitute the most appropriate policy when the government applies a market view policy.

2.4.2.5. Recurrence in public funding

Regarding the recurrence of being granted public funding, the literature indicates that a firm whose R&D activity was subsidised in the past is more likely to be subsidised again (González & Pazó 2008). Nevertheless, Zúñiga et al. (Zúñiga-Vicente et al. 2014) noted that there are different reasons supporting alternative assumptions about the effect of public subsidies on private R&D investment. For example, because firms that are granted public subsidies for their R&D are more likely to benefit from grants that reduce their own risk and cost of financing R&D projects, the odds of a crowding-out effect for frequent recipients of R&D subsidies are increased (Lööf & Heshmati 2005). Alternatively, it can be argued that because firms that have received a subsidy for a R&D project may subsequently apply for new subsidies to keep financing the same project, it can be expected that public R&D subsidies have a crowding-in effect on these firms' R&D investments (Duguet 2003).

2.4.2.6. Size of the subsidy granted to firms

One of the most debated issues has been the effect of the grant size on the crowding-in and crowding-out effects; in other words, does increasing the amount of the subsidy also increase private spending invested in R&D projects, or conversely, does it lead to decreasing R&D expenditures by firms? Several arguments have been provided by the literature in order to explain why R&D subsidies can lead to the displacement of private R&D.

There are contrary reasons for supporting "the more the better", resulting in the crowding-out effect of private funding. This means public funding may result in an undesirable replacement effect of the private investment. The main factor hindering R&D activities is the lack of qualified personnel (Mohnen et al. 2008). An inefficiency, as a result of R&D activities supported by public grants, is the higher demand for R&D personnel, increasing their wages (Wolff & Reinthaler 2008). R&D subsidies can easily translate into researcher wage increases (Goolsbee 1998).

The size of projects can be another variable to be considered as a cause of displacement of private R&D investment (Aschhoff 2009). First, stimulation effects are more likely for large projects than for small ones. Thus, small projects have a higher tendency to lead to a crowding-out effect than larger projects. Second, a firm's R&D capacity cannot be extended at will in the short-run even if the firm is awarded public support for a project. Firms cannot be willing to make excessive long term employment commitments. If larger projects are subsidised and considering a restricted R&D employment market, firms undertake the large projects, reallocating funds and employers from other projects to the subsidised project and abandoning those previous projects. This would result in a reduction of private R&D investment. Other dangers of excessive grants are financing duplicate R&D and redirecting financing towards more risky (Irwin & Klenow 1996) and thus less successful projects (Setter & Tishler 2005). Moreover, government incentives can lead to the creation of expensive R&D facilities (David et al. 2000), but firms equipped with this R&D infrastructures may continue to apply for new subsidised R&D projects in order to cover these fixed costs, without regard for improved economic performance and the advancement of knowledge. The project could be concluded without social benefits and the firm would not profit beyond the coverage of its fixed costs. These firms with more experience and better equipment for R&D could prevent other companies with better projects from being awarded R&D subsidies.

2.4.3. Effect on companies

As Aschoff (Aschhoff 2009) proposes, there are different effects of grants on a firm's R&D expenditures: a full crowding-out effect, if R&D subsidies substitute company expenditures; partial crowding-out, if the firm's expenditures in R&D would decrease in the situation of public funding; no effect of subsidies on a firm's own R&D; and an additional effect, if the firm increases privately financed R&D spending when subsidies are received.

The literature shows ambiguous results regarding these findings. A full crowding-out effect has been rejected by (Aerts et al. 2006; Clausen 2007; Ali-Yrkkö 2004; Kaiser 2006; Heijs & Herrera 2004; Görg & Strobl 2007), whereas Lach (Lach 2002) found a partial replacement of private R&D expenditures with public funding. Streicher et al. (Streicher et al. 2004) found that private funding increases when R&D projects are subsidised by public grants. Aerts (Aerts 2008) asserted these mixed results are due to the heterogeneity of samples belonging to different countries and industrial sectors.

Görg and Strobl (Görg & Strobl 2007) found additional effects of small grants, rejecting the crowding-out of medium grants. Aschhoff (Aschhoff 2009) also showed that grants should have a minimum size to cause an impact on a firm's privately financed R&D and that medium- and large-scale grants increase firms' R&D spending depending on the size of the project.

Larger projects are more dependent on public funding. Guellec and Pottelsberghe (Guellec & Van Pottelsberghe De La Potterie 2003) found an inverted U-shaped curve in the relationship between public subsidies and private expenditures in R&D funding. The subsidy effect is positive but marginally decreasing up to a certain threshold, beyond which the effect becomes negative. This confirms a crowding-in effect of moderate grants and a crowding-out effect for subsidies beyond a certain level (Zúñiga-Vicente et al. 2014).

Chapter III. Methodology

This section of the doctoral thesis explains the methodology utilized to determine the value of the flexibility for both the companies and the public institutions for specific R&D projects.

3.1. Factors considered in R&D project valuation & Stage-gate framework

Companies have realized that R&D project management differs from traditional projects. The main uncertainty in the latter is the market risk that might affect future cash-in. However, an R&D project is affected not only by market evolution, but also by its technical success and the potential emergence of substitutes during the development of the product. Therefore, R&D requires a specific management framework to handle its risks and decisions to be taken during its lifecycle. In this sense, a new approach was developed to manage R&D projects, known as stage-gate methodology (Cooper et al. 2018). R&D projects, in contrast with traditional large projects, differ mainly in the high uncertainty related to the investment, not only due to the uncertainty of the market demand for the product being developed but also to the probability of technical success. Therefore, companies must adapt their investment in order not to commit excessive resources to a potential failure. Cooper (Cooper et al. 2018) proposed a scheme by which each phase of the R&D project – namely the initial design, advanced design, first prototype, scale-up, and commercial - is given a specific budget and deadline. By doing so, the project is forced through a review process before beginning a new phase. These periodic revisions allow the managers to pause the development, cancel (kill) the project if the expectations are not promising, or the reverse, boost investment to reach the goals earlier than originally planned. These options on the part of managers are essential to the point of this article.

First, the mere option of companies to abandon the project adds value to the R&D investment because not all the resources must be committed at the outset.

This may seem obvious; however, using traditional DCF techniques, this possibility is not modelled.

Second, the company has the option to defer (pause) the project for a few years to gain information about the market or the technology. This delay also has value because if the new market expectations are more promising, the company can continue the R&D project while retaining the possibility to abandon it in the future. Again, traditional DCF cannot include this deferment action in the model.

Third, if the technical success seems to be even better than initially planned or the market demand is greater, the company can allocate more resources to finish the R&D project earlier and therefore arrive sooner to the market. As DCF does not model any change during simulations, this possibility is again neglected.

This framework allows companies not to commit all the resources for a project at the very beginning, but it establishes several gates the project would pass or not depending on the technical success and the market evolution. If a project seems to be viable and the market perspectives are reasonable good, according to stage-gate methodology, the company should release more funds to continue the development. This tool ensures the company does not devote too many resources to a project about to fail or which will not be profitable in the future. As mention above, lying behind a stage-gate decision, there are at least two RO. One of them is the option to abandon the project (at each gate) and the second would be the decision to defer the project. For instance, it could be a defer decision based on the current market estimations, or due to a certain regulation under discussion. The project could be delayed one year and re-evaluated to decide then either to continue or not with more information available.

To evaluate an R&D project using NPV, the first step is to estimate the total market for the technology and the correspondent market share. This market share would be translated into a cash-in per year during the commercialization phase. Prior to that, an R&D investment phase is necessary in which there is cash-out from the company. Using discounted cash flow, the future cash-in would be discounted together with the cash-out. If the NPV is above cero, the project would be undertaken. The main issue applying DCF is to determine the discount rate, which is related to the cost of capital of the company, representing its opportunity cost.

The second uncertainty would be the technical success of the R&D phase (Siddiqui et al. 2007), in which NPV "simulates" private risk by adding subjective probabilities. Using Monte-Carlo simulation, a probability distribution of the NPV can be obtained, depending on the market and technical variables and probabilities associated to each iteration.

In the analysis of R&D projects using DCF, the effect of grants is always beneficial. Grants will reduce the R&D investment phase; therefore the NPV will increase no matter the conditions imposed to the project by the funding agency, because DCF cannot handle them and they are not included in the numerical analysis.

3.2. Common R&D incentives in Spain and Europe

There are plenty of incentives for R&D projects, as explained in the literature review of section 2. The subsidies most frequently used in Spain and given by the European Commission are direct funds to undertake an R&D project. Tax incentives are more oriented to past R&D activities or the commercial exploitation of results rather than to initiate new projects.

Depending on the technical maturity of the technology, being the distinction between Research and Development, and the type of the beneficiary of the incentive (privately or publicly held, small, medium or large company), there is a range of incentives between 25% and 100%. For mature projects, Spanish funding starts at 25% for large companies. This funding rate increases up to 100% for Research projects and/or R&D centres.

In addition to the financial help, there is a drawback for companies accepting these incentives, namely, the lack of flexibility. Accepting one of these grants imposes a deadline to finish the project based on a project chart and the minimum execution of budgeted costs. The three options explained above contrast somewhat with the traditional way of valuing incentives. These drawbacks are completely ignored by DCF because this model would not include the lack of flexibility imposed nor the potential advantage of developing a technology or product earlier or faster.

Using the RO framework, a more suitable tool for valuing these options will be taken into account and a recommendation for funding bodies will therefore be proposed.

3.3. Qualitative effect of grants in terms of managerial flexibility

Real option theory is well known for enhancing the value of projects under uncertainty (Martínez-Ceseña et al. 2013). In R&D projects this managerial flexibility would be only considered if managers are willing to exercise the options. This might not be always the case if managers cannot or are reluctant to apply all the options, for instance they could be not willing to abandon their project. In those cases the use of RO is useless because it provides a value considering a managerial flexibility that is not real.

As stated before, stage-gate is a well-known methodology to manage R&D projects in which there are at least two RO embedded: the option to abandon the project at each gate and the option to defer the investment. Scholars have deeply analysed how to apply RO to a project model to include the managerial flexibility. Particularly, Fernandes et al. (Fernandez et al. 2011) analyse the ability to delay an investment, in order to obtain more information and thus reducing uncertainty.

However, it is at this point where a grant imposes some restrictions to the project. A company receiving public R&D funds limits its managerial flexibility. To keep the analysis numerically tractable and for clarity purposes, we will assume a company applying the stage-gate methodology to its R&D projects; simplified to two RO (abandon and defer). The concession of a grant limits both RO:

- Abandon option: this option will not be possible any longer. Otherwise, the company should have to refund the grant back to the funding agency.

- Defer option: a priori, a company could defer the development of the R&D project as much as considered –without taking into account competitors' reactions. However, a grant imposes a deadline to the project.

3.4. Case approach

The structure of the case would be firstly to determine the value of the project using NPV. Afterwards, the beneficial financial effect of grants is considered, thus reducing R&D investment and therefore increasing NPV. Thirdly, a RO model is applied to evaluate the project with two sources of flexibility: abandon and defer. Finally, the value of the two options limited by the grant will be calculated. Therefore, a contrast between the financial benefit from the grant and the limit in the managerial flexibility provides the minimum grant acceptable by the company. To avoid excessive noise in the model, an old project has been chosen so that there is no uncertainty in the market demand. DCF is applied to the R&D investment costs, the accepted grant, and the commercial revenues; the NPV is straightforward. One of the ideas in this doctoral thesis, however, is to accelerate the start of the project by two years, although the commercial revenues start flowing in the same year. In this case, a larger grant would be required.

By using real options valuation (ROV), the existing flexibility embedded in the project is evaluated, determining the equivalent grant. Different modifications of the case will be presented, all of them calculated using ROV to include the managerial flexibility.

NPV analysis presents limitations with regard to the assessment of R&D projects. Specifically, according to Borissiouk and Peli (Borissiouk et al. 2001), two important limitations of this method are that firstly it uses a discount rate that is constant, although different rates should be used at each R&D stage due to the changes in future uncertainty; and secondly, NPV tends to underestimate the potential value of projects because it ignores the impact of economic uncertainty. Specifically, Borissiouk and Peli (Borissiouk et al. 2001) argue that the value of managerial flexibility to adjust the development process (of a technology, in our case) to the uncertainty is disregarded (Trigeorgis 1996). Similarly, Martín-Barrera et al. (Martín-Barrera et al. 2016) highlight that NPV underestimates the value of R&D projects because, although flexibility adds value to R&D projects, this method fails to adequately reflect the flexibility of decision-making.

Managerial flexibility is particularly necessary for the assessment R&D projects because their development takes place over decades and their return is not generally achieved in the short-term(Lee & Shih 2010). Their profits are collected in future investment opportunities following a successful R&D project (Myers 1977). With specific regard to Renewable Energy projects, the assessment using NPV is not suitable due to the fact that such projects are subject to the high volatility of energy markets during their prolonged development (Myers 1977; Lee et al. 2010; Duffie et al. 1999). In this regard, a full review of traditional methods used in energy markets, besides NPV, that are suitable for assessing energy projects can be found in Santos et al. (Santos et al. 2014): internal rate of return, return on investment, payback period, benefit-cost ratio and levelised cost. These traditional methods consider risk but, ignoring management opportunities arising in the duration of project, they do not take into account the possibilities for reducing risk with the management of investments.

For the purposes of simplicity, only two options are considered from the company's perspective: defer and abandon. For the funding body, it will be interesting to analyse the effect on companies undertaking the R&D project earlier. This may lead to the company obtaining commercial revenues and the country benefitting from technological development sooner.

3.4.1. NPV calculation

The choice of an old R&D project has been intentional to avoid simulations on market and market share evolutions. The commercial revenue of the project can be calculated with certainty because the market share is already know, as well as costs and benefits of the R&D project.

Using a DCF method with the commercial revenues and the R&D costs, the NPV is straightforward. The only parameter to define is the discount rate. This will be explained in the numerical case.

3.4.2. Effect of grants in NPV

The previous NPV will be enhanced once the grant is considered. The effect of the grant is translated into revenues during the R&D investment phase. This means, the total cash flow on the project improves because there will be more cash-in.

3.4.3. RO model

Next step is to quantitatively asses how much value do the abandon and the defer options add to the project. A binomial lattice approach is followed (Kodukula et al. 2006).

Once the managerial flexibility has been quantified, the limit imposed by the funding agency is calculated and contrasted with the financial benefit from previous section. The result will be the minimum grant that equals the value lost by the limitation of managerial flexibility.

Chapter IV. First case: The Private Company

The first case of this doctoral thesis is to present the point of view of the private company. The following numerical case will explore the minimum grant threshold a private company should require in order to accept such grant. Contrarily to the wrong conclusion of NPV by which all the grants are positive for the company; this section calculates the value of flexibility of a R&D project lost due to the grant; and therefore the minimum grant to compensate such loss of value.

4.1. Project description

In the renewable energy sector, the solar power is increasingly important. The International Energy Agency (IEA) forecasts more than 400 GW of electrical capacity installed in year 2035 (IEA 2008) even in its most pessimistic scenario. Within solar technology, there are two main alternatives: photovoltaic (PV) and concentrated solar power (CSP). The latter is relatively new and it is gaining market share. According to the IEA, it will double its capacity by 2030.

CSP uses mirrors or lenses to concentrate a large area of sunlight onto a small area. Electrical power is produced when the concentrated light is converted to heat which usually drives a steam turbine connected to an electrical power generator. There are two main technologies within CSP: towers and troughs. Tower uses trackers that follow the sun and concentrate into a solar receiver in the top of the tower. Trough (or parabolic trough) consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line (European Solar Thermal Electricity Association 2014).

The R&D project to be analysed in this paper fits in the trough category, particularly to develop a new trough, longer than the previously used at that time being 150 meters long instead of the 100 m length used by its competitors. Besides economies of scale, this new tracker had the advantage of being lighter due to a new design, reduction of operation and maintenance costs due to easier mirror cleaning, less complex realignment requirements, and fewer components. The project name was 'Eurotrough' and it was made by a consortium of companies in the late 90s (Ciemat et al. 2014).

The project received two grants from the European Commission (EC) under two different contracts covering sequential stages of the development. Table 1 summarizes the total declared costs and public R&D funds from the European Union (EU contribution) per contract.

Table 1: Eurotrough I & II start and end dates, declared costs and EU contribution

	Start date	End date	Total declared costs	EU Contribution
Eurotrough I	1-Ago-98	31-Jan-01	2.402.514 €	1.199.899 €
Eurotrough II	1-Oct-00	31-Dec-02	1.993.707 €	996.851 €

Even though CSP plants are complex, large installations with hundreds of design parameters (European Solar Thermal Electricity Association 2014), there are two particularly important that roughly determine the size and cost: electrical capacity which defines the size of the steam turbine; and the storage capacity expressed as how many hours the plant is able to work at full load with no sun. There is a positive correlation between those two with the size and therefore the cost of the plant. The larger the plant is, the more number of solar reflectors are required and therefore the improvement per tracker, due to having more efficient troughs, will be more substantial. There is a limit in this correlation whereas adding more trackers do not improve the profitability of the plant.

4.2. Parameter estimation

The first step is to calculate the improvement the new trough brings over the previous one. To do so, a tool, called System Advisor Model, designed by the National Renewable Energy Laboratory (NREL) from United States is run (NREL 2014). This tool enables to simulate the behaviour of all type of CSP plant in any location worldwide, defining its main parameters such as electrical capacity, storage size and, among others, model of trough. The output is the NPV of the designed plant.

Simulations[1] were run with the trough previous to the R&D project (LS-3) and with the developed one (ET150). For both troughs, 10 locations were simulated[2] with different storage hours[3] covering all the normal ranges of design. Therefore, for each number of storage hours, the average (of the 10 locations) of the difference in both troughs' NPV was calculated, with the results provided in figure 1. The figure is normalized per unit of installed MW.

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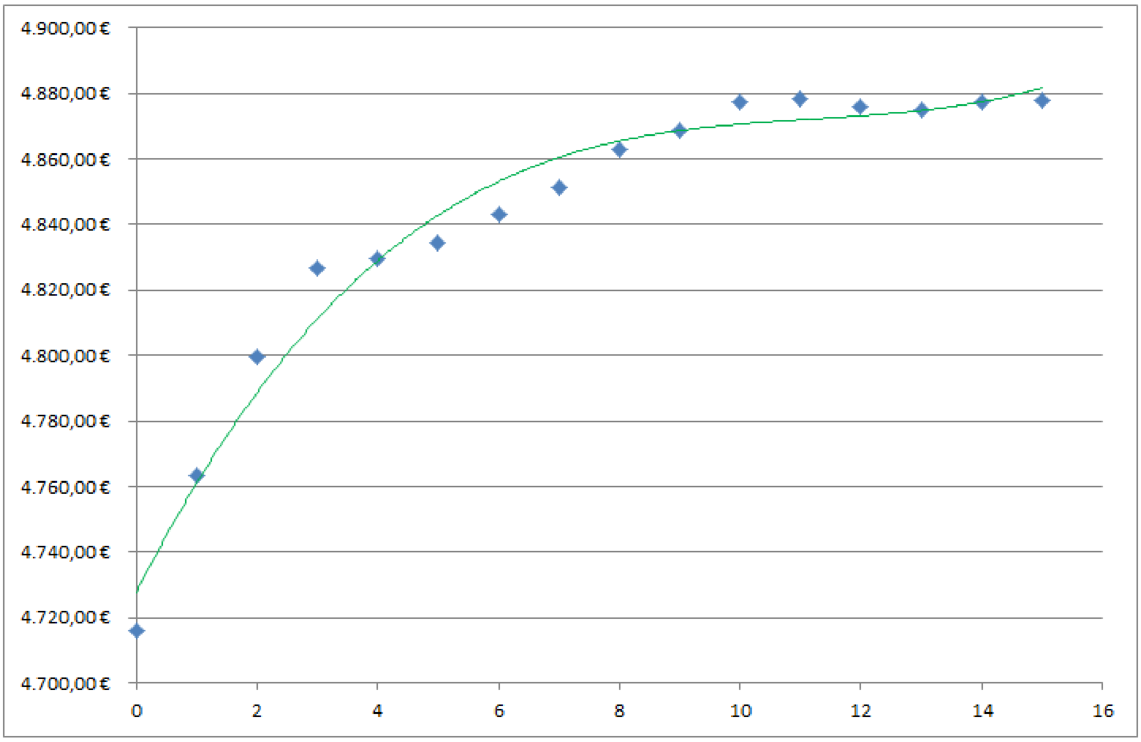
[1] Parameters of the simulation: Parabolic Trough physical model, Utility Independent Power Producer, electrical output of 50 MW, 4 troughs per loop, tracking error of 1.00 for LS-3 and 0.99 for ET150, the remaining parameters as default except the model of 2 types of troughs (LS-3 and ET150), 10 locations and 16 storage hours.

[2] Phoenix, Tucson, Colorado Springs, Grand Junction, Albuquerque and Tonopah (US), El Cairo Int Airport (EGY), Almeria, Granada and Sevilla (ESP).

[3] From 0 to 15 in steps of 1h.

Figure 1: ET150 versus LS-3 NPV improvement as function of storage hours



These results allow to calculate market revenues of the technology: NREL (NREL 2014) has registered all the commercial CSP power plants worldwide indicating electrical capacity, type of trough (LS-3, ET150 or others) and storage size. Applying the function of improvement in NPV as function of the storage hours per installed MW to all the CSP plants retrieved from NREL, the worldwide NPV per year is calculated and shown in table 2.

Table 2: NPV of commercial revenues discounted at indicated year

2006	243 159.55 €
2007	952 284.55 €
2008	1 296 778.64 €
2009	1 398 113.19 €
2010	3 343 509.25 €
2011	2 703 466.25 €
2012	136 322.02 €
2013	1 013 243.07 €
Total	**11 086 876.50 €**

For the purpose of this paper, there are no more Eurotrough structures foreseen to be installed in any future CSP plant. The NPV is discounted to two years prior the plant starts operating, because the construction time is, on average, 24 months. The sum of these NPV discounted at 1998 (the year the R&D project was initiated) is the value of the underlying asset.

Table 3 summarises all the parameters that will be applied in the case:

Table 3: Parameters for the binomial tree

Stock price S_0	3 634 194.92 €
Discount rate r	10%
Volatility σ	30%
Risk-free rate rf	5%
Exercise price 1 X_1	808 838.00 €
Exercise price 2 X_2	808 838.00 €
Exercise price 3 X_3	808 838.00 €
Exercise price 4 X_4	996 853.50 €
Exercise price 5 X_5	996 853.50 €
Duration stage 1 T_1	1
Duration stage 2 T_2	1
Duration stage 3 T_3	1
Duration stage 4 T_4	1
Duration stage 5 T_5	1
Incremental time step δt	1
$u = \exp(\sigma\sqrt{\delta t})$	1.34986
$d = 1/u$	0.7408
$p = (\exp(rf\delta t)-d)/(u-d)$	0.5097

(1) S_0, as stated before, is the value of the underlying asset, calculated discounting to 1998 all the NPV of every single CSP plant using Eurotrough built worldwide.

(2) Discount rate (r) is the opportunity cost of the company undertaking the investment. For confidentiality, no discount rate of any of the companies in the consortium has been used; but a figure (10%) in the range. Using another discount rate would change the absolute results, requiring a higher or lower grant, but it would not affect to the analysis nor the discussion.

(3) Risk-free rate (rf) is the discount rate assumed to be riskless discount rate, on the basis of the U.S Treasury spot rate of return, with is maturity equivalent's to the option's time to maturity.

(4) Volatility (σ) is the risk of the expected returns. The market risk has been eliminated by using a technology already implemented. However, there is a risk associated to the performance of the CSP plant, depending on the weather, the availability factor of the plant, variations in the price of labour or some commodities such as water for cleaning mirrors, etc. After simulations were run, a deviation of 30% was detected. Identically to the discount rate, a different value would require a different minimum grant, remaining the validity of the discussion.

(5) Exercise price (of period) i (X_i) means the cost of undertaking the following stage. The project has been divided into 5 stages (being one year-long each of those) in which the company can decide whether to continue (exercising the option at price X_i) or abandon at current stage. The cost of each period is extracted from table, assuming Eurotrough 1 is undertaken in 1998, 1999 and 2000 (being the same investment per year, although the period in 1998 is shorter) and Eurotrough 2 into 2001 and 2002.

(6) Duration stage (T_i) is the length of each stage. It is assumed to be one year each, representing the company could abandon the project at the beginning of each new year.

(7) Incremental step (δt) is each one of the discrete periods the model is divided.

(8) *u* and *d*: are the RO parameters applied to the binomial tree according to (Kodukula et al. 2006) and (Hull 2009). S_o is the initial value of the asset, but in the first time increment, it either goes up or down and from there continues to go either up or down in the following time increments. The up and down movements are represented by u and d factors, where $u>1$ and $d=1/u$. The magnitude of these factors depends on the volatility of the underlying asset.

(9) p: is the risk-neutral probability that enables to uses the risk-free rate as discount rate.

4.3. Scenario analysis

With the use of the previous parameters, the NPV at 1998 of the R&D investment without any grant is 0.01 M€, which means a ROI of roughly 0%. This cash-flow has considered the five R&D investments in 1998-2002, three idle years (2003, 2004 and 2005) and commercial cash-in (from table 2) in the period 2006-2013. The detailed cash-flow is in table 4.

However, if the grant is considered, the previous NPV improves significantly. Using the grant given by the EC (50%) supposed to be in 1999 for Eurotrough I and 2002 for Eurotrough II –this assumption states the grant is received the following year after its concession; the NPV of the project increases up to 1.785 M€ (ROI equals to 41%). The detailed cash-flow is in table 5. In this scenario, there is no way of introducing the loss of flexibility since the DCF does not allow to valuate it

Table 4: Base case cash-flow. All figures in k€.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eurotrough I	- 801	- 801	- 801														
Eurotrough II				- 997	- 997												
Grant																	
Commercial revenues									243	953	1 297	1 398	3 344	2 703	136	1 013	
Total	- 801	- 801	- 801	- 997	- 997	-	-	-	243	953	1 297	1 398	3 344	2 703	136	1 013	-
discount rate:	**10%**																
NPV (@1998)	**14**																
Total R&D investment	- 4 396																
ROI	0%																

Table 5: Grant case cash-flow. All figures in k€.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eurotrough I	- 801	- 801	- 801														
Eurotrough II				- 997	- 997												
Grant		1 200			997												
Commercial revenues									243	953	1 297	1 398	3 344	2 703	136	1 013	
Total	- 801	399	- 801	- 997	-	-	-	-	243	953	1 297	1 398	3 344	2 703	136	1 013	-
discount rate:	**10%**																
NPV (@1998)	**1 785**																
Total R&D investment	- 4 396																
ROI	41%																

4.4. RO Model

Finally, applying RO (without grants) implies building a binomial tree with the following results showed in table 6. This table is divided in seven sections: the first area indicates the theoretical value of the underlying asset, starting with S0 which is the NPV of the commercial revenues at 1998 and in each node the value can either go up by u or down by d. The second section is the nominal value of the underlying asset. Thirdly, the option value of stage 5 calculated following (Hull 2009) by which final node equals to the maximum of the underlying asset value minus the exercise price or zero (if the exercise price is greater than the asset, the option value is zero because it is not executed). This last node does not account for the defer option, only for abandon since it is the last opportunity the company can exercise the option and therefore execute the R&D project. Therefore, the option value in the last node, for instance $S0 \cdot u^6$ would be max $\{S0 \cdot u^6 - X5 ; 0\}$. All the terminal nodes are calculated the same way.

Going backwards to intermediate nodes, at each step there is a comparison between exercising the option at that node and waiting for the next time step. In this case, for example the valuation of the node $S0 \cdot u^5$ would be $[p \cdot (S0 \cdot u^6) + (1-p) \cdot (S0 \cdot u^5 \cdot d)] \cdot \exp(-r\, \delta t)$.

Once all the option values for stage-5 have been calculated, in order to determine stage-4 option values, the same procedure applies but using as underlying asset the stage-5 option values. Once stage-4 is calculated, it is possible to compute stage-3 and so on until stage-1 is determined.

Value of stage-1 at time zero is the real option value for the project.

Figure 2: Evolution of the underlying asset and real option value at each node

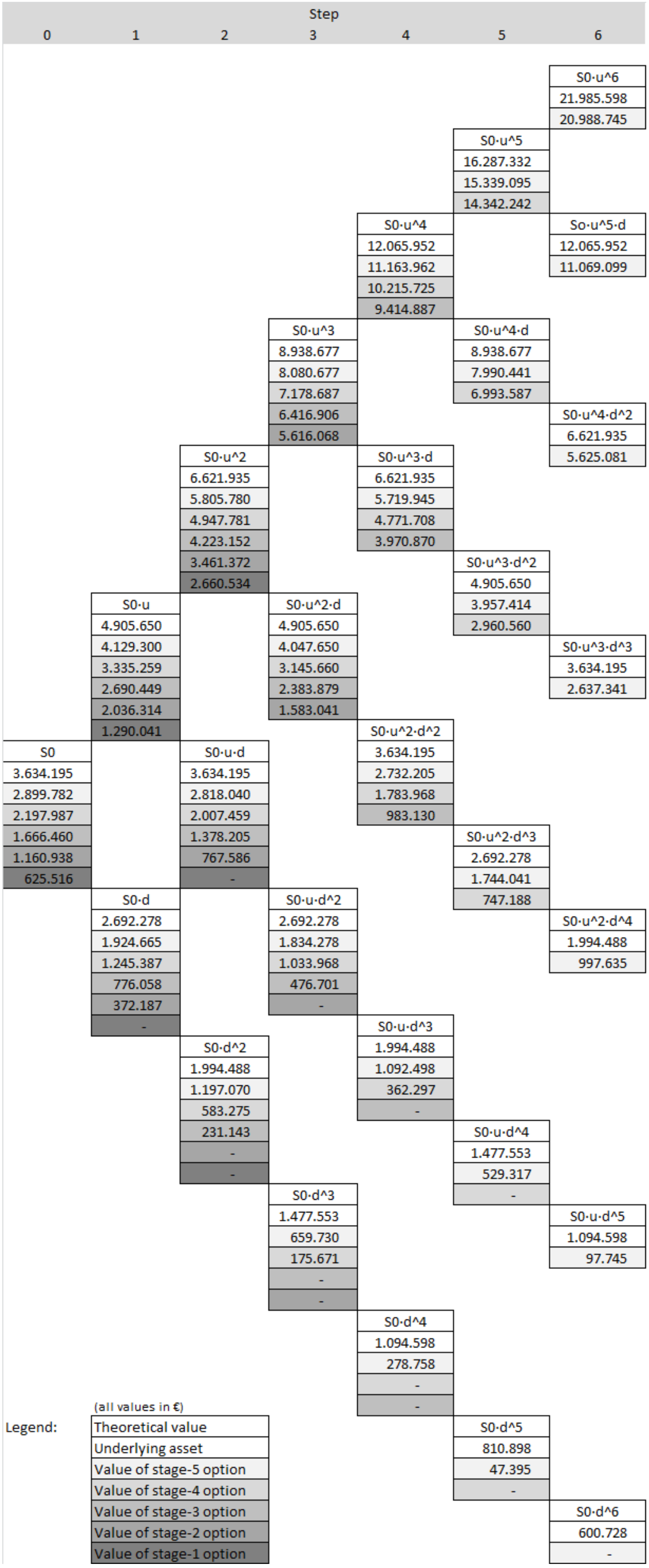


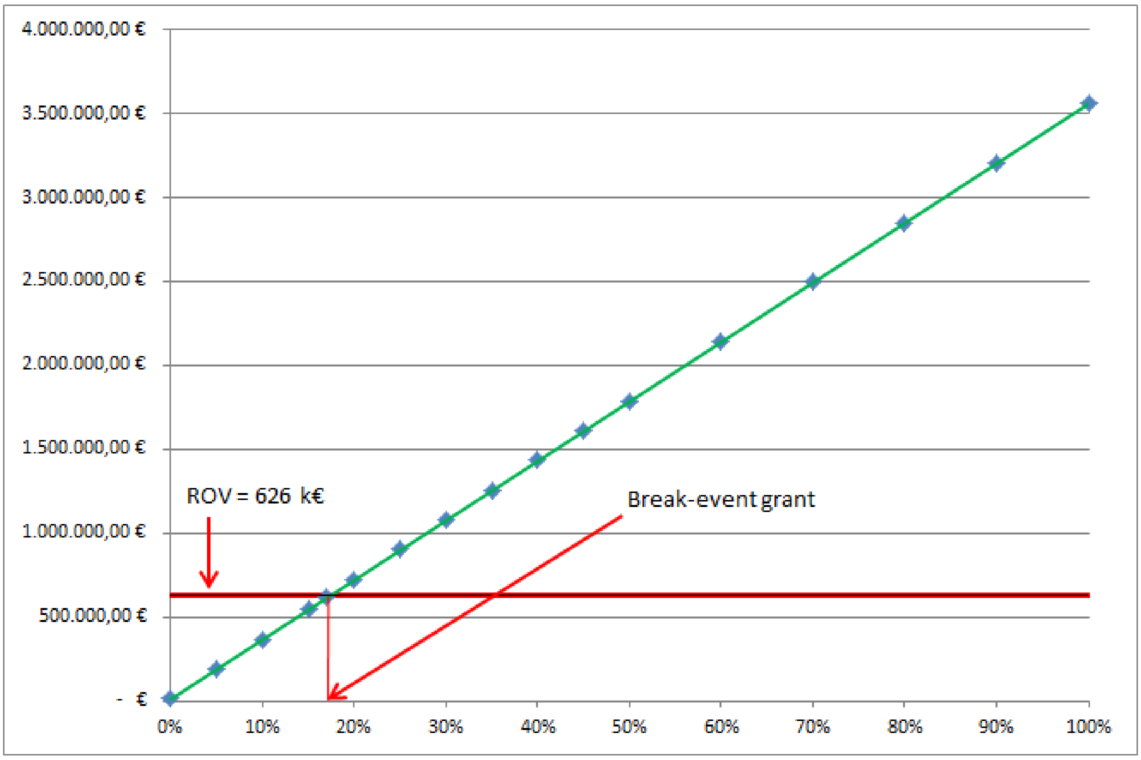
Table 6: Evolution of the underlying asset and real option value at each time step

Time step						
0	1	2	3	4	5	6
S0	S0·u	So·u^2	S0·u^3	S0·u^4	So·u^5	S0·u^6
	S0·d	S0·u·d	S0·u^2·d	S0·u^3·d	S0·u^4·d	S0·u^5·d
		S0·d^2	S0·u·d^2	S0·u^2·d^2	S0·u^3·d^2	S0·u^3·d^2
			S0·d^3	S0·u·d^3	S0·u^2·d^3	S0·u^3·d^3
				S0·d^4	S0·u·d^4	S0·u^2·d^4
					S0·d^5	S0·u·d^5
						S0·d^6
Evolution of the underlying asset value [figures in k€]						
3 634	4 906	6 622	8 939	12 066	16 287	21 986
	2 692	3 634	4 906	6 622	8 939	12 066
		1 994	2 692	3 634	4 906	6 622
			1 478	1 994	2 692	3 634
				1 095	1 478	1 994
					811	1 095
						601
Stage-5 option value [figures in k€]						
2 900	4 129	5 806	8 081	11 164	15 339	20 989
	1 925	2 818	4 048	5 720	7 990	11 069
		1 197	1 834	2 732	3 957	5 625
			660	1 092	1 744	2 637
				279	529	998
					47	98
						0
Stage-4 option value [figures in k€]						
2198	3335	4948	7179	10216	14342	
	1245	2007	3146	4772	6994	
		583	1034	1784	2961	
			176	362	747	
				0	0	
					0	
Stage-3 option value [figures in k€]						
1 666	2 690	4 223	6 417	9 415		
	776	1 378	2 384	3 971		
		231	477	983		
			0	0		
				0		
Stage-2 option value [figures in k€]						
1 161	2 036	3 461	5 616			
	372	768	1 583			
		0	0			
			0			
Stage-1 option value [figures in k€]						
626	1 290	2 661				
	0	0				
		0				

The value of further stages increase as the technical uncertainty is cleared, ie.: as we move forward in the stages. In this RO analysis, the defer option is considered up to two years (the idle time between the original R&D project would finish in 2002, and one year prior to the first commercial one which is 2006) plus the option to abandon at each node. The value with managerial flexibility is 0.626 M€ (ROI = 14%).

Figure 3 shows the results: The horizontal line represents the RO value with the options to abandon and defer up to 2 years. The increasing one reflects the NPV as a function of the grants (expressed as the ratio between contribution and declared costs). The break-even grant that equals with the RO value is 17.25%. This means that grants below 17.25% are not beneficial for the company because the loss of flexibility is worth more than the financial incentive.

Figure 3: NPV as function of the received grant



4.5. Varying the conditions

There might be some variation to the base case. For instance, many funding agencies allow asking for a deferment of 1 year. In this case, the flexibility to analyse is not the abandon option plus 2-year defer option but abandon plus 1 year. In this case, the minimum grant would be not 17.25% but 12.5%, using the same methodology. The option to abandon should stay in the analysis; otherwise the funding agency would not provide funds for the project. Shorter or longer deferral periods would alter the minimum grant, but the rationale of the case is not modified.

4.6 Discussion

Whereas most of the literature has approached the evaluation of renewable energy policy (Yu et al. 2006; Boomsma et al. 2012; Lee et al. 2011; Lin et al. 2013;

Reuter et al. 2012; Monjas-Barroso et al. 2013; Zhang et al. 2014; Kumbaroğlu et al. 2008) from a government or funding body perspective, we have focused on the point of view of the companies. These companies may accept or not a grant only if the financial incentive overcomes the flexibility barriers imposed, ie.: there is a break-even grant for the companies. Besides that, we have precisely located our research in the specific R&D management framework known as Stage-gate: whether the company should continue with the development, delay or simply abandon it (NREL 2014). One of the differences between our paper and literature on Stage-gate is that we have quantitatively assessed the value of abandon and defer option. To illustrate this idea, table 7 shows the project value under DCF with and without grants and ROA.

Table 7: Project value for each case: DCF with and without grant and ROA

Valuation technique	Grant?	Project value
DCF	No	0.01 M€
DCF	Yes	1.785 M€
ROA	No	0.626 M€

The base case (DCF with no grant) has no value at all; the R&D investment would equal the commercial revenues for the project. However, if granted, the total NPV improves up to 1.785 M€. Nonetheless, this figure should not be taken as total improvement because DCF is not showing the drawback: the loss on flexibility which is worth 0.626 M€. Therefore, in this case, the grant should be accepted because is higher than the flexibility embedded in the project. Actually the net improvement to the project is not 1.785 M€ but 1.160 M€ (1.785 – 0.626). In this case, the break-even grant is 0.626 M€. If the project were granted, no matter if the analysis is performed with DCF or with ROA, since in absence of all flexibility, a typical RO approach behaves as a DCF technique (Martínez-Ceseña et al. 2011).

Literature on ROA has approached renewable energy projects on a commercial stage (Santos et al. 2014; Martínez-Ceseña et al. 2011; Amran et al. 1999; Fernandes et al. 2011; Faulkner 1996; Venetsanos et al. 2002; David et al. 2003; Fleten et al. 2004; Sarkis et al. 2008; Ashuri et al. 2011; Hedman et al. 2006; Zhang et al. 2005; Kjærland et al. 2010) whereas there are uncertainties which are both external; such as electricity prices, demand curve, wind speed, solar irradiation or water flow, and internal: mostly the design of the electricity generation plant. However, our approach simplifies those uncertainties (due to the use of an old R&D project in which the market share is already know, the price is calculated trough (Zúñiga et al. 2014) which already considers solar irradiation, performance of the plant, etc) to focus on the R&D management: the real options embedded in the R&D project. Moreover, comparing our work with the literature describing ROA versus DCF in R&D projects (Tsui 2005; Hodota 2006; Trang et al. 2002), we have consider a completely new option for a company: being able to lose some flexibility (and therefore control) over a project to get a financial incentive.

Chapter V. Second case: The Public Institution

This case is a new perspective on the situation described in (Martín-Barrera et al. 2016), in which a company faced the dilemma of accepting or rejecting a grant to finance a R&D project. In that case, besides the financial benefit of the grant, the drawback was the reduction of flexibility imposed by the European Commission. Therefore, a minimum grant was required to compensate the value lost on flexibility.

This new perspective raises a different approach, however: the recommendation will be aimed at the financing body rather than the companies. The purpose of this numerical case is to illustrate the maximum grant a financing body should offer to companies in order to accelerate their research, this value being lower than the 100% that may crowd out private investment.

In other words, because there is a minimum grant above 0% companies should require, there must be a maximum grant below 100% financing bodies should not exceed.

Although this case is based on a specific technology, the value of its presentation resides in the possibility of subsequently extrapolating the methodology to any other technology. The use of ROV is not Renewable Energy specific, but applicable to any R&D project undertaken by a private company or group of companies which presents flexibility. Furthermore, this case is not dependent on the European system of grants, but applies to any subsidy provided worldwide which provides an economic incentive to private companies while limiting flexibility in any way -setting a deadline, for example.

In this section, we present the numerical case in which we compare the original investment the company made and the maximum equivalent grant given by a financing body (the European Commission in this case) that would have been necessary to accelerate the project by a couple of years. Subsequently, due to the high sensitivity of certain parameters, a further analysis is undertaken under different assumptions.

As previously mentioned, the choice of an old project is intentional for two main reasons: (a) The main difference in using an ongoing project would be the need to project the total market and the corresponding market share captured by the R&D project results. This would complicate the analysis by adding more uncertainty to the calculations and deviating attention from the ROV. The significant advantage of using old technology is that all the potential revenues of the project are perfectly defined. Furthermore, (b) this case was presented by Martín-Barrera et al. (Martín-Barrera et al. 2016) from the company's point of view. By using the same case, this analysis complements the previous one by adding the funding body's perspective. Thus the full analysis is performed and determines on the one hand the minimum grant a company should accept and on the other, the maximum grant a funding body should offer.

5.1 Project description

This project describes the development of a new component for Concentrated Solar Energy (CSP). This technology complements the traditional Photovoltaics (PV) using the Sun as source of energy. Together, there could be more than 400 GW of electrical capacity installed by 2035, according to the International Energy Agency (IEA) (IEA 2008). CSP is divided into two technologies: tower and troughts; however, both are based on the same principle which is to concentrate sunlight using mirrors and produce heat to drive a steam turbine. The tower uses trackers that follow the sun and concentrate light onto a solar receiver on the top of the tower. The trough (or parabolic trough) consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line (European Solar Thermal Electricity Association 2014).

This R&D project seeks the development of a new 150-metre-long trough as opposed to the former 100 metre LS-3 used by its competitors. Besides the economies of scale provided by a larger component, this tracker has a lighter design that reduces operation and maintenance costs due to easier mirror cleaning, and fewer components. The R&D project name was 'Eurotrough', and it was carried out by a consortium of companies in the late 1990s (Ciemat et al. 2014). Eurotrough received two different grants from the European Commission (EC) called Eurotrough I and Eurotrough II. The below table describes the start and end dates, the cost declared by the consortium, and the grant received from the EC called the EU contribution.

Table 8: Eurotrough I & II Start and End Dates, Declared Costs and EU Contribution

Contract	Start Date	End Date	Total Declared Costs	EU Contribution
Eurotrough I	1-Ago-98	31-Jan-01	2 402 514 €	1 199 899 €
Eurotrough II	1-Oct-00	31-Dec-02	1 993 707 €	996 851 €

The project started in August 1998 with a grant of approximately 50% of the total declared cost. The question is: how much grant money would have been necessary to bring forward the investment by two years, i.e., to 1996? Of course, a 100% grant will always incentivise companies, but we argue that this is not the optimal funding rate.

5.2 Parameter estimation

Although CSP plants are large, complex installations with hundreds of design parameters (European Solar Thermal Electricity Association 2014), there are two particularly important aspects that roughly determine the size and cost: the nominal output, which defines the size of the steam turbine, and the storage capacity, expressed as the number of hours the plant is able to work at full load with no sun. The higher any of these two parameters is, the larger the solar field is. A larger solar field positively impacts on the benefits of using more efficient trackers since the benefit is multiplied more times over.

The improvement of the new trough over the previous one is clearly described in (Martín-Barrera et al. 2016), in which different locations were simulated using incremental storage hours. The results are given in figure 1 of the previous chapter which shows the incremental NPV per hour of storage, normalised to electrical megawatt (MWe) of installed capacity.

With these results, determining the market revenues of the technology is straightforward because all the commercial power plants that use this technology are already known and no new plants will be built using that technology. The fact of using an old R&D projects helps to determine the exact market revenues. If the project were online, these revenues should be estimation based on market share projections.

NREL (NREL 2014) details all the commercial power plants using Eurotrough worldwide, combining the list (which details electrical capacity and number of storage hours) and the increments in NPV per MWe and storage hour given in figure 1. The total NPV due to technology at the beginning of each year is shown in the below table.

Table 9: NPV of commercial revenues using Eurotrough rather than LS3 discounted at indicated year

Year	Commercial revenue of R&D project
2006	243 159.55 €
2007	952 284.55 €
2008	1 296 778.64 €
2009	1 398 113.19 €
2010	3 343 509.25 €
2011	2 703 466.25 €
2012	136 322.02 €
2013	1 013 243.07 €
Total	11 086 876.50 €

to assess the value of flexibility embedded in the project, the necessary parameters for the use of ROV are defined in the following table and explained here.

Table 10: Value of the parameters for the binomial tree of the original case (investment in 1998)

Parameter	Value
(1) Stock price S_0	3 634 194.92 €
(2) Discount rate r	10%
(3) Risk-free rate rf	5%
(4) Volatility σ	30%
(5) Exercise price 1 X_1	808 838.00 €
(5) Exercise price 2 X_2	808 838.00 €
(5) Exercise price 3 X_3	808 838.00 €
(5) Exercise price 4 X_4	996 853.50 €
(5) Exercise price 5 X_5	996 853.50 €
(6) Duration stage-1 T_1	1
(6) Duration stage-2 T_2	1
(6) Duration stage-3 T_3	1
(6) Duration stage-4 T_4	1
(6) Duration stage-5 T_5	1
(7) Incremental time step δt	1
(8) $u = \exp(\sigma\sqrt{\delta t})$	1.34986
(8) $d = 1/u$	0.7408
(9) $p = (\exp(rf\delta t) - d)/(u-d)$	0.5097

(1) S_0 is the value of the underlying asset, calculated by discounting to 1998 all of the NPV of every single CSP plant using Eurotrough built worldwide from table 2.

(2) Discount rate (r) is the opportunity cost of the company undertaking the investment. There is a sensitivity analysis based on discount rate for being one of the parameters that mostly affects the results.

(3) Risk-free rate (rf) is the discount rate assumed to be the riskless discount rate on the basis of the U.S. Treasury spot rate of return, with maturity equivalent to the option's time to maturity.

(4) Volatility (σ) is the risk of the expected returns. The market risk has been eliminated using a technology that has been already implemented. There is a risk associated with the performance of the CSP plant, however, depending on the weather, the availability factor of the plant, variations in the price of labour or certain commodities, such as water for cleaning mirrors. In this case, a volatility of 30% is determined. Nonetheless, there is also a sensitivity analysis of the volatility.

(5) Exercise price of period i (X_i) means the cost of undertaking stage i. The R&D project has been divided into 5 stages (each being one year) in which the company can decide whether to continue (exercising the option at price Xi) or abandon at the current stage. The cost of each period is extracted from table 1, assuming Eurotrough I is undertaken in 1998, 1999 and 2000 (with the same investment each year, although the period in 1998 is shorter), and Eurotrough II is undertaken in 2001 and 2002.

(6) Duration stage (Ti) is the length of each stage. It is assumed to be one year, indicating that the company could abandon the project at the beginning of each year following the stage gate approach (Cooper et al. 2018).

(7) Incremental step (δt) is the discrete periods into which the model is divided. In this case, the step is one year.

(8) u and d are the RO parameters applied to the binomial tree according to (Kodukula et al. 2006) y (Hull 2009). S_0 is the initial value of the asset, but in the first time increment, it could either go up or down and from there continues to go either up or down in the following time steps. The up and down movements are represented by u and d factors, where u>1 and d=1/u. The magnitude of these factors depends on the volatility of the underlying asset.

(9) p is the risk-neutral probability, which makes it possible to use the risk-free rate as a discount rate according to (Kodukula et al. 2006; Hull 2009).

5.3 Scenario analysis

In this section, the objective is to compare the original investment (1998 with 50% grant) with different volatility and risk scenarios in 1996 if the EC had tried to boost the investment.

5.3.1 Original investment in 1998

The original investment was decided in 1998. At that time, with the costs of table 1, the revenues from table 2 and the discount rate from table 3, the NPV of the project was nearly zero. Due to the positive effect of the grant, however, the NPV rose to 1.79 M Eur., meaning a ROI of approximately 40%. The detailed cash flow is included in Table 4.

In (Martín-Barrera et al. 2016), there was a study of the positive financial effects of the grant versus the obligations imposed by signing a contract with the EC to develop the project. In fact, a minimum grant of 17.25% was determined as the break-even point between the improvements due to the EC contributions minus the value lost because of the lack of flexibility.

5.3.2. What would be the required grant to bring the project forward to 1996?

According to Brown et al. (Brown et al. 2012), because R&D knowledge spills across firms and even countries, suggesting that socially optimal rates of R&D are likely to be much higher than privately optimal levels, R&D faces financing constraints such that its private investment may be below the optimal level. In

Europe, there are funds to finance sustainable energy projects to overcome market failures (Streimikiene 2005).

For any funding body, and for society in general, it is advantageous to research and develop new technologies as soon as possible to boost the technological potential of the country and help its economic growth.

The further from the market a new idea is, however, the riskier for the promoter. From this point forward, we will assume that even the EC wants the consortium to develop Eurotrough a few years earlier; the first commercial plant is still built in 2006. This assumption is the most negative for the company because revenues are received much later than the investment. However, we have decided to explore only the EC initiative to bring the inversion forward to 1996, without any side benefits, such as receiving revenues sooner. By doing so, the task is only focused on the grant. It is reasonable to think that the sooner the R&D project is finished; the sooner a new commercial power plant will be built. Therefore, if the R&D project had been performed in 1996, the first commercial power plant could have been built before 2006. This idea will be explored in greater detail at a later point.

The selection of 2 years is considered reasonable because a 1-year period has a moderate effect and 3 or more years have a deep impact on the parameter estimation because a much higher volatility applies. It is unlikely that companies could start much earlier than 2 years simply due to the state of the art.

With these values, the NPV in 1996 with everything else equal (see cash-flow in table 5) would be 1.16 M Eur. This assumption is not realistic, however, as there is a higher risk involved because the new trough is being developed 2 years earlier.

To better model the investment in 1996, the discount risk should be higher. A reasonable figure is 13%, although sensitivity analyses are performed in this paper. In this case, the NPV drops to 0.32 M Eur. This means it is highly unlikely any private company would continue with the project so early on.

Therefore, any funding body willing to accelerate the R&D would need to increase the grant so that it equals the higher risk companies are facing.

With regard to Research projects (further from market, higher risk), typically there are grants that cover up to 100% of the costs. If this were the case, the NPV would be 1.99 M Eur with the adjusted discount rate of 13%. This figure is even higher than the original of 1.79 M Eur the company had in 1998.

By fine-tuning the incentive to equal the NPV of 1998, a grant of 94% would be required. As will be discussed in the following section, however, very high incentives are not optimal.

5.4 RO model

In the previous sections, the value associated with the flexibility of the project has not been taken into account. This flexibility will impact the required grant.

In (Martín-Barrera et al. 2016), the flexibility of the project was calculated in 1998, using the same parameters as shown in table 3. That case sought the equilibrium between grants and the loss of flexibility imposed. The main flexibility of an R&D project is split into two potential actions managers can take, as stated above: i) delay the development of the project until more information about the market and the potential profitability is gathered, and ii) abandon the R&D project if it is not profitable.

Because this case faces new characteristics, it is necessary to update some of the RO parameters of table 3. The updated parameters are redefined in table 6.

(1) Stock Price S_0: the new value is lower than the original because the net present value is not at 1998 but at 1996, applying a higher discount rate.

(2) Discount rate r: as discussed in the previous section, a higher discount rate must be applied because the decision to initiate the project is taken 2 years earlier.

(4) Volatility σ: similar to the discount rate, having up to two extra years induces a higher volatility to the system. Volatility has been escalated according to the discount rate.

(6) Duration stage-1 T_1: this value increases to 3, the original one-year value plus the two additional years.

(8) & (9) u, d and p: these values are calculated directly from the previous ones.

To calculate ROV (without grants) and for the purpose of simplicity, a binomial tree is built, with the results shown in the following table.

Table 11: Evolution of the underlying asset and real option value at each time step

Time step	0	1	2	3	4	5	6	7	8
	S0	S0·u	S0·u^2	S0·u^3	S0·u^4	S0·u^5	S0·u^6	S0·u^7	S0·u^8
		S0·d	S0·u·d	S0·u^2·d	S0·u^3·d	S0·u^4·d	S0·u^5·d	S0·u^6·d	S0·u^7·d
			S0·d^2	S0·u·d^2	S0·u^2·d^2	S0·u^3·d^2	S0·u^4·d^2	S0·u^5·d^2	S0·u^6·d^2
				S0·d^3	S0·u·d^3	S0·u^2·d^3	S0·u^3·d^3	S0·u^4·d^3	S0·u^5·d^3
					S0·d^4	S0·u·d^4	S0·u^2·d^4	S0·u^3·d^4	S0·u^4·d^4
						S0·d^5	S0·u·d^4	S0·u^2·d^5	S0·u^3·d^5
							S0·d^6	S0·u·d^6	S0·u^2·d^6
								S0·d^7	S0·u·d^7
									S0·d^8
Evolution of the underlying asset value [figures in k€]									
	2 087	3 113	4 645	6 929	10 337	15 421	23 006	34 320	51 200
		1 399	2 087	3 113	4 645	6 929	10 337	15 421	23 006
			938	1 399	2 087	3 113	4 645	6 929	10 337
				629	938	1 399	2 087	3 113	4 645
					421	629	938	1 399	2 087
						282	421	629	938
							189	282	421
								127	189
									85
Stage-5 option value [figures in k€]									
	1 514	2 458	3 922	6 155	9 521	14 563	22 104	33 372	50 203
		842	1 427	2 366	3 833	6 071	9 435	14 473	22 009
			416	752	1 324	2 263	3 743	5 981	9 340
				166	329	638	1 200	2 165	3 648
					41	94	212	481	1 090
						-	-	-	-
							-	-	-
								-	-

-

Stage-4 option value [figures in k€]								
	1 120	1 930	3 257	5 374	8 663	13 661	21 155	32 375
		527	967	1 738	3 043	5 169	8 487	13 476
			196	393	776	1 496	2 795	4 984
				44	100	227	515	1 168
					-	-	-	-
						-	-	-
							-	-
								-

Stage-3 option value [figures in k€]							
	837	1 527	2 722	4 722	7 938	12 899	20 355
		321	640	1 253	2 393	4 407	7 686
			75	171	388	879	1 994
				-	-	-	-
					-	-	-
						-	-
							-

Stage-2 option value [figures in k€]						
	568	1 114	2 139	3 998	7 177	12 099
		150	333	737	1 631	3 607
			7	15	35	79
				-	-	-
					-	-
						-

Stage-1 option value [figures in k€]					
	387	794	1 614	3 236	6 376
		71	162	366	830
			-	-	-
				-	-
					-

This table is divided into seven sections: the upper area indicates the theoretical value of the underlying asset, starting with S_0, which is the NPV of the commercial revenues at 1996 (the original was calculated until 1998); in each node, the value can either go up by u or down by d. The second area is the nominal value of the underlying asset. The third area is the option value of stage-5 calculated following 47], by which the final node equals the maximum of the underlying asset value minus the exercise price or zero (if the exercise price is greater than the asset, the option value is zero because it is not executed). This last node does not account for the defer option, only for abandon because it is the company's final opportunity to exercise the option and therefore execute the R&D project. Therefore, the option value in the last node, for instance $S_0 \cdot u^8$, would be max $\{S_0 \cdot u^8 - X_5; 0\}$. All of the terminal nodes are calculated identically. Working backwards to the intermediate nodes, at each step, there is a comparison between exercising the option at that node and waiting for the next time step. In this case, for example, the valuation of the node $S_0 \cdot u^7$ would be $[p \cdot (S_0 \cdot u^8)+(1-p) \cdot (S_0 \cdot u^7 \cdot d)] \cdot \exp(-r\ \delta t)$.

Once all of the option values for stage-5 have been calculated, the same procedure applies to calculate further stages in which the previous option is the underlying asset of the lower stage. For instance, stage-4 will use stage-5 option value as underlying asset. The value of stage-1 at time zero is the real option value for the project.

The value of higher stages increases as the technical uncertainty is cleared, i.e., as we move forward in the stages the R&D results are clearer as the probability of success is higher. In this RO analysis, the defer option is considered for up to four years (the period between 1996 and 1998, plus 2-year idle time - 2003 and 2004 –, after the R&D project is finished in 2002 and before the first power plant starts construction) plus the option to abandon at each node. The value of managerial flexibility is 0.387 M€.

The difference in the value obtained in this project, compared to the original 1998 starting point, which is 0.626 M€ (Martín-Barrera et al. 2016), is due to the higher discount rate and the two extra periods the underlying asset has been discounted.

5.5 Sensitivity analysis

The scenario so far has been conservative regarding the parameters. Due to the high impact of both the volatility and the discount rate on the equivalent grant, however, it is necessary to further explore the impact. Therefore, a sensitivity analysis is performed in this section in order to fully understand the implications.

5.5.1 Sensitivity analysis: discount rate

The discount rate is the most sensitive parameter of the model. Table 12 shows the results using the following notation:

g_r': is the grant required in 1996 to equal the NPV in 1998 with a 50% grant. This value does not consider flexibility and assumes the first commercial power plant will still open in 2006 and that the volatility is 40%.

ROV (σ=40%): is the Real Option Value (i.e., the flexibility value) depending on the discount rate. The calculations are the same as described in the previous section and tables. The great difference is due to the value of the underlying asset S_0 discounted at different rates. The lower the rate, the higher the initial value and therefore the higher the ROV.

g_r'': this is the grant required in 1996 to equal the NPV in 1998 with a 50% grant including the ROV; therefore, a lower grant is needed.

Table 12: Sensitivity analysis of the Discount Rate

Discount Rate	g_r'	ROV (σ=40%)	g_r''	Difference
10%	68%	890.109 €	43%	25%
11%	77%	693.771 €	57%	20%
12%	86%	528.286 €	70%	16%
13%	94%	386.768 €	82%	12%
14%	101%	275.990 €	92%	9%
15%	107%	184.770 €	102%	5%

In conclusion, the required grant increases almost 12% per each 1% increase in the discount rate.

5.5.2 Sensitivity analysis: volatility

The volatility impact, however, is lower than the discount rate. Using a similar notation as before:

g_σ': the grant required in 1996 to equal the NPV in 1998 with a 50% grant, assuming the discount rate is 10% in 1998 but in 13% in 1996. Because volatility only affects ROV and this value already includes flexibility in the analysis, the value is the same regardless of the change in σ.

ROV (r=13%): Real Option Value (i.e., the value of the flexibility) depending on the volatility using a discount rate of 13%. The higher the volatility, the greater the flexibility value and therefore the ROV.

g_σ'': the grant required in 1996 to equal the NPV in 1998 with a 50% grant, including the value of flexibility. As stated before, the effect is lower compared to the discount rate.

In conclusion, the required grant decreases 6% per 10% increase in volatility, as this table shows.

Table 13: Sensitivity analysis of the Volatility

σ	g_{σ}'	ROV(r=13%)	g_{σ}''	Difference
30%	94%	180.446 €	88%	6%
40%	94%	386.768 €	82%	12%
50%	94%	585.338 €	76%	18%

5.3.2 What if the first commercial plant were built sooner?

Although up to this point it has been assumed that the first commercial power plant was still built in 2006, if the R&D project began in 1996 rather than 1998, it is not unreasonable to assume that the first commercial power plant including this new component would have been built in 2004 and not in 2006.

Assuming a discount rate of 13% and volatility equals 40% (same values as the base case), the NPV in 1996 would have been 0.90 M€ and the ROV = 0.387 M€. This flexibility value is close to the original case because there are two factors in this value:

- A positive effect of S_0 because it is discounted from 2004 rather than 2006; therefore, the initial value is greater.

- A negative effect because the time to exercise the options is decreased by two years.

In this particular case (r=13%, σ=40%), there seems to be a balance between the two factors.

Obviously, if the model were calculated with r=10% and σ=40%, the ROV would be exactly the same as the original case in 1998 because the flexibility would have been the same. These results show there is little correlation between the required grant and the commercial power plant being built earlier. Therefore, it is safe to continue using the 2006-year with no major impact on the calculations.

5.6 Combining parameters

The previous sub-sections have performed a sensitivity analysis based on two individual parameters, the discount rate and the volatility. For the sake of providing a complete overview, however, this section compares three different scenarios.

The notation is the same as before: g′ is the required grant in each scenario to equal the NPV in 1998 with 50% grant. After valuing the flexibility, the new required grant g′′ is lower. The results are shown in the below table.

Table 14: Comparison of three different scenarios

Scenario	Discount Rate	Volatility	1st Commercial Revenue	g′	ROV	g′′
Base	r = 13%	σ = 40%	2006	94%	386.768 €	82%
Optimistic	r = 10%	σ = 50%	2004	50%	1.100.156 €	19%
Pessimistic	r = 15%	σ = 30%	2006	107%	83.457 €	105%

The main takeaway of this section is that the great value associated with flexibility depends on the discount rate; to a lesser degree, on volatility; and finally, on the commercial year. This finding creates no new problems with valuing R&D projects, however, as the discount rate is also the main factor in any conventional DCF (Brealey et al. 2008).

5.7 Discussion

The case presented is a real case undertaken by a consortium of private companies that decided to start an R&D project in 1998 with a certain amount of grant funding (50% of the total cost). This facilitated a minimum NPV in the investment, taking into account the uncertainties associated with any R&D project, namely technical success and market demand.

According to the market estimations and the expected NPV presented in (Martín-Barrera et al. 2016), the project would be undertaken only with a grant because the NPV without any grant was close to zero. This grant helps companies to overcome market inefficiencies regarding R&D (Streimikiene et al. 2007; Pennings et al. 1997).

If the financing body, for instance the EC, wanted to incentivise the companies to start the project earlier, however, thus bringing forward the commercial plant and eventually increasing competitiveness, a larger grant would be necessary to balance the higher risks borne by the companies.

To equal the NPV of 1998 in 1996, the grant would need to be not 50% but 94%.[1] This creates two drawbacks:

a) Clearly, it is a very expensive measure and it would not be possible to bring the project forward more than a couple of years. Almost duplicating the grant would mean that half of the companies would be able to receive incentives.

b) The closer a grant is to 100%, the higher the risk of projects with less commercial prospects going forward. For instance, a large R&D company or an R&D centre with no real commercial interest could apply for the grant for the sake of keeping their employees busy while covering structural costs. If there is no real risk for the company and consequently no commitment on the company's

[1] 94% in the base case, Subsection 4.3.4.1 performed a sensitivity analysis and this grant could be a slightly lower or even greater. The rationale of the discussion remains the same.

part, it is difficult to estimate whether the project has any feasible expected profitability.

The previous drawbacks are based on a non-flexibility scenario. As discussed earlier, however, the company has the option to defer the development as well as to abandon the project if the estimations are not promising. Including the value of the flexibility given by the results in table 7, the grant can be lowered. In fact, from the required 94% to equal the NPV in 1996 at a higher discount rate, an equivalent grant of 82% can be offered. The difference between 94% and 82% is precisely the value of the flexibility. As previously stated, this value is based on a very conservative scenario and is subject to reduction as the flexibility increases. Some findings regarding this statement are as follows:

i) If the R&D project starts earlier, it is reasonable to assume the first commercial power plant will also be built earlier. This effect would increase the value of the underlying asset, as subsection 4.3.4.3 showed (albeit with a moderate effect).

ii) If the above reasoning were not true, this would mean the project has a higher volatility value than the one used in the numerical case. A higher volatility means a greater ROV and a lower required grant in 1996. Subsection 4.3.4.2 determined a reduction of 6% in the required grant for every 10% increase in volatility. In fact, this relationship would be greater if the project's start date was advanced by more than 2 years because the impact of the volatility is increased with the length of the options.

iii) If neither i) nor ii) were true, it would mean the risk is not so high, and therefore, the discount rate would also decrease. In this case, similar to i), the underlying asset value would not only increase but would be boosted. Subsection 4.3.4.1 determined a reduction of 12% in the required grant per 1% decrease in the discount rate.

Chapter VI. Conclusions

Flexibility allows some of the uncertainty to be resolved before irreversible expenditures are made, enabling managers to make decisions that bring their operations closer to maximizing profits

The current paradigm in the valuation and assessment of R&D projects has been questioned because their level of flexibility and embedded options. Several studies have demonstrated how ROA should be applied in this kind of projects, developing appropriated frameworks to evaluate projects of different R&D areas. The uncertainty of R&D projects, the spillover benefits R&D expenditures provide to society and the increased risk and reduced cost of capital have justified governments implement public policies to subsidy, and ROA has been used for evaluation of subsidy schemes of several countries. But obtaining public funding imposes loss of flexibility in the management of its projects for companies once a grant is awarded. These restrictions have to be considered in assessment of projects and policies. Moreover, one of the most debated question in the literature has been if public incentives stimulate (crowding-in) or reduce private investment (crowding-out). This work presents the implications in assessment of these restrictions for companies and governments in two empirical studies for the same project but with different perspectives, using ROA.

The first case (chapter 4) proved not any subsidy should be enough for private companies. On the one hand, grants improve cash-flow via incomes during the R&D investment period. On the other, they reduce the total value of the R&D project because of the stated limitations. The value added to a project by a grant is significantly lower than its nominal amount due to the loss of flexibility for the manager. In this case, stage-gate is useless because flexibility, which has proved to represent a significant share of the project (Santos et al. 2014; Martínez-Ceseña et al. 2011; Davis et al. 2003), is non-existent. Therefore, a minimum acceptable grant (a break-even point) that equals the loss in flexibility has been calculated. If some options are included in the incentive program, there will be less lost value due to inflexibility and a greater minimum grant acceptable. So, flexible grant schemes could provide higher value for companies, although the economic subsidies would be lower. The analysis framework used in ROA has to include the options restrictions because of the government grant; this provides a more accurate project value. On the contrary to NPV, in which any additional income will always improve the valuation of the project, the reality is that grants below a threshold imply a loss of value for the investment, as they impose certain constrains limiting the company managerial flexibility. Companies need to balance on one hand the additional income due to the grant and on the other the limitations imposed (such as setting a deadline, not allowing to abandon the project so the investment is irreversible, discarding switching to alternative technologies, etc.) and realize the underlying value on flexibility could be much greater that the incentive.

When a policy R&D incentive is designed, it should be recognized that financial terms are considered by companies facing an R&D investment as well as side effects such as the flexibility permitted during development. Some works analyse policy evaluation models from the perspective of governments and investors (Zhang et al. 2014). However, this approach will be useful to policy makers defining new public R&D financing policies because it provides a new way to quantify a concern faced by many companies. A new variable has been added to the debate regarding whether public R&D financing crowds-in or crowds-out private spending: the flexibility of the grant scheme. This new idea adds to the current literature and offers tools for policy makers that will help shape a more complete public R&D policy.

For these reasons, the second case (chapter 5) set the focus on the rationale for public institutions. They should incentive the promotion of R&D projects but without displacing (ie. crowding-out) the private investment. Then, rather than providing very large grants which also presents other drawbacks such as free-riders; public institutions could think about alternative schemes with a lower grant but with much more flexibility. Thus, this new grant scheme could be equally attractive for private companies although the nominal grant is substantially lower. Grants can be divided in two terms: the well-known financial incentive, the only one used to date; and a new term, the freedom given to companies. This freedom, namely flexibility, enhances the R&D project because companies do have different options over the course of the project such as abandoning the project at any time if the technical or economic feasibility is not clear; deferring development until the market demand or some technical barriers are clarified; switching to a more promising technology, and so on. This flexibility has been quantified using Real Options Valuation in order to determine the reduction in the grant size. This work has proved it is equally attractive for companies to have a traditional high (in monetary terms) grant that is very restrictive with almost no flexibility at all or the new paradigm of a lower grant with embedded options, for instance, the opportunity to abandon the project at any time or defer the project several years. This finding helps to contribute the existing debate regarding the size of the grant and its crowing-out effect. It seems reasonable to argued that a lower grant that shares the risk with private companies brings some advantages:

(i) Because the grant is smaller, the funding body can reach more projects and companies with the same budget, facilitating long-term stability in public R&D funding policy that is less dependent on yearly national budgets.

(ii) Companies could be more sincere and honest with the outcomes of R&D projects. Currently, abandoning a R&D project has two immediate consequences: returning the incentive received and reducing the probability of receiving public money in the future due to the reputation loss. Because there is an information asymmetry between the private company and the funding body, current grant schemes encourage the temptation not to abandon certain R&D failures in order not to harm the firm's ability to be awarded grants in the future.

(iii) As stated above, the lower the grant is, the less crowding-out effect it represents. According to the literature, the crowding-out effect appears to be correlated with large grants. Therefore, lower grants are less likely to negatively displace private R&D investment.

(iv) Finally, the risk-sharing profile obliges companies to be selective with truly feasible R&D projects. Schemes in which financing reaches 100% of the investment may incentivise free-riders whose sole goal is to receive grants to maintain R&D structures without any real commercial potential.

This second study has presented two scenarios a funding body may face at any time: on the one hand, reducing the nominal grant but awarding it in the same year, and on the other, deciphering the impact of awarding the grant earlier when the company faces higher risk in alignment with the goal of bringing knowledge to society sooner without bearing all the cost of the R&D project. After the calculations, a sensibility analysis over the design parameters of R&D activity was performed proving that Real Options Valuation, as DCF, is mostly affected by the discount rate, so no new significant variables are introduced to the valuation. Other parameters such as volatility have a much lower impact on the equivalent grant calculation.

In summary, this doctoral thesis has proven the following statements:

- NPV techniques are not valid for R&D project valuation under grant schemes.
- Companies should require a grant above a minimum threshold to balance the loss of flexibility imposed by the grant requirements.
- Public institutions should never provide 100% grants; but lower and more flexible incentives which are equally attractive for companies.
- Then, there is an optimal balance between 0% and 100% that will depend on how mature is the project and therefore the managerial flexibility still embedded.

Further research could be done in at least two areas: the first one would be to increase the number of RO included in the evaluation of the flexibility. Besides abandon and defer options, there are others such as switch technology that could be suitable to different markets, or increase resources allocated to foster the research and gain market share, both to better adapt the project to market circumstances. The more options included in the analysis, the greater added value due to flexibility and the greater minimum grant acceptable. However, new flexible grant schemes could provide higher value to companies, although the economic help were lower. This is exactly what this paper should provide to policy makers, create awareness that not only the financial terms are considered by companies when facing an R&D investment, but side effects such as the flexibility allowed during the development. In this sense, an even further research would be to include real option "in" projects, not "on" projects. RO "in" projects mean to model not only actions that managers have, but also concerns design features built into the project.

For the public institution, this work is not suggesting that reducing grants is an always desired action for all funding bodies, as there are other side-effects not analyzed here. One of the main drawbacks could be a bias towards very mature R&D projects with clear market perspectives, thus neglecting funding for research projects on large temporary horizons due to the inherently higher risk.

Finally, the future is wide open for this field of research, including more personalized analysis to several types of projects depending on its matureness. However, the main achievement, if any, of this doctoral thesis is to create awareness of the flaws of NPV to assess R&D projects whereas Real Option Valuation is the most natural tool to fully valuate these plans, not yet assets.

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Appendix I

Application of real options valuation for analysing the impact of public R&D financing on renewable energy projects: A company' s perspective

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Application of real options valuation for analysing the impact of public R&D financing on renewable energy projects: A company's perspective

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ABSTRACT

This paper contrasts the financial benefit of grants given to research and development projects with the reduction in managerial flexibility they impose, which implies a loss in the value of the project. To quantify this loss of value, real options analysis has been adopted as the most suitable framework to assess and quantify managerial flexibility. This idea is illustrated by the case of a research and development project in renewable energy, specifically Concentrated Solar Power. Our results show that the value added by the grants is less than the nominal incentives received as a result of the loss of flexibility for managers; they cannot apply certain options such as deferral, nor can they abandon the project. Therefore, a break-even grant is proposed that equals the financial incentive with the loss of managerial flexibility. Under this break-even point, the grant should be rejected. This paper will create awareness for both policy makers and private companies regarding a more accurate assessment of grants to research and development funding as well as provide insights to improve grant schemes without increasing the amount of public funds.

Contents

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1. Introduction

The use of renewable energy for electricity generation has been assessed as beneficial throughout the oil price fluctuations [1]. According to Krozer [1], the growing use of renewable energy has not increased consumer electricity prices except in countries where it is minimally used, and it has had a moderating effect on prices in countries that consume a large amount of renewable energy. Therefore, although uncompetitive when oil prices are low, renewable energy is attractive when the price of fossil fuel is high. An anti-cycling policy that anticipates high fossil fuel prices through enforcement and support of renewable energy during low price phases is socially beneficial.

A subsequent issue would be whether public research and development (R&D) financing is complementary to private R&D spending or a substitute that tends to crowd it out. Currently, there are policies such as feed-in tariff (FiT), renewable portfolio standard (RPS), tax rebates and direct subsidies and grants to promote R&D investment. The use of grants to encourage private R&D financing has been discussed in previous works [2], with the positive conclusion that it amplifies the effect of private R&D rather than crowding it out [3]. Results confirm that public funding of R&D expenditure through subsidies has a positive impact on the decision to pursue R&D internally [4]. Moreover, some results indicate that receiving public R&D funds increases privately financed R&D. Ali-Yrkkö [3] suggests that this additional effect is greater in large firms rather than in small firms.

Furthermore, some scholars have already investigated the optimality of the modulation of public R&D financing [5] to strike a balance between crowding-in effects and crowding-out effects that typically plague public policy. Policy makers are assigned the task of modulating public intervention, and they have access to research and work that serves the needs of the energy policymaking community [6]. The perspective of policy makers and funding agencies [7] has been taken into account to determine the optimal funding strategy in several R&D areas. However, the point of view of private companies has been neglected in terms of whether a grant will have a positive impact or have no benefit for the firm.

It is apparent that if a public R&D policy replaces private investment, the policy is not appropriate. However, as there is an upper limit that should not be exceeded by policy makers, there might also be a lower limit that companies should not accept; in most of cases, direct subsidies restrict management choices to defer, abandon or modify the scale or technology of a project. Real Options Analysis (ROA) allows an investor to define the optimal time to invest or to estimate the value of project uncertainties because the Real Options (RO) methodology makes it possible to assess the management flexibility of a project [8].

The goal of this paper is to assess the loss of flexibility sustained by management and the resulting need to determine the lower limit of a grant, according to which companies should decline public R&D funds. To this end, this study will analyse an investment in a Concentrated Solar Power (CSP) R&D project through the application of the traditional Net Present Value (NPV) method; then, the project is valuated with the RO methodology to assess the loss of flexibility associated with grant acceptance.

Previous studies [8–12] regarding R&D projects in renewable energy valuation have not considered the loss of flexibility imposed by grants. This paper helps strengthen the RO framework for assessing energy R&D projects, making investors more aware of the costs involved in government grants. In addition, ROA has been used for policy evaluation [6,13–19]. In this sense, policy makers will have a new perspective when defining public R&D: the jeopardy of managerial flexibility. Restrictive grant policies negatively impact the development of projects; however, deferring to companies in certain respects would increase the projects' value with no extra cost to governments.

Section 2 will help determine our contribution to the previous literature. First, we explain why ROA is a more suitable framework for valuing R&D projects. However, we examine whether real options (flexibility) can be limited by external and internal factors. Second, we re-examine previous papers regarding the application of ROA to renewable energy projects. The literature is mainly focused on external and internal uncertainties about the implementation phase and commercial phase of these projects and the options that can be taken. In our case, we focus on the research and development phase and, based on a specific R&D management framework, the flexibility provided for managers in this phase. Next, as ROA is used to evaluate R&D public programs, the literature is revised in this section too, as our results provide insights for improving grant schemes. The point of view of companies is not taken into account in these papers, but a notable observation from this paper is that firms might refuse grants if the cost of accepting them (in terms of loss of flexibility) is higher than the financial incentive.

Section 3 presents the rationale for adopting ROA and DCF (Discounted Cash Flow) in this case, and the stage-gate approach for the R&D phase of the project will be explained. The stage-gate approach is adopted to achieve a higher level of flexibility in the R&D phase. Section 4 presents the project description, parameter estimation and results of valuation, with and without grants. Section 4 addresses the discussion results in light of the previous literature. Finally, conclusions and further research are presented.

2. Literature review

The first subsection addresses RO theory with regard to the concepts of RO and managerial flexibility. In addition, this subsection highlights how RO is viewed by the specialized literature as a suitable method for the evaluation of investment projects and enumerates the main approaches for the valuation of RO, such as decision trees, partial differential equations and Monte-Carlo. The second subsection specifically addresses the literature regarding the evaluation of R&D projects in renewable energy technologies in terms of both external and internal uncertainties. Finally, the third subsection addresses RO in policy evaluations of renewable energy projects, and this completes the literature review.

2.1. RO theory

A financial option is the right but not the obligation to trade products at a specific time for a predetermined price [20]. These products are contracts between two parties, typically consumers and sellers. RO extends that financial theory to real asset assessments. Therefore, an RO can be defined as the right but not the obligation to make an investment decision concerning real assets [21], for instance, defer its development, build a prototype, abandon a project, alter its scale, switch to another technology, etc. [22]. These possible actions are known as managerial flexibility, and they enhance the value of projects. There are two options studied in this paper: one is the defer option, giving the manager the ability to wait before investing money. The value derived from waiting is in the form of additional information about the investment or the resolution of an uncertainty (such as a new law or regulation) [23]. The second is the abandon option, which reflects in a more realistic manner the reality of the project; if the evolution of the market or the technical success is not as expected, the company can stop investing in an unprofitable project. However, the flexibility associated with these options is not always available. Due to external or internal factors, in this case being funded by a grant, flexibility can be constrained.

In other words, RO provides management flexibility, which offers significant value in the presence of uncertainty. Technically, the RO method is more appropriate for valuation of R&D projects than Discounted Cash Flow (DCF) because plans are options, not assets. For a real option, the underlying security is the present value of the business plan [24]. Special features of energy R&D projects suggest that ROA is more suitable than traditional methods such as NPV for assessing their economic valuation, as shown by Santos et al. [8]. In most cases, energy R&D projects are irreversible because associated investments are partially or completely irreversible. Therefore, the assets of these projects cannot be used in other activities or different companies. In addition, there is a high level of commercial uncertainty, especially in the liberalized electricity market [25]. Moreover, investment can occur within a flexible timeframe. Finally, by designing the project, investors have several generation technologies that are associated with different uncertainty levels. Therefore, ROA has been recommended as more appropriate than traditional NPV for judging R&D projects [26].

Myers [27] was the first to recognize the analogy between financial options and real world investments, coining the expression "real option" based on the similarity between the valuation of R&D investments and financial options. Mapping an investment opportunity onto a call option [28] implies that the stock price would be equal to the present value of the project operating assets to be acquired (or developed); the exercise price is the expenditure required (or the R&D investment); the time to expiration would be the length of time the decision may be deferred; the risk-free rate of return equals the time value of money, and finally, the variance of returns on stock represents the riskiness of the project assets.

The evolution of financial options began in the early 70s due to growing dissatisfaction with discounted cash flow (DCF) methods at the same time that significant breakthroughs in options theory were developed by Fisher Black, Myron Scholes [29] and Robert Merton [30], who were the first to price their value. Subsequently, Cox et al. introduced the pricing formula for binomial trees [31]. Decision trees only capture the substantial value of the option to abandon; however, RO captures the value from the management of market risk (risk that cannot be diversified) that seeks to adapt the project to market circumstances. However, other approaches have been tried to determine the valuation of RO. For instance, Amran and Kulatilaka [32] use partial differential equations to express mathematically the value of an option and its dynamics [33]. Another approach is to simulate uncertainty with the Monte-Carlo method.

2.2. Application of RO to R&D projects

The problem with DCF is the mind-set that has developed around it. For example, the Japanese approach to R&D valuation is not consistent with DCF thinking because growth and markets are more important than return on investment (ROI) [34]. Despite this, DCF is still commonly used in R&D valuation; some examples are Tsui [10], who applies RO theory to fuel cell vehicles; Hodota [11], to an intelligent transportation system; and Trang [12], to the pharmaceutical industry. All of them valuate the project with DCF, implying no flexibility. DCF underestimates the value of R&D projects, and in consequence, this method fails to adequately reflect the flexibility of decision making [23] in the face of uncertainty in the energy market, for example, fossil fuel prices. Flexibility of decision making is an important variable to consider because it allows organizations and governments to respond promptly to market uncertainties and rapidly commercialize new technologies [35]. As new information arrives and market condition-related uncertainties are resolved, firms can adjust their strategy to take advantage of future opportunities [36]. That is, flexibility adds value to projects. For these reasons, traditional valuation methods such as DCF are inadequate, ROA being a more appropriate method to evaluate managerial flexibility.

In the field of renewable energies, Venetsanos et al. [37] proposed a framework for the appraisal of power projects under uncertainty within a competitive market environment. This framework includes the following stages: uncertainty and resource attributes, RO identification of the project and evaluation of the project value. Using a Black–Scholes model, ROA provided a positive option value of a wind project and DCF gave a negative value. Amran and Kulatilaka [32] defined a methodology to value RO based on four steps: (i) frame the application by identifying the possible decisions that could be taken and when they might be made; (ii) implement the option valuation model (in this paper, a binomial lattice is approached); (iii) review the results and compare them against other methods (in this case, NPV); and (iv) redesign the option model valuation to produce better results.

ROA has been used to evaluate renewable energy technologies in the face of uncertain fossil fuels [38]. In fact, most recent papers have considered these external uncertainties (the market price of fuel or electricity) because it is the easiest type of uncertainty for handling RO models, with the added advantage that there are no interactions with the performance of the project. However, renewable energy projects have at least one internal uncertainty: wind speed, water flows, solar radiation, new equipment efficiency, etc. [9]. Nevertheless, RO research regarding wind and photovoltaic projects is beginning to address these internal uncertainties [39–42]. So, for instance, in hydropower projects, the most frequent uncertainty is water flow [42–44]. Santos et al. [8] applies RO to a mini-hydro power plant, and Martínez and Mutale [22] describe the case of a hydropower plant comparing three different valuation methods: The first uses DCF; the second, what the authors call typical RO (including only the option to defer the project); and finally, advanced RO, in which the time and design of the project are options. In the absence of flexibility, RO behaves like DCF; but if there is flexibility, RO increases the project's value. Therefore, the minimum value in RO equals the optimal DCF. Siddiqui and Fleten [45] analyse how a firm may proceed with staged commercialization and deployment of alternative energy technologies. The work carried out by Karamitsos [46] is remarkable because the company perspective is considered, not in terms of analysing grants but comparing methodologies to evaluate R&D projects in the power sector. However, no previous study has focused on the design of the performance schemes for these phases to provide flexibility (value) to the project.

2.3. RO in policy evaluation of renewable energy projects

Unlike fossil energy, which is occupies a central place in the current environment, renewable energy is at an important stage of its development and needs the support of policy. Environmental policies are associated with uncertainties such as carbon, fuel and electricity prices and natural resources. For this reason, RO is an effective tool to evaluate energy projects. Thus, RO theory has been used by some authors to analyse the policy evaluation of renewable energy in several countries.

In this line of research, Kumbaroğlu et al. [25] designed a model to guide policy planning in relation to renewable energy projects in Turkey and concluded that the diffusion of renewable energy technologies occurs only if there are targeted policies. Lee and Shih [36] applied RO to renewable power generation in Taiwan, and they proposed a model that is useful for quantifying the policy value on different renewable energy development policies. In addition, in the case of Taiwan and for wind energy technologies, Lee and Shih [15] constructed a model based on the binomial RO method that helps reduce policy implementation costs and facilitate an estimation of benefits brought by specific policies. For the cases of wind power and pumped storage in Germany and Norway, Reuter et al. [17] employed a RO model to investigate the specific characteristics of renewable technologies and their associated uncertainties by taking into account market effects of investment decisions. Monjas and Balibrea [18] conducted a comparative study on an investment project for renewable energy in Denmark, Finland and Portugal, based on RO. This study assessed how the ROs affect the expanded net present value of the project and also evaluated the public incentives in these countries for wind energy. In addition, Barroso and Iniesta [47] performed a valuation of investments in wind power generation in Germany using RO and concluded that this approach improves the valuation methodology for such projects by modeling the primary uncertainties affecting the projects and incorporating the uncertainties arising from public support for renewable energy. Lin and Wesseh [16] studied the feed-in tariff for solar power generation via RO in China. An important conclusion of this study is that solar energy technologies in China have a significant amount of value that cannot be detected when the hidden costs of non-renewable energy are not reflected in prices. In addition, in the case of China, Lin and Wesseh [48] used an RO model to evaluate wind energy technologies for power generation by calculating the optimal feed-in tariff policy solution. They concluded that the RO approach is suitable for evaluating the viability of renewable energy programs and the robustness of feed-in tariffs rates. Likewise, Wesseh and Lin [49] applied RO theory to analyse various scenarios and to quantify the benefits of R&D funding for renewable power generation in Liberia. Moreover, Wang et al. [50] used an RO model to evaluate biomass power production investment in China and considered several uncertainties, for example, straw purchase price, government incentives, and technological improvements. They concluded that immediate investment in biomass power production in this country was not optimal. Boomsma et al. [14] analysed both the feed-in tariff and renewable energy certificate trading under a RO approach in a case study based on wind power in Norway. So, while the feed-in tariff encourages earlier investment, renewable energy certificate trading creates incentives for larger projects once the investment has been undertaken. Yu et al. [13] evaluated the use of feed-in tariff in the wind energy sector in the Spanish market. Using RO analysis, these authors conclude that both the values and operation risk of wind generation assets are changed by the switchable tariff. Zhang et al. [19] have proposed an RO model to evaluate the unit decision value and save-path rate for renewable energy development; they applied this model to the case of solar photovoltaic power generation in China. Furthermore, Jeon et al. [51] have proposed a method based on system dynamics and RO to optimize financial subsidies and public R&D investments for renewable energy technologies, and they have applied this method to the case of photovoltaic technology in Korea.

The abovementioned studies have contributed to the specialized literature about the use of RO in policy evaluation of renewable energy projects. Within this line of research, our study attempts to make a contribution by considering the costs to companies as a consequence of a loss of flexibility after a subsidy has been granted for an R&D project. An example related to a renewable energy technology is presented, using for its analysis the RO theory. In this sense, the cost of this loss of flexibility should be considered both by companies when they develop an investment project and by policy makers when they design a subsidy policy for renewable energy projects.

3. Methodology

The first subsection explains the stage-gate approach to provide a framework that offers flexibility in the R&D phase. The second subsection addresses factors affecting R&D project management, such as market evolution, technical success and emergence of substitutes, as well as noting the adequacy of the stage-gate methodology in managing R&D projects. Furthermore, this subsection considers NPV to evaluate R&D projects. The third subsection delves into the effects of grants in the application of RO to evaluate those projects; it specifically takes into account deferral and abandon options. Finally, the fourth subsection presents the steps of the model framework used in this paper to compare NPV and RO in the case of an R&D project for renewable energy.

3.1. The R&D phase framework: stage-gate approach

Companies now understand that R&D project management differs from that of traditional projects. The main uncertainty in the latter is the market risk that might affect the future cash-in. However, R&D projects are affected not only by the evolution of the market but also by their technical success and the potential emergence of substitutes during the development of the product. Therefore, to manage these uncertainties, R&D requires a specific management framework to manage risks and decisions during the project lifecycle. Thus, a new approach was developed to manage R&D projects, known as the stage-gate methodology [52]. This framework allows companies not to commit all of the resources for a project at the very beginning, and it establishes several gates through which the project must pass depending on the technical success and market evolution. If a project seems viable and the market perspectives are reasonably good, according to the stage-gate methodology, the company should release additional funds to continue development. This tool ensures the company does not devote an excessive amount of resources to a project that is about to fail or that will not be profitable in the future. Actually, at least two RO are part of the stage-gate decision. One is the option to abandon the project (at each gate), and the second is the decision to defer the project, for example, a defer decision based on current market estimations or a certain regulation under discussion. The project could be delayed by one year and re-evaluated once more information is available.

3.2. Factors considered in an R&D project valuation

To evaluate an R&D project using NPV, the first step is to estimate the total market for the technology and the correspondent market share. This market share would be translated into a cash-in per year during the commercialization phase. Prior to that, an R&D investment phase is necessary in which there is cash-out from the company. Using discounted cash flow, the future cash-in would be discounted together with the cash-out. If the NPV is above zero, the project is undertaken. The main issue regarding DCF is to determine the discount rate, which is related to the cost of capital of the company, representing its opportunity cost.

The second uncertainty is the technical success of the R&D phase, in which NPV "simulates" private risk by adding subjective probabilities. Using Monte-Carlo simulation, a probability distribution of the NPV can be obtained, depending on the market and technical variables and probabilities associated to each iteration. In the analysis of R&D projects using DCF, the effect of grants is always beneficial. Grants reduce the R&D investment phase; therefore, NPV will increase regardless of the conditions imposed on the project by the funding agency; DCF cannot handle them as they are not included in the numerical analysis.

3.3. Qualitative effect of grants in terms of managerial flexibility

Real option theory is known for enhancing the value of projects under uncertainty [9]. In R&D projects, this managerial flexibility is considered only if managers are willing to exercise the options. This might not always be the case if managers cannot or are reluctant to apply all of the options; for instance, they could be not willing to abandon their project. In those cases, the use of RO is useless because it provides a value using a managerial flexibility that is not real.

As stated previously, stage-gate is a well-known methodology for managing R&D projects; there are at least two embedded RO: the option to abandon the project at each gate and the option to defer the investment. Scholars have analysed how to apply RO to a project model to include managerial flexibility.

However, it is at this point that a grant imposes restrictions on the project. A company receiving public R&D funds limits its managerial flexibility because managers do not have the option to abandon or defer the project, and they have to invest according to a schedule. To ensure that the analysis is numerically tractable and for purposes of clarity, we will assume a company that applies the stage-gate methodology to its R&D projects, simplified to two RO (abandon and defer). The concession of a grant limits both RO:

- Abandon option: This option will no longer be possible. Otherwise, the company should have to refund the grant to the funding agency.
- Defer option: A priori, a company could defer the development of the R&D project – without taking into account competitors' reactions. However, a grant imposes a deadline on the project.

3.4. Model framework

The structure of the model framework would be first to determine the value of the project using NPV. In this regard, the choice of a dated R&D project has been intentional to avoid simulations of market and market share evolutions. The commercial revenue of the project can be calculated with certainty because the market share is already known, as well as the costs and benefits of the R&D project. Using a DCF method with the commercial revenues and the R&D costs, the NPV is straightforward. The only parameter to define is the discount rate. This will be explained in the fourth section of the paper.

Second, the beneficial financial effects of grants are considered, which reduce R&D investment and increase NPV. Specifically, the effect of the grant is translated into revenues during the R&D investment phase, which means the total cash flow for the project improves because there will be more cash-in.

Third, an RO model is applied to quantitatively assess how much value the abandon and defer options add to the project [53]. A binomial lattice approach is adopted for this purpose. Finally, the value of the two options limited by the grant will be calculated. Once managerial flexibility has been quantified in this way, a contrast between the financial benefit from the grant and the limit in managerial flexibility provides a measure for the minimum grant acceptable by the company; this minimum grant equals the value lost by the limitation of managerial flexibility.

4. Results: parameter estimation and scenario analysis

First, we describe the case study. Second, we identify the parameters to be estimated, although some components of uncertainty will be neglected. Finally, we present the value of both the DCF and ROA and whether the project is financed through a grant for the purpose of discussing the result in the next section.

4.1. Project description

In the renewable energy sector, solar power is increasingly important. In its most pessimistic scenario, the International Energy Agency (IEA) forecasts that more than 400 GW of electrical capacity will be installed in 2035 [54]. Within solar technology, there are two main alternatives: photovoltaic (PV) and concentrated solar power (CSP). The latter is relatively new, and it is gaining market share. According to the IEA, it will double its capacity by 2030.

CSP uses mirrors or lenses to concentrate a large area of sunlight into a small area. Electrical power is produced when the concentrated light is converted to heat, which usually drives a steam turbine connected to an electrical power generator. There are two main technologies in CSP: towers and troughs. The tower uses trackers that follow the sun and concentrate light onto a solar receiver on the top of the tower. The trough (or parabolic trough) consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line [55].

The R&D project analysed in this paper is in the trough category; specifically, it involves the development of a new trough, one that is 150 m long rather than the typical 100 m, the length of its competitors. In addition to economies of scale, this tracker has a new design that is lighter, reduced operation and maintenance costs due to easier mirror cleaning, less complex realignment requirements, and fewer components. The project name was 'Eurotrough', and it was made by a consortium of companies in the late 90s [56].

The project received two grants from the European Commission (EC) under two different contracts called Eurotrough I and Eurotrough II, which covered the sequential stages of development. Table 1 shows for each of the two contracts the start and end dates, the cost declared by the consortium (costs may have been higher, but the companies did not communicate this to the EC) and the grant received from the European Union (through the EC) called the EU contribution.

Although CSP plants are complex, large installations with hundreds of design parameters [55], there are two particularly important aspects that roughly determine the size and cost: electrical capacity, which defines the size of the steam turbine, and the storage capacity, expressed as the number of hours the plant is able to work at full load with no sun. There is a positive correlation between these two with the size and therefore the cost of the plant. The larger the plant is, the greater the number of solar reflectors that are required, and therefore, the improvement per tracker, due to the more efficient troughs, will be more substantial. There is a limit in this correlation in that adding more trackers does not improve the profitability of the plant.

4.2. Parameter estimation

The first step is to calculate the improvement the new trough brings over the previous one. The System Advisor Model, designed by the National Renewable Energy Laboratory (NREL) in the United States, is run [57]. This tool makes it possible to simulate the behavior of all types of CSP plants in any location worldwide and defines its main parameters such as electrical capacity, storage size and, among others, model of trough. The output is the NPV of the designed plant.

Table 1
Eurotrough I & II start and end dates, declared costs and EU contribution.

Contract	Start date	End date	Total declared costs (€)	EU Contribution (€)
Eurotrough I	1-Ago-98	31-Jan-01	2.402.514	1.199.899
Eurotrough II	1-Oct-00	31-Dec-02	1.993.707	996.851

Simulations[1] were run with the trough previous to the R&D project (LS-3) and with the developed one (ET150). For both troughs, 10 locations were simulated[2] with different storage hours[3] covering all of the normal ranges of design. Therefore, for each number of storage hours, the average (of the 10 locations) of the difference in both troughs' NPV was calculated, with the results provided in Fig. 1. The figure is normalized per unit of installed MW. Fig. 1 reflects the previous rationale at the end of Section 4.1, as the plant has larger storage hours; there are more trackers required and therefore a larger improvement in NPV. However, there is a saturation limit at approximately 9 h of storage, and adding more storage does not improve NPV.

These results make it possible to calculate the market revenues of the technology: the market capacity is given by NREL [58], which has registered all of the commercial CSP power plants worldwide, indicating electrical capacity, type of trough (LS-3, ET150 or others) and storage size in the period 2006–2013. We would assume the Eurotrough to be obsolete after 2013, so there is no market for this product. To obtain the benefit of using Eurotrough rather than LS-3, we will use Fig. 1, which indicates the NPV improvement of Eurotrough over LS-3 per hour of storage and per MW. Table 2 summarizes the results for NPV improvement associated with the market share every year. Each row represents an increment in NPV due to Eurotrough, taking into account market share (number of plants and size). Therefore, Table 2 provides the value (discounted at the beginning of each year) of the R&D project.

So, prior to using ROA, it is necessary to define the parameters, which are shown in Table 3, with the corresponding definition and meaning afterwards.

(1) S_0, as stated previously, is the value of the underlying asset, calculated by discounting to 1998 all of the NPV of every single CSP plant using Eurotrough built worldwide from Table 2.

(2) Discount rate (r) is the opportunity cost of the company undertaking the investment. For confidentiality, no discount rate of any of the companies in the consortium has been used; however, a figure within the range (10%) has been used. Another discount rate would change the absolute results, requiring a higher or lower grant, but it would not affect the analysis or discussion.

(3) Risk-free rate (rf) is the discount rate assumed to be the riskless discount rate on the basis of the U.S. Treasury spot rate of return, with maturity equivalent to the option's time to maturity.

(4) Volatility (σ) is the risk of the expected returns. The market risk has been eliminated using a technology already implemented. However, there is a risk associated with the performance of the CSP plant, depending on the weather, the availability factor of the plant, variations in the price of labor or some commodities such as water for cleaning mirrors, etc. Simulations were run using @Risk to perform a Monte-Carlo; mean and standard deviation were calculated by the program, reaching 25.14 and 48.87, respectively. The simulation period was 42 years (the lifetime that a technology might be in use; its initial R&D phase up to the last plant operating in the world). In this case, a volatility of 30% is determined. Similar to the discount rate, a different value would require a different minimum grant to retain the validity of the discussion.

(5) Exercise price (of period) i (X_i) means the cost of undertaking the following stage. The project has been divided into 5 stages (each being one year), in which the company can decide whether to continue (exercising the option at price X_i) or abandon at the current stage. The cost of each period is extracted from Table 1, assuming Eurotrough I is undertaken in 1998–2000 (with the same investment each year, although the period in 1998 is shorter), and Eurotrough II is undertaken in 2001 and 2002.

(6) Duration stage (T_i) is the length of each stage. It is assumed to be one year, indicating that the company could abandon the project at the beginning of each year following the stage-gate approach [52].

(7) Incremental step (δt) is the discrete periods into which the model is divided. In this case, the step is one year.

(8) u and d are the RO parameters applied to the binomial tree according to [53,59]. S_0 is the initial value of the asset, but in the first time increment, it either goes up or down and from there continues to go either up or down in the following time increments. The up and down movements are represented by u and d

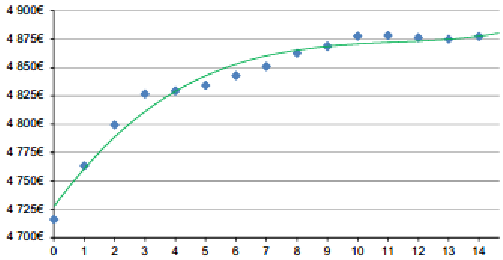

Fig. 1. ET150 NPV improvement as function of storage hours.

Table 2
NPV of commercial revenues using Eurotrough rather than LS3 discounted at indicated year.

Year	Commercial revenue of R&D project (€)
2006	243,159.55
2007	952,284.55
2008	1,296,778.64
2009	1,398,113.19
2010	3,343,509.25
2011	2,703,466.25
2012	136,322.02
2013	1,013,243.07
Total	11,086,876.50

Table 3
Value of the parameters for the binomial tree.

Parameter	Value
(1) Stock price S_0	3,634,194.92 €
(2) Discount rate r	10%
(3) Risk-free rate rf	5%
(4) Volatility σ	30%
(5) Exercise price 1X_1	808,838.00 €
(5) Exercise price 2X_2	808,838.00 €
(5) Exercise price 3X_3	808,838.00 €
(5) Exercise price 4X_4	996,853.50 €
(5) Exercise price 5X_5	996,853.50 €
(6) Duration stage 1T_1	1
(6) Duration stage 2T_2	1
(6) Duration stage 3T_3	1
(6) Duration stage 4T_4	1
(6) Duration stage 5T_5	1
(7) Incremental time step δt	1
(8) $u = \exp(\sigma\sqrt{\delta t})$	1.34986
(8) $d = 1/u$	0.7408
(9) $p = (\exp(rf\delta t) - d)/(u - d)$	0.5097

[1] Parameters of the simulation: Parabolic Trough physical model, Utility Independent Power Producer, electrical output of 50 MW, 4 troughs per loop, tracking error of 1.00 for LS-3 and 0.99 for ET150, the remaining parameters as default except the model of 2 types of troughs (LS-3 and ET150), 10 locations and 16 storage hours.

[2] Phoenix, Tucson, Colorado Springs, Grand Junction, Albuquerque and Tonopah (US), El Cairo Int Airport (EGY), Almeria, Granada and Sevilla (ESP).

[3] From 0 to 15 in steps of 1 h.

Table 4
Base case cash-flow. All figures in k€.

	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eurotrough I	−801	−801	−801														
Eurotrough II				−997	−997												
Grant																	
Commercial revenues									243	953	1297	1398	3344	2703	136	1013	
Total	−801	−801	−801	−997	−997	–	–	–	243	953	1297	1398	3344	2703	136	1013	–
Discount rate(%)	**10**																
NPV (@1998)	**14**																
Total R&D investment	−4396																
ROI(%)	0																

factors, where $u>1$ and $d=1/u$. The magnitude of these factors depends on the volatility of the underlying asset.

(9) p is the risk-neutral probability, which makes it possible to use the risk-free rate as a discount rate according to [53,59].

4.3. Scenario analysis

4.3.1. NPV calculation

With the previous parameters, the NPV for the 1998 R&D investment without any grant is 0.01 M€, which means an ROI of approximately 0%. This cash-flow incorporates the five R&D investments in 1998–2002, three idle years (2003–2005) and the commercial cash-in (from Table 2) in the period 2006–2013. The detailed cash-flow is in Table 4.

4.3.2. Effect of grants in NPV

However, if the grant is considered, the previous NPV improves significantly. Using the grant given by the EC (50%), which was supposed to be in 1999 for Eurotrough I and 2002 for Eurotrough II, this assumption states that the grant is received the following year after its concession; the NPV of the project increases to 1.785 M€ (ROI equals to 41%). The detailed cash-flow is in Table 5. In this scenario, there is no way of introducing the loss of flexibility because it is not possible to evaluate it with DCF.

4.3.3. RO model

Finally, applying RO (without grants) implies building a binomial tree, with the results shown in Table 6. This table is divided into seven sections: the first area indicates the theoretical value of the underlying asset, starting with S_0, which is the NPV of the commercial revenues at 1998; and in each node, the value can either go up by u or down by d. The second section is the nominal value of the underlying asset. The third is the option value of stage 5 calculated following [53], by which the final node equals the maximum of the underlying asset value minus the exercise price or zero (if the exercise price is greater than the asset, the option value is zero because it is not executed). This last node does not account for the defer option, only for abandon because it is the last opportunity the company can exercise the option and therefore execute the R&D project. Therefore, the option value in the last node, for instance $S0 \cdot u$^6, would be max $\{S_0 \cdot u\text{^}6 – X_5; 0\}$. All of the terminal nodes are calculated the same way.

Going backwards to intermediate nodes, at each step, there is a comparison between exercising the option at that node and waiting for the next time step. In this case, for example, the valuation of the node $S0 \cdot u$^5 would be $[p \cdot (S_0 \cdot u\text{^}6)+(1-p) \cdot (S_0 \cdot u\text{^}5 \cdot d)] \cdot \exp(-r\delta t)$.

Once all of the option values for stage-5 have been calculated, to determine stage-4 option values, the same procedure applies but using as an underlying asset the stage-5 option values. Once stage 4 is calculated, it is possible to compute stage 3 and so on until stage 1 is determined. The value of stage 1 at time zero is the real option value for the project.

The value of further stages increases as the technical uncertainty is cleared, i.e., as we move forward in the stages. In this RO analysis, the defer option is considered up to two years (the idle time between the original R&D project would finish in 2002 and one year prior to the first commercial one, which is 2006[4]) plus the option to abandon at each node. The value with managerial flexibility is 0.626 M€ (ROI = 14%).

Fig. 2 shows the results: The horizontal line represents the RO value with the options to abandon and defer up to 2 years. The increasing one reflects the NPV as a function of the grants (expressed as the ratio between contribution and declared costs). The break-even grant that equals the RO value is 17.25%. This means that grants below 17.25% are not beneficial for the company because the loss of flexibility is worth more than the financial incentive.

4.3.4. Varying the conditions

There might be some variation in the base case. For instance, many funding agencies allow a deferment of 1 year. In this case, the flexibility to analyse is not the abandon option plus the 2-year defer option but abandon plus 1 year. In this case, the minimum grant would not be 17.25% but 12.5% using the same methodology. The option to abandon should stay in the analysis; otherwise, the funding agency would not provide funds for the project. Shorter or longer deferral periods would alter the minimum grant, but the rationale of the case is not modified.

5. Discussion

Whereas most of the literature has addressed the evaluation of renewable energy policy [13–19,25] from a government or funding body perspective, we have focused on the point of view of the companies. These companies accept a grant only if the financial incentive overcomes the flexibility barriers imposed, i.e., there is a break-even grant for the companies. In addition, we have focused our research within the specific R&D management framework known as stage-gate: whether the company should continue with the development, delay or simply abandon it [52]. One of the differences between our paper and the literature on stage-gate is that we have quantitatively assessed the value of the abandon and defer option. To illustrate this idea, Table 7 shows the project value under DCF with and without grants and ROA.

The base case (DCF with no grant) has no value at all; the R&D investment would equal the commercial revenues for the project. However, if granted, the total NPV improves to 1.785 M€. Nonetheless, this figure should not be taken as a total improvement because DCF is not showing the loss in flexibility, which is worth

[4] This assumption is conservative, considering the R&D project has to be finished one year before the first commercial construction starts.

techniques do not incorporate into the analysis of R&D valuation projects the obligations imposed by funding agencies once a grant is awarded. These obligations normally involve deadlines, and often, the company is not allowed to either postpone or abandon the investment.

On the one hand, grants improve cash-flow via incomes during the R&D investment period. On the other, they reduce the total value of the R&D project because of the stated limitations. The value added to a project by a grant is significantly lower than its nominal amount due to the loss of flexibility for the manager. In this case, stage-gate is useless because flexibility, which has proved to represent a significant share of the project [8,22,36], is non-existent. Therefore, a minimum acceptable grant (a break-even point) that equals the loss in flexibility has been calculated. If some options are included in the incentive program, there will be less lost value due to inflexibility and a greater minimum grant acceptable. So, flexible grant schemes could provide higher value for companies, although the economic subsidies would be lower. The analysis framework used in ROA has to include the options restrictions because of the government grant; this provides a more accurate project value.

When a policy R&D incentive is designed, it should be recognized that financial terms are considered by companies facing an R&D investment as well as side effects such as the flexibility permitted during development. Some works analyse policy evaluation models from the perspective of governments and investors [19]. However, this approach will be useful to stakeholders defining new public R&D financing policies because it provides a new way to quantify a concern faced by many companies. A new variable has been added to the debate regarding whether public R&D financing crowds-in or crowds-out private spending: the flexibility of the grant scheme. This new idea adds to the current literature and offers tools for policy makers that will help shape a more complete public R&D policy.

Further research could increase the number of RO included in the evaluation of flexibility. In addition to abandon and defer options, other possibilities, such as switch technology, may be suitable for certain markets; adaptation to new technologies is also a viable option if the technology under development becomes obsolete during the R&D phase; finally, an increase in resources to foster development, enter the market earlier and gain market share may help the project adapt to the marketplace.

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Appendix II

Impact of flexibility in public R&D funding: How real options could avoid the crowding-out effect

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Impact of flexibility in public R & D funding: How real options could avoid the crowding-out effect

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ABSTRACT

This paper explores new mechanisms to ensure grants are additional to private research and development investment with no displacing or crowding-out effect. Our results indicate that by studying the flexibility embedded in these type of projects, using the real options framework, it is possible to reduce the size of grants given by financing bodies while remaining equally attractive to companies. This result is reached due to the higher flexibility provided in potential new grant schemes. In addition to the obvious consequence of less expensive public R & D funding, there are other side benefits to this new scheme, such as avoiding the crowding-out effect while also allowing more honest and sincere research and development investment by companies because they are sharing the risk with the funding body. This paper presents a case study - an R & D project carried out in the Concentrated Solar Power sector - in which we propose and calculate the effect of providing the grant 2 years earlier with a sensitivity analysis performed over the discount rate, volatility and first commercial revenue. This paper may encourage funding bodies to consider implementing alternative grant schemes valuing the flexibility embedded in R & D projects.

1. Introduction

Private research and development (R & D) investment in renewable energy technologies is often associated with market failure from the economic perspective [1]. This designation is employed to describe a situation in which there are no conditions to reach an efficient allocation of resources [2]. Thus, companies that invest in this type of project do not realise the full potential benefits that said projects could generate. Specifically, these projects positively impact society as society benefits from a less polluted environment, for instance. In fact, society demands greater investment by private companies in renewable energy R & D projects that would naturally be carried out by companies under perfect market conditions.

One of the main reasons justifying the use of public funding for private R & D investments is precisely to overcome this market inefficiency in order to reach the socially optimal level of development [2]. In this way, public funding can help companies to receive some of the potential benefits that are generated by their R & D projects, as well as incentivising R & D projects that, due to their high cost and risk, would not be undertaken by companies despite being socially valuable projects [3].

When public funding for private R & D investment is considered, specifically by means of public subsidies, one of the questions that has attracted the attention of researchers regards the effect of these public subsidies on private R & D investment [4–6]. In particular, the specialised literature has distinguished two types of effect: the crowding-in effect, which implies that public subsidies to R & D projects tend to stimulate private R & D investment and therefore have an additive effect; and the crowding-out effect, which, on the contrary, implies that public subsidies to R & D investments tend to reduce private investment with the result that public funding would negatively displace private R & D investment. As shown by Zúñiga et al. [7], the empirical evidence of this effect is inconclusive: they found differences that may be due to factors such as the countries and industries considered, or the empirical approach conducted. In their wide literature review, these authors highlight that most studies have not considered the amount of the subsidy granted to the firm in their empirical assessments. Various factors, however, support the existence of a level of inflection in the subsidy amount that reduces private R & D investment (for instance, the rising of specialised workforce costs [8,9]; the reduction of inflection in the efficiency of these subsidies for larger projects [4,10–12]; or that these projects stop having the desired level of efficiency in relation to the social benefits that justify the existence of these subsidies).

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This paper aims to fill the gap in the existing literature by establishing a reference for policy makers and funding bodies to determine the maximum amount of public subsidies to be given to private R & D investment in order to accelerate companies' R & D activity while reducing the crowding-out effect on private investment. In order to do so, this paper applies the Real Option Analysis (ROA) to the case of an R & D project in solar thermal power carried out by a consortium of European companies.

The traditional technique of Net Present Value (NPV) presents several important limitations to value R & D projects, such as the use of a static risk-adjusted discount rate, the underestimation of the impact of economic uncertainty [13], and the failure to consider the value of the flexibility. In this respect, the ROA allows us to overcome these limitations, particularly when the uncertainty conditions that characterise the current context are considered [14] because the ROA values the flexibility which implies that managers can readjust their R & D projects in the face of the potential impact of both external and internal factors [13,15].

Thus, this paper contributes to the specialised literature by proposing an assessment system based on ROA that justifies the reduction of the amount of public subsidies for private R & D investment by showing that companies could prefer a lower public subsidy for their R & D investment, but that the public subsidy allows them greater flexibility by permitting options such as abandoning or deferring the R & D project. Traditionally, public subsidies to R & D programmes, such as the European Commission's Horizon2020 programme [16], restrict the flexibility of companies when deciding whether to continue their project. We did not confirm the anticipated results in this study; the decision to abandon a project, if this were the case, would imply the partial repayment of the public subsidy – if the funding body considers the project has not reached a minimum level - which, in turn, would reduce the probability of being granted future subsidies as a consequence of the reputation loss of the company towards the funding body. Likewise, since the probability of a crowding-out effect can be expected to increase with the subsidy size [6], other things being equal, the proposal of this paper also contributes to reducing the probability of said effect because it justifies the reduction of the public subsidy to private R & D investment. Hence in restructuring classical grant schemes by giving firms options, these companies could decide to undertake projects a few years earlier and accept lower levels of grant funding. Thus, a more flexible scheme could reduce the crowding-out effect, deferring the inflection point where grants are less efficient for attracting private investors.

The remainder of this paper is structured as follows: Section 2 presents the literature review by considering firstly, the main factors that can impact the relationship between public subsidies to R & D and private R & D investment, and, secondly, the specific influence of the subsidy size on the R & D activity of private companies. Section 3 describes a methodology known as stage-gate that companies use as an R & D framework, a reference to common R & D incentives in Spain and Europe, and the model framework employed in this paper. Section 4 presents the empirical analysis including project description, parameter estimation and scenario analysis. Section 5 addresses the discussion of results obtained in the study, and Section 6 presents the study's conclusions.

2. Rationale for R & D grants: motivation, limitations and effect on companies

This section describes the main goals sought by Governments and Public Bodies when subsidising private R & D investment., Furthermore, a set of limitations to this process is described.

2.1. Reasons to subsidise R & D investments

There are several justifications for the subsidisation of R & D investment, first and foremost being the uncertainty surrounding the technical and economic success of an R & D project and its potential benefits [17]. In fact, government R & D expenditures are funded through public agencies because it may generate social benefits beyond the direct provision of government services. A further objective is pursued with this spending: generating social benefits in the form of knowledge and "training" spillovers [4]. Second, a company will never be able to appropriate all returns of a successful R & D project because the developed knowledge can quickly and easily diffuse into the public domain [18]. These are positive externalities to society that are not remunerated to firms. Third, firms take the risk that the knowledge created in their R & D programme will be available to other companies (free riders), taking advantage of the progress of R & D programmes from competitors [18]. Fourth, external funding for R & D projects is relatively scarce. Managers are reluctant to reveal all the features of company projects to external parties, including investors, due to the strategic nature of R & D activities and to avoid disclosing critical information to competitors [19]. Investors are discouraged from supporting R & D projects because they face problems of information asymmetry, such as adverse selection and moral hazard [20]. R & D investments are more risky and their assessment is less reliable for external parties [21]. In subsidising R & D projects, both firms and investors are compensated for several reasons: the uncertainty of the project, the spillover benefits R & D expenditures provide to society, and the increased risk and reduced cost of capital. Therefore, because subsidies are a necessary tool for the development of knowledge in society, this paper contributes to optimising how they are awarded.

2.2. Limiting factors

The main factors regarding the equilibrium between public Research & Development (R & D) subsidies and private R & D investment are reviewed below. Probably the most important issue, one which also deeply affects this work, is the effect of the size of the grant given to firms and its effects on firms' R & D activity.

2.2.1. The equilibrium between public R & D subsidies and private R & D investment

The results of studies on the relationship between public R & D subsidies and private R & D investment are highly heterogeneous due to, among other reasons, the differences between each analysed industrial sector, the country to which the firms belong, and the methodology employed [7]. In the specialised literature, it is nevertheless possible to distinguish some factors that have been frequently considered, such as the size of the firm, the economic context, the type of incentive, and the recurrence in the public funding. As it is most likely the most important issue, the size of the grant will be discussed separately in following subsections.

2.2.2. Size of the firm

As regards the size of the firm, Busom [22] found in a sample of Spanish companies that smaller firms are more likely to apply for and be granted a subsidy. This is probably aligned with the public agency's goals, which may be to incentivise R & D investment in small and medium enterprises (SMEs). In the same sense, in another study on Spanish firms, González and Pazó [23] concluded that subsidies have a greater effect on inducing new R & D activities in smaller firms. Meanwhile, Ali-Yrkkö [5] concluded that receiving a positive decision to obtain public R & D funds increases privately financed R & D and that this effect is also bigger in large firms than in small firms, although the results of Lööf and Heshmati [24] show that there are additive effects of public R & D financing on private research expenditures only for small firms. Duguet [25] considered a sample of French firms and found that the probability of being awarded a subsidy increases with the debt ratio and the importance of privately funded R & D, as well as with the size of firms. Görg and Strobl [26] conducted their study on

Irish firms and concluded that for small domestic plants, grants serve to increase private R & D spending. In their study of a sample of Turkish firms, ÖzceliK and Taymaz [27] found that smaller R & D players benefit more from R & D support and therefore with better performance research, which suggests again that public R & D support is likely to play a more important role in stimulating private R & D in small firms. Moreover, regarding Belgian firms, Meuleman and De Maeseneire [28] found that obtaining an R & D subsidy provides a positive signal about the quality of small and medium-sized enterprises and results in better access to long-term debt. They further found that investors and banks may require firms to obtain an R & D subsidy as a condition for receiving funds.

2.2.3. Economic context

In relation to small and medium-sized enterprises but also considering the influence of the economic context in their study, Hud and Hussinger [29] analysed the impact of public R & D subsidies on the R & D investment of German companies during the latest economic crisis. They found an overall positive effect of R & D subsidies on R & D investment attitude from companies, although there is evidence of a crowding-out effect during the 2009 crisis. Furthermore, when the German economy started to recover in 2010, the subsidy effect was smaller than in the pre-crisis years. Wiser and Pickle [30] also considered the influence of the economic and political context in which companies develop the power plant financing process for renewable energy projects. They conducted five case studies showing policies that do not provide long-term stability or that have negative secondary impacts on investment decisions will increase financing costs and therefore could dramatically reduce policy effectiveness. This work specifically highlights that the importance of policy stability to renewable energy developers and financial investors should not be underestimated. In fact, changes in renewable energy subsidies have tended to be abrupt and therefore disruptive to developers and investors.

2.2.4. Type of incentive

The effect of the type of incentive on the relationship between public R & D subsidies and private R & D investment has also been considered by specialised literature. In this vein, Guellec and Potterie [31] analysed whether tax incentives and direct subsidies stimulate business-funded R & D in 17 OECD countries. They found that although tax incentives and direct subsidies stimulate private R & D investments in the short run, direct subsidies are more effective than tax incentives in the long term. In a later study also considering figures from 17 OECD countries, Guellec and Potterie [32] concluded that both direct government funding of R & D performed by firms and R & D tax incentives have a positive effect on business financed R & D and that they are more effective when they are stable over time. Another important conclusion of Guellec and Potterie [32] was that direct government funding and R & D tax incentives are substitutes. Thus, the increased intensity of one reduces the effect of the other on private R & D. More recently, Abolhosseini and Heshmati [33] compared feed-in-tariffs, tax incentives and tradable green certificates as the main mechanisms used by governments to finance renewable energy development programmes. They concluded that tax credits constitute an attractive mechanism for private investors because they directly increase investor liquidity. On the other hand, while feed-in-tariffs are a suitable mechanism as a policy to develop renewable energy sources when low investor risk is preferred, tradable green certificates constitute the most appropriate policy when the government applies a market view policy.

2.2.5. Recurrence in public funding

Regarding the recurrence of being granted public funding, the literature indicates that a firm whose R & D activity was subsidised in the past is more likely to be subsidised again [23]. Nevertheless, Zúñiga et al. [7] noted that there are different reasons supporting alternative assumptions about the effect of public subsidies on private R & D investment. For example, because firms that are granted public subsidies for their R & D are more likely to benefit from grants that reduce their own risk and cost of financing R & D projects, the odds of a crowding-out effect for frequent recipients of R & D subsidies are increased [24]. Alternatively, it can be argued that because firms that have received a subsidy for a R & D project may subsequently apply for new subsidies to keep financing the same project, it can be expected that public R & D subsidies have a crowding-in effect on these firms' R & D investments [25].

2.2.6. Size of the subsidy granted to firms

One of the most debated issues has been the effect of the grant size on the crowding-in and crowding-out effects; in other words, does increasing the amount of the subsidy also increase private spending invested in R & D projects, or conversely, does it lead to decreasing R & D expenditures by firms? Several arguments have been provided by the literature in order to explain why R & D subsidies can lead to the displacement of private R & D.

There are contrary reasons for supporting "the more the better", resulting in the crowding-out effect of private funding. This means public funding may result in an undesirable replacement effect of the private investment. The main factor hindering R & D activities is the lack of qualified personnel [9]. An inefficiency, as a result of R & D activities supported by public grants, is the higher demand for R & D personnel, increasing their wages [8]. R & D subsidies can easily translate into researcher wage increases [34].

The size of projects can be another variable to be considered as a cause of displacement of private R & D investment [10]. First, stimulation effects are more likely for large projects than for small ones. Thus, small projects have a higher tendency to lead to a crowding-out effect than larger projects. Second, a firm's R & D capacity cannot be extended at will in the short-run even if the firm is awarded public support for a project. Firms cannot be willing to make excessive long term employment commitments. If larger projects are subsidised and considering a restricted R & D employment market, firms undertake the large projects, reallocating funds and employers from other projects to the subsidised project and abandoning those previous projects. This would result in a reduction of private R & D investment. Other dangers of excessive grants are financing duplicate R & D and redirecting financing towards more risky [11] and thus less successful projects [12]. Moreover, government incentives can lead to the creation of expensive R & D facilities [4], but firms equipped with this R & D infrastructures may continue to apply for new subsidised R & D projects in order to cover these fixed costs, without regard for improved economic performance and the advancement of knowledge. The project could be concluded without social benefits and the firm would not profit beyond the coverage of its fixed costs. These firms with more experience and better equipment for R & D could prevent other companies with better projects from being awarded R & D subsidies.

2.3. Effect on companies

As Aschhoff [10] proposes, there are different effects of grants on a firm's R & D expenditures: a full crowding-out effect, if R & D subsidies substitute company expenditures; partial crowding-out, if the firm's expenditures in R & D would decrease in the situation of public funding; no effect of subsidies on a firm's own R & D; and an additional effect, if the firm increases privately financed R & D spending when subsidies are received.

The literature shows ambiguous results regarding these findings. A full crowding-out effect has been rejected by [5,26,35–38], whereas Lach [39] found a partial replacement of private R & D expenditures with public funding. Streicher et al. [40] found that private funding increases when R & D projects are subsidised by public grants. Aerts [41] asserted these mixed results are due to the heterogeneity of samples belonging to different countries and industrial sectors.

Görg and Strobl [26] found additional effects of small grants, rejecting the crowding-out of medium grants. Aschhoff [10] also showed that grants should have a minimum size to cause an impact on a firm's privately financed R & D and that medium- and large-scale grants increase firms' R & D spending depending on the size of the project.

Larger projects are more dependent on public funding. Guellec and Pottelsberghe [32] found an inverted U-shaped curve in the relationship between public subsidies and private expenditures in R & D funding. The subsidy effect is positive but marginally decreasing up to a certain threshold, beyond which the effect becomes negative. This confirms a crowding-in effect of moderate grants and a crowding-out effect for subsidies beyond a certain level [7].

3. Methodology

A numerical case is presented in this work using the same methodology as in Martín-Barrera et al. [42], but in this case, the point of view is the funding body and not the company. For the funding body strategy, however, it is necessary to understand how companies think, value and behave to provide the right incentives that fit their needs.

The first subsection will explain how companies manage R & D using the stage-gate approach [43], followed by a discussion of the most common incentives in Spain and the effect they produce in companies. Finally, a description of the real options (RO) framework and its application on valuing managerial flexibility is presented so that funding bodies can take it into account.

3.1. R & D framework in companies: stage-gate

R & D projects, in contrast with traditional large projects, differ mainly in the high uncertainty related to the investment, not only due to the uncertainty of the market demand for the product being developed but also to the probability of technical success. Therefore, companies must adapt their investment in order not to commit excessive resources to a potential failure. Cooper [43] proposed a scheme by which each phase of the R & D project – namely the initial design, advanced design, first prototype, scale-up, and commercial – is given a specific budget and deadline. By doing so, the project is forced through a review process before beginning a new phase. These periodic revisions allow the managers to pause the development, cancel (kill) the project if the expectations are not promising, or the reverse, boost investment to reach the goals earlier than originally planned. These options on the part of managers are essential to the point of this article.

First, the mere option of companies to abandon the project adds value to the R & D investment because not all the resources must be committed at the outset. This may seem obvious; however, using traditional DCF techniques, this possibility is not modelled.

Second, the company has the option to defer (pause) the project for a few years to gain information about the market or the technology. This delay also has value because if the new market expectations are more promising, the company can continue the R & D project while retaining the possibility to abandon it in the future. Again, traditional DCF cannot include this deferment action in the model.

Third, if the technical success seems to be even better than initially planned or the market demand is greater, the company can allocate more resources to finish the R & D project earlier and therefore arrive sooner to the market. As DCF does not model any change during simulations, this possibility is again neglected.

3.2. Common R & D incentives in Spain and Europe

There are plenty of incentives for R & D projects, as explained in the literature review of Section 2. The subsidies most frequently used in Spain and given by the European Commission are direct funds to undertake an R & D project. Tax incentives are more oriented to past R & D activities or the commercial exploitation of results rather than to initiate new projects.

Depending on the technical maturity of the technology, being the distinction between Research and Development, and the type of the beneficiary of the incentive (privately or publicly held, small, medium or large company), there is a range of incentives between 25% and 100%. For mature projects, Spanish funding starts at 25% for large companies. This funding rate increases up to 100% for Research projects and/or R & D centres.

In addition to the financial help, there is a drawback for companies accepting these incentives, namely, the lack of flexibility. Accepting one of these grants imposes a deadline to finish the project based on a project chart and the minimum execution of budgeted costs. The three options explained above contrast somewhat with the traditional way of valuing incentives. These drawbacks are completely ignored by DCF because this model would not include the lack of flexibility imposed nor the potential advantage of developing a technology or product earlier or faster.

Using the RO framework, a more suitable tool for valuing these options will be taken into account and a recommendation for funding bodies will therefore be proposed.

3.3. Model framework

The structure of the model will first determine the value of the project using DCF and NPV. To avoid excessive noise in the model, an old project has been chosen so that there is no uncertainty in the market demand. DCF is applied to the R & D investment costs, the accepted grant, and the commercial revenues; the NPV is straightforward. One of the ideas in this paper, however, is to accelerate the start of the project by two years, although the commercial revenues start flowing in the same year. In this case, a larger grant would be required.

By using real options valuation (ROV), the existing flexibility embedded in the project is evaluated, determining the equivalent grant.[1] Different modifications of the case will be presented, all of them calculated using ROV to include the managerial flexibility.

NPV analysis presents limitations with regard to the assessment of R & D projects. Specifically, according to Borissiouk and Peli [13], two important limitations of this method are that firstly it uses a discount rate that is constant, although different rates should be used at each R & D stage due to the changes in future uncertainty; and secondly, NPV tends to underestimate the potential value of projects because it ignores the impact of economic uncertainty. Specifically, Borissiouk and Peli [13] argue that the value of managerial flexibility to adjust the development process (of a technology, in our case) to the uncertainty is disregarded [44]. Similarly, Martín-Barrera et al. [42] highlight that NPV underestimates the value of R & D projects because, although flexibility adds value to R & D projects, this method fails to adequately reflect the flexibility of decision-making.

Managerial flexibility is particularly necessary for the assessment R & D projects because their development takes place over decades and their return is not generally achieved in the short-term [45]. Their profits are collected in future investment opportunities following a successful R & D project [46]. With specific regard to Renewable Energy projects, the assessment using NPV is not suitable due to the fact that such projects are subject to the high volatility of energy markets during their prolonged development [45,47]. In this regard, a full review of traditional methods used in energy markets, besides NPV, that are suitable for assessing energy projects can be found in Santos

[1] We will define the *equivalent grant* as the grant given (either sooner or later, although in this case we will consider sooner) that equals the value of a project for the company compared to the grant given in the reference year.

et al. [15]: internal rate of return, return on investment, payback period, benefit-cost ratio and levelised cost. These traditional methods consider risk but, ignoring management opportunities arising in the duration of project, they do not take into account the possibilities for reducing risk with the management of investments.

For the purposes of simplicity, only two options are considered from the company's perspective: defer and abandon. For the funding body, it will be interesting to analyse the effect on companies undertaking the R & D project earlier. This may lead to the company obtaining commercial revenues and the country benefitting from technological development sooner.

4. Numerical case: project description, parameter estimation and scenario analysis

This case is a new perspective on the situation described in [42], in which a company faced the dilemma of accepting or rejecting a grant to finance a R & D project. In that case, besides the financial benefit of the grant, the drawback was the reduction of flexibility imposed by the European Commission. Therefore, a minimum grant was required to compensate the value lost on flexibility.

This new perspective raises a different approach, however: the recommendation will be aimed at the financing body rather than the companies. The purpose of this numerical case is to illustrate the maximum grant a financing body should offer to companies in order to accelerate their research, this value being lower than the 100% that may crowd out private investment.

In other words, because there is a minimum grant above 0% companies should require, there must be a maximum grant below 100% financing bodies should not exceed.

Although this case is based on a specific technology, the value of its presentation resides in the possibility of subsequently extrapolating the methodology to any other technology. The use of ROV is not Renewable Energy specific, but applicable to any R & D project undertaken by a private company or group of companies which presents flexibility. Furthermore, this case is not dependent on the European system of grants, but applies to any subsidy provided worldwide which provides an economic incentive to private companies while limiting flexibility in any way -setting a deadline, for example.

In this section, we present the numerical case in which we compare the original investment the company made and the maximum equivalent grant given by a financing body (the European Commission in this case) that would have been necessary to accelerate the project by a couple of years. Subsequently, due to the high sensitivity of certain parameters, a further analysis is undertaken under different assumptions.

As previously mentioned, the choice of an old project is intentional for two main reasons: (a) The main difference in using an ongoing project would be the need to project the total market and the corresponding market share captured by the R & D project results. This would complicate the analysis by adding more uncertainty to the calculations and deviating attention from the ROV. The significant advantage of using old technology is that all the potential revenues of the project are perfectly defined. Furthermore, (b) this case was presented by Martín-Barrera et al. [42] from the company's point of view. By using the same case, this analysis complements the previous one by adding the funding body's perspective. Thus the full analysis is performed and determines on the one hand the minimum grant a company should accept and on the other, the maximum grant a funding body should offer.

4.1. Project description

This project describes the development of a new component for Concentrated Solar Energy (CSP). This technology complements the traditional Photovoltaics (PV) using the Sun as source of energy.

Table 1
Eurotrough I & II Start and End Dates, Declared Costs and EU Contribution.

Contract	Start Date	End Date	Total Declared Costs	EU Contribution
Eurotrough I	1-Ago-98	31-Jan-01	2,402,514 €	1,199,899 €
Eurotrough II	1-Oct-00	31-Dec-02	1,993,707 €	996,851 €

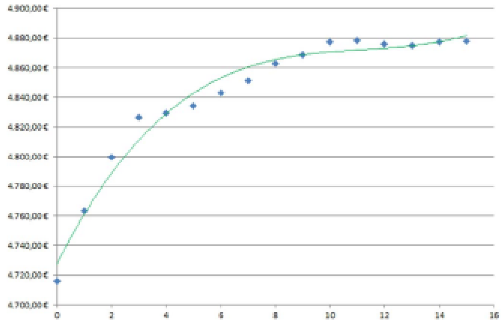

Fig. 1. ET-150 versus LS-3 NPV improvement (€) as function of storage hours (h) normalised to MW installed.

Together, there could be more than 400 GW of electrical capacity installed by 2035, according to the International Energy Agency (IEA) [48]. CSP is divided into two technologies: tower and troughts; however, both are based on the same principle which is to concentrate sunlight using mirrors and produce heat to drive a steam turbine. The tower uses trackers that follow the sun and concentrate light onto a solar receiver on the top of the tower. The trough (or parabolic trough) consists of a linear parabolic reflector that concentrates light onto a receiver positioned along the reflector's focal line [49].

This R & D project seeks the development of a new 150-metre-long trough as opposed to the former 100 m LS-3 used by its competitors. Besides the economies of scale provided by a larger component, this tracker has a lighter design that reduces operation and maintenance costs due to easier mirror cleaning, and fewer components. The R & D project name was 'Eurotrough', and it was carried out by a consortium of companies in the late 1990s [50]. Eurotrough received two different grants from the European Commission (EC) called Eurotrough I and Eurotrough II. Table 1 describes the start and end dates, the cost declared by the consortium, and the grant received from the EC called the EU contribution.

The project started in August 1998 with a grant of approximately 50% of the total declared cost. The question is: how much grant money would have been necessary to bring forward the investment by two years, i.e., to 1996? Of course, a 100% grant will always incentivise companies, but we argue that this is not the optimal funding rate.

4.2. Parameter estimation

Although CSP plants are large, complex installations with hundreds of design parameters [49], there are two particularly important aspects that roughly determine the size and cost: the nominal output, which defines the size of the steam turbine, and the storage capacity, expressed as the number of hours the plant is able to work at full load with no sun. The higher any of these two parameters is, the larger the solar field is. A larger solar field positively impacts on the benefits of using more efficient trackers since the benefit is multiplied more times over.

Table 2
NPV of commercial revenues using Eurotrough rather than LS3 discounted at indicated year.

Year	Commercial revenue of R & D project
2006	243,159.55 €
2007	952,284.55 €
2008	1,296,778.64 €
2009	1,398,113.19 €
2010	3,343,509.25 €
2011	2,703,466.25 €
2012	136,322.02 €
2013	1,013,243.07 €
Total	11,086,876.50 €

Table 3
Value of the parameters for the binomial tree of the original case (investment in 1998).

Parameter	Value
(1) Stock price S_0	3,634,194.92 €
(2) Discount rate r	10%
(3) Risk-free rate rf	5%
(4) Volatility σ	30%
(5) Exercise price 1 X_1	808,838.00 €
(5) Exercise price 2 X_2	808,838.00 €
(5) Exercise price 3 X_3	808,838.00 €
(5) Exercise price 4 X_4	996,853.50 €
(5) Exercise price 5 X_5	996,853.50 €
(6) Duration stage−1 T_1	1
(6) Duration stage−2 T_2	1
(6) Duration stage−3 T_3	1
(6) Duration stage−4 T_4	1
(6) Duration stage−5 T_5	1
(7) Incremental time step δt	1
(8) $u = \exp(\sigma\sqrt{\delta t})$	1.34986
(8) $d = 1/u$	0.7408
(9) $p = (\exp(rf\delta t) - d)/(u-d)$	0.5097

The improvement of the new trough over the previous one is clearly described in [42], in which different locations were simulated using incremental storage hours. The results are given in Fig. 1 which shows the incremental NPV per hour of storage, normalised to electrical megawatt (MWe) of installed capacity.

With these results, determining the market revenues of the technology is straightforward because all the commercial power plants that use this technology are already known and no new plants will be built using that technology. The fact of using an old R & D projects helps to determine the exact market revenues. If the project were online, these revenues should be estimation based on market share projections.

NREL [51] details all the commercial power plants using Eurotrough worldwide, combining the list (which details electrical capacity and number of storage hours) and the increments in NPV per MWe and storage hour given in Fig. 1. The total NPV due to technology at the beginning of each year is shown in Table 2.

to assess the value of flexibility embedded in the project, the necessary parameters for the use of ROV are defined in Table 3 and explained here.

(1) S_0 is the value of the underlying asset, calculated by discounting to 1998 all of the NPV of every single CSP plant using Eurotrough built worldwide from Table 2.
(2) Discount rate (r) is the opportunity cost of the company undertaking the investment. There is a sensitivity analysis based on discount rate for being one of the parameters that mostly affects the results.
(3) Risk-free rate (rf) is the discount rate assumed to be the riskless discount rate on the basis of the U.S. Treasury spot rate of return, with maturity equivalent to the option's time to maturity.
(4) Volatility (σ) is the risk of the expected returns. The market risk has been eliminated using a technology that has been already implemented. There is a risk associated with the performance of the CSP plant, however, depending on the weather, the availability factor of the plant, variations in the price of labour or certain commodities, such as water for cleaning mirrors. In this case, a volatility of 30% is determined. Nonetheless, there is also a sensitivity analysis of the volatility.
(5) Exercise price of period i (X_i) means the cost of undertaking stage i. The R & D project has been divided into 5 stages (each being one year) in which the company can decide whether to continue (exercising the option at price Xi) or abandon at the current stage. The cost of each period is extracted from Table 1, assuming Eurotrough I is undertaken in 1998, 1999 and 2000 (with the same investment each year, although the period in 1998 is shorter), and Eurotrough II is undertaken in 2001 and 2002.
(6) Duration stage (Ti) is the length of each stage. It is assumed to be one year, indicating that the company could abandon the project at the beginning of each year following the stage gate approach [43].
(7) Incremental step (δt) is the discrete periods into which the model is divided. In this case, the step is one year.
(8) u and d are the RO parameters applied to the binomial tree according to [52] y [53]. S_0 is the initial value of the asset, but in the first time increment, it could either go up or down and from there continues to go either up or down in the following time steps. The up and down movements are represented by u and d factors, where $u > 1$ and $d = 1/u$. The magnitude of these factors depends on the volatility of the underlying asset.
(9) p is the risk-neutral probability, which makes it possible to use the risk-free rate as a discount rate according to [53].

4.3. Scenario analysis

In this section, the objective is to compare the original investment (1998 with 50% grant) with different volatility and risk scenarios in

Table 4
Cash flow of the original investment in 1998. All figures in k€ unless otherwise stated.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eurotrough I			− 801	− 801	− 801														
Eurotrough II						− 997	− 997												
Grant				1 200			997												
Commercial revenues											243	953	1 297	1 398	3 344	2 703	136	1 013	
Total	–	–	**− 801**	**399**	**− 801**	**− 997**	–	–	–	–	**243**	**953**	**1 297**	**1 398**	**3 344**	**2 703**	**136**	**1 013**	–
Discount rate [%]	10																		
NPV (@1998)	**1 785**																		
Total R & D investment	− 4 396																		
ROI [%]	41																		

Table 5
Cash flow of the original investment moved to 1996 with two different discount rates. All figures in k€ unless otherwise stated.

	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014
Eurotrough I	−801	− 801	− 801																
Eurotrough II				− 997	− 997														
Grant		1 200			997														
Commercial revenues											243	953	1 297	1 398	3 344	2 703	136	1 013	
Total	**− 801**	**399**	**− 801**	**− 997**	–	–	–	–	–	–	**243**	**953**	**1 297**	**1 398**	**3 344**	**2 703**	**136**	**1 013**	–
Discount rate [%]	10	13																	
NPV (@1996)	**1 156**	**322**																	
Total R & D investment	− 4 396	− 4 396																	
ROI [%]	26	7																	

Table 6
Updated parameters for the investment in 1996.

Parameter	Value
(1) Stock price S_0	2,087,028.08 €
(2) Discount rate r	13%
(4) Volatility σ	40%
(6) Duration stage−1 T_1	3
(8) u = exp (σ√δt)	1.4918
(8) d = 1/u	0.6703
(9) p = (exp (rfδt) − d)/(u-d)	0.4637

1996 if the EC had tried to boost the investment. Recommendations are posed for discussion in Section 5.

4.3.1. Original investment in 1998

The original investment was decided in 1998. At that time, with the costs of Table 1, the revenues from Table 2 and the discount rate from Table 3, the NPV of the project was nearly zero. Due to the positive effect of the grant, however, the NPV rose to 1.79 M Eur., meaning a ROI of approximately 40%. The detailed cash flow is included in Table 4.

In [42], there was a study of the positive financial effects of the grant versus the obligations imposed by signing a contract with the EC to develop the project. In fact, a minimum grant of 17.25% was determined as the break-even point between the improvements due to the EC contributions minus the value lost because of the lack of flexibility.

4.3.2. What would be the required grant to bring the project forward to 1996?

According to Brown et al. [54], because R & D knowledge spills across firms and even countries, suggesting that socially optimal rates of R & D are likely to be much higher than privately optimal levels, R & D faces financing constraints such that its private investment may be below the optimal level. In Europe, there are funds to finance sustainable energy projects to overcome market failures [55].

For any funding body, and for society in general, it is advantageous to research and develop new technologies as soon as possible to boost the technological potential of the country and help its economic growth.

The further from the market a new idea is, however, the riskier for the promoter. From this point forward, we will assume that even the EC wants the consortium to develop Eurotrough a few years earlier; the first commercial plant is still built in 2006. This assumption is the most negative for the company because revenues are received much later than the investment. However, we have decided to explore only the EC initiative to bring the inversion forward to 1996, without any side benefits, such as receiving revenues sooner. By doing so, the task is only focused on the grant. It is reasonable to think that the sooner the R & D project is finished; the sooner a new commercial power plant will be built. Therefore, if the R & D project had been performed in 1996, the first commercial power plant could have been built before 2006. This idea will be explored in greater detail at a later point.

The selection of 2 years is considered reasonable because a 1-year period has a moderate effect and 3 or more years have a deep impact on the parameter estimation because a much higher volatility applies. It is unlikely that companies could start much earlier than 2 years simply due to the state of the art.

With these values, the NPV in 1996 with everything else equal (see cash-flow in Table 5) would be 1.16 M Eur. This assumption is not realistic, however, as there is a higher risk involved because the new trough is being developed 2 years earlier.

To better model the investment in 1996, the discount risk should be higher. A reasonable figure is 13%, although sensitivity analyses are performed in this paper. In this case, the NPV drops to 0.32 M Eur. This means it is highly unlikely any private company would continue with the project so early on.

Therefore, any funding body willing to accelerate the R & D would need to increase the grant so that it equals the higher risk companies are facing.

With regard to Research projects (further from market, higher risk), typically there are grants that cover up to 100% of the costs. If this were the case, the NPV would be 1.99 M Eur with the adjusted discount rate of 13%. This figure is even higher than the original of 1.79 M Eur the company had in 1998.

By fine-tuning the incentive to equal the NPV of 1998, a grant of 94% would be required. As will be discussed in the following section, however, very high incentives are not optimal.

4.3.3. RO model

In the previous sections, the value associated with the flexibility of the project has not been taken into account. This flexibility will impact the required grant.

In [42], the flexibility of the project was calculated in 1998, using the same parameters as shown in Table 3. That case sought the equilibrium between grants and the loss of flexibility imposed. The main flexibility of an R & D project is split into two potential actions managers can take, as stated above: i) delay the development of the project until more information about the market and the potential profitability is gathered, and ii) abandon the R & D project if it is not profitable.

Because this case faces new characteristics, it is necessary to update some of the RO parameters of Table 3. The updated parameters are redefined in Table 6.

(1) Stock Price S_0: the new value is lower than the original because the net present value is not at 1998 but at 1996, applying a higher discount rate.

(2) Discount rate r: as discussed in the previous section, a higher

Table 7
Evolution of the underlying asset and real option value at each time step.

TTTime step	0	1	2	3	4	5	6	7	8
	S0	S0·u	S0·u^2	S0·u^3	S0·u^4	S0·u^5	S0·u^6	S0·u^7	S0·u^8
		S0·d	S0·u·d	S0·u^2·d	S0·u^3·d	S0·u^4·d	S0·u^5·d	S0·u^6·d	S0·u^7·d
			S0·d^2	S0·u·d^2	S0·u^2·d^2	S0·u^3·d^2	S0·u^4·d^2	S0·u^5·d^2	S0·u^6·d^2
				S0·d^3	S0·u·d^3	S0·u^2·d^3	S0·u^3·d^3	S0·u^4·d^3	S0·u^5·d^3
					S0·d^4	S0·u·d^4	S0·u^2·d^4	S0·u^3·d^4	S0·u^4·d^4
						S0·d^5	S0·u·d^4	S0·u^2·d^5	S0·u^3·d^5
							S0·d^6	S0·u·d^6	S0·u^2·d^6
								S0·d^7	S0·u·d^7
									S0·d^8
Evolution of the underlying asset value [figures in k€]									
	2087	3113	4645	6929	10,337	15,421	23,006	34,320	51,200
		1399	2087	3113	4645	6929	10,337	15,421	23,006
			938	1399	2087	3113	4645	6929	10,337
				629	938	1 399	2087	3113	4645
					421	629	938	1399	2087
						282	421	629	938
							189	282	421
								127	189
									85
Stage−5 option value [figures in k€]									
	1 514	2 458	3 922	6 155	9 521	14,563	22,104	33,372	50,203
		842	1 427	2 366	3 833	6 071	9 435	14,473	22,009
			416	752	1 324	2 263	3 743	5 981	9 340
				166	329	638	1 200	2 165	3 648
					41	94	212	481	1 090
						–	–	–	–
							–	–	–
								–	–
									–
Stage−4 option value [figures in k€]									
	1 120	1 930	3 257	5 374	8 663	13,661	21,155	32,375	
		527	967	1 738	3 043	5 169	8 487	13,476	
			196	393	776	1 496	2 795	4 984	
				44	100	227	515	1 168	
					–	–	–	–	
						–	–	–	
							–	–	
								–	
Stage−3 option value [figures in k€]									
	837	1 527	2 722	4 722	7 938	12,899	20,355		
		321	640	1 253	2 393	4 407	7 686		
			75	171	388	879	1 994		
				–	–	–	–		
					–	–	–		
						–	–		
							–		
Stage−2 option value [figures in k€]									
	568	1 114	2 139	3 998	7 177	12,099			
		150	333	737	1 631	3 607			
			7	15	35	79			
				–	–	–			
					–	–			
						–			
Stage−1 option value [figures in k€]									
	387	794	1 614	3 236	6 376				
		71	162	366	830				
			–	–	–				
				–	–				
					–				

discount rate must be applied because the decision to initiate the project is taken 2 years earlier.

(4) Volatility σ: similar to the discount rate, having up to two extra years induces a higher volatility to the system. Volatility has been escalated according to the discount rate.

(6) Duration stage-1 T_1: this value increases to 3, the original one-year value plus the two additional years.

(8) & (9) u, d and p: these values are calculated directly from the previous ones.

To calculate ROV (without grants) and for the purpose of simplicity, a binomial tree is built, with the results shown in Table 7. This table is divided into seven sections: the upper area indicates the theoretical value

Table 8
Sensitivity analysis of the Discount Rate.

Discount Rate	g_r'	ROV (σ=40%)	g_r''	Difference
10%	68%	890.109 €	43%	25%
11%	77%	693.771 €	57%	20%
12%	86%	528.286 €	70%	16%
13%	94%	386.768 €	82%	12%
14%	101%	275.990 €	92%	9%
15%	107%	184.770 €	102%	5%

Table 9
Sensitivity analysis of the Volatility.

σ	g_σ'	ROV (r=13%)	g_σ''	Difference
30%	94%	180.446 €	88%	6%
40%	94%	386.768 €	82%	12%
50%	94%	585.338 €	76%	18%

of the underlying asset, starting with S_0, which is the NPV of the commercial revenues at 1996 (the original was calculated until 1998); in each node, the value can either go up by u or down by d. The second area is the nominal value of the underlying asset. The third area is the option value of stage-5 calculated following [52], by which the final node equals the maximum of the underlying asset value minus the exercise price or zero (if the exercise price is greater than the asset, the option value is zero because it is not executed). This last node does not account for the defer option, only for abandon because it is the company's final opportunity to exercise the option and therefore execute the R & D project. Therefore, the option value in the last node, for instance $S_0{\cdot}u^8$, would be max $\{S_0{\cdot}u^8 - X_5; 0\}$. All of the terminal nodes are calculated identically. Working backwards to the intermediate nodes, at each step, there is a comparison between exercising the option at that node and waiting for the next time step. In this case, for example, the valuation of the node $S_0{\cdot}u^7$ would be $[p{\cdot}(S_0{\cdot}u^8)+(1\text{-}p){\cdot}(S_0{\cdot}u^7{\cdot}d)]{\cdot}\exp(-r\ \delta t)$.

Once all of the option values for stage-5 have been calculated, the same procedure applies to calculate further stages in which the previous option is the underlying asset of the lower stage. For instance, stage-4 will use stage-5 option value as underlying asset. The value of stage-1 at time zero is the real option value for the project.

The value of higher stages increases as the technical uncertainty is cleared, i.e., as we move forward in the stages the R & D results are clearer as the probability of success is higher. In this RO analysis, the defer option is considered for up to four years (the period between 1996 and 1998, plus 2-year idle time –2003 and 2004 –, after the R & D project is finished in 2002 and before the first power plant starts construction) plus the option to abandon at each node. The value of managerial flexibility is 0.387 M€.

The difference in the value obtained in this project, compared to the original 1998 starting point, which is 0.626 M€ [42], is due to the higher discount rate and the two extra periods the underlying asset has been discounted.

4.3.4. Sensitivity analysis

The scenario so far has been conservative regarding the parameters. Due to the high impact of both the volatility and the discount rate on the equivalent grant, however, it is necessary to further explore the impact. Therefore, a sensitivity analysis is performed in this section in order to fully understand the implications.

4.3.4.1. Sensitivity analysis: discount rate. The discount rate is the most sensitive parameter of the model. Table 8 shows the results using the following notation:

g_r': is the grant required in 1996 to equal the NPV in 1998 with a 50% grant. This value does not consider flexibility and assumes the first commercial power plant will still open in 2006 and that the volatility is 40%.

ROV (σ=40%): is the Real Option Value (i.e., the flexibility value) depending on the discount rate. The calculations are the same as described in the previous section and Table 7. The great difference is due to the value of the underlying asset S_0 discounted at different rates. The lower the rate, the higher the initial value and therefore the higher the ROV.

g_r'': this is the grant required in 1996 to equal the NPV in 1998 with a 50% grant including the ROV; therefore, a lower grant is needed.

In conclusion, the required grant increases almost 12% per each 1% increase in the discount rate.

4.3.4.2. Sensitivity analysis: volatility. The volatility impact, however, is lower than the discount rate. Using a similar notation as before:

g_σ': the grant required in 1996 to equal the NPV in 1998 with a 50% grant, assuming the discount rate is 10% in 1998 but in 13% in 1996. Because volatility only affects ROV and this value already includes flexibility in the analysis, the value is the same regardless of the change in σ.

ROV (r=13%): Real Option Value (i.e., the value of the flexibility) depending on the volatility using a discount rate of 13%. The higher the volatility, the greater the flexibility value and therefore the ROV.

g_σ'': the grant required in 1996 to equal the NPV in 1998 with a 50% grant, including the value of flexibility. As stated before, the effect is lower compared to the discount rate.

In conclusion, the required grant decreases 6% per 10% increase in volatility, as Table 9 shows.

4.3.4.3. What if the first commercial plant were built sooner?. Although up to this point it has been assumed that the first commercial power plant was still built in 2006, if the R & D project began in 1996 rather than 1998, it is not unreasonable to assume that the first commercial power plant including this new component would have been built in 2004 and not in 2006.

Assuming a discount rate of 13% and volatility equals 40% (same values as the base case), the NPV in 1996 would have been 0.90 M€ and the ROV =0.387 M€. This flexibility value is close to the original case because there are two factors in this value:

1. A positive effect of S_0 because it is discounted from 2004 rather than 2006; therefore, the initial value is greater.
2. A negative effect because the time to exercise the options is decreased by two years.

Table 10
Comparison of three different scenarios.

Scenario	Discount Rate	Volatility	1st Commercial Revenue	g'	ROV	g"
Base	r=13%	σ=40%	2006	94%	386.768 €	82%
Optimistic	r=10%	σ=50%	2004	50%	1.100.156 €	19%
Pessimistic	r=15%	σ=30%	2006	107%	83.457 €	105%

In this particular case (r=13%, σ=40%), there seems to be a balance between the two factors.

Obviously, if the model were calculated with r=10% and σ=40%, the ROV would be exactly the same as the original case in 1998 because the flexibility would have been the same. These results show there is little correlation between the required grant and the commercial power plant being built earlier. Therefore, it is safe to continue using the 2006-year with no major impact on the calculations.

4.3.5. Combining parameters

The previous sub-sections have performed a sensitivity analysis based on two individual parameters, the discount rate and the volatility. For the sake of providing a complete overview, however, this section compares three different scenarios.

The notation is the same as before: g' is the required grant in each scenario to equal the NPV in 1998 with 50% grant. After valuing the flexibility, the new required grant g'' is lower. The results are shown in Table 10.

The main takeaway of this section is that the great value associated with flexibility depends on the discount rate; to a lesser degree, on volatility; and finally, on the commercial year. This finding creates no new problems with valuing R & D projects, however, as the discount rate is also the main factor in any conventional DCF [56].

5. Discussion

The case presented is a real case undertaken by a consortium of private companies that decided to start an R & D project in 1998 with a certain amount of grant funding (50% of the total cost). This facilitated a minimum NPV in the investment, taking into account the uncertainties associated with any R & D project, namely technical success and market demand.

According to the market estimations and the expected NPV presented in [42], the project would be undertaken only with a grant because the NPV without any grant was close to zero. This grant helps companies to overcome market inefficiencies regarding R & D [55,57].

If the financing body, for instance the EC, wanted to incentivise the companies to start the project earlier, however, thus bringing forward the commercial plant and eventually increasing competitiveness, a larger grant would be necessary to balance the higher risks borne by the companies.

To equal the NPV of 1998 in 1996, the grant would need to be not 50% but 94%.[2] This creates two drawbacks:

a) Clearly, it is a very expensive measure and it would not be possible to bring the project forward more than a couple of years. Almost duplicating the grant would mean that half of the companies would be able to receive incentives.
b) The closer a grant is to 100%, the higher the risk of projects with less commercial prospects going forward. For instance, a large R & D company or an R & D centre with no real commercial interest could apply for the grant for the sake of keeping their employees busy while covering structural costs. If there is no real risk for the company and consequently no commitment on the company's part, it is difficult to estimate whether the project has any feasible expected profitability.

The previous drawbacks are based on a non-flexibility scenario. As discussed earlier, however, the company has the option to defer the development as well as to abandon the project if the estimations are not promising. Including the value of the flexibility given by the results in Table 7, the grant can be lowered. In fact, from the required 94% to equal the NPV in 1996 at a higher discount rate, an equivalent grant of 82% can be offered. The difference between 94% and 82% is precisely the value of the flexibility. As previously stated, this value is based on a very conservative scenario and is subject to reduction as the flexibility increases. Some findings regarding this statement are as follows:

i) If the R & D project starts earlier, it is reasonable to assume the first commercial power plant will also be built earlier. This effect would increase the value of the underlying asset, as Subsection 4.3.4.3 showed (albeit with a moderate effect).
ii) If the above reasoning were not true, this would mean the project has a higher volatility value than the one used in the numerical case. A higher volatility means a greater ROV and a lower required grant in 1996. Subsection 4.3.4.2 determined a reduction of 6% in the required grant for every 10% increase in volatility. In fact, this relationship would be greater if the project's start date was advanced by more than 2 years because the impact of the volatility is increased with the length of the options.
iii) If neither i) nor ii) were true, it would mean the risk is not so high, and therefore, the discount rate would also decrease. In this case, similar to i), the underlying asset value would not only increase but would be boosted. Subsection 4.3.4.1 determined a reduction of 12% in the required grant per 1% decrease in the discount rate.

6. Conclusions

This paper presents a new approach for the application of real options that may help funding bodies to reduce the amount of grant funding given to companies, while maintaining a level of attractiveness such that private R & D investment is not affected.

One of the key findings of this work is that grants can be divided into two terms: the well-known financial incentive, the only one used to date; and a new term which is the freedom given to companies. This freedom, namely flexibility, enhances the R & D project because companies do have different options over the course of the project, as abandoning it at any time if the technical or economic feasibility is not clear; deferring its development until the market demand or certain technical barriers are clarified; or switching to a more promising technology, among others. This flexibility has been quantified using Real Options Valuation in order to determine a reduction in the grant size while maintaining attractiveness for companies.

This work has proved it is equally attractive for companies to have a traditional high grant (in monetary terms), albeit very restrictive with almost no flexibility at all, or, conversely the new paradigm presented in this paper consisting of a lower grant but with embedded options such as the opportunity to abandon the project at any time or defer the project by several years. This finding helps to contribute to the existing debate regarding the size of the grant and its crowding-out effect.

The main conclusion of this work defends the premise that a lower grant that shares the risk with private companies does entail certain advantages:

(i) According to the literature, the lower the grant, the lower the implied crowding-out effect. Therefore, lower grants are less likely to negatively displace private R & D investment.
(ii) Additionally, providing smaller grants allows the funding body to finance more projects and companies within the same budget, facilitating long-term stability in public R & D funding policy.
(iii) This risk-sharing profile obliges companies to be selective with truly feasible R & D projects forcing them to be more sincere and honest with the outcomes of R & D projects. Under the current grant system, abandoning a R & D project has two immediate consequences: the return of the received incentive and the reduced likelihood of receiving another grant in the future. Hence, current grant schemes encourage the temptation of not

[2] 94% in the base case, Subsection 4.3.4.1 performed a sensitivity analysis and this grant could be a slightly lower or even greater. The rationale of the discussion remains the same.

abandoning certain R & D failures.

(iv) Lastly, traditional grant schemes in which financing covers 100% of the investment may incentivise free-riders whose sole aim is to receive grants in order to maintain large corporate R & D structures without any commercial potential.

Nonetheless, this paper has its own limitations. This work is not suggesting that reducing grants is an always desired action for all funding bodies, as there are other side-effects not analysed here. One of the main drawbacks could be a bias towards very mature R & D projects with clear market perspectives, thus neglecting funding for research projects on large temporary horizons due to the inherently higher risk.

However, the main findings of our work highlights how funding bodies can promote R & D investment not only with financial incentives but also with other mechanisms at no cost such as providing flexibility to companies. These new mechanisms would result in more honest research and development.

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Appendix III

Each of the two cases of this doctoral thesis correspond to manuscripts that have been published in "Renewable and Sustainable Energy Reviews" (RSER) (Elsevier), a top-5 journal in its area. RSER is ranked #1 under "Sustainable Energy" by Google Scholar according to h5 index, it is also ranked in the 96th percentile of Renewable Energy, Sustainability and the Environment according to CiteScore, (#5 out of 117 journals) and have been in the Quartile 1 (Q1) since 2002 according to SJR. Appendix I presents the first paper published and Appendix II the correspondent second one. Besides this, the first article has already been cited twice without double-counting the reference in the second article.

JCR Impact Factor & Ranking

Source: http://journalinsights.elsevier.com/journals/1364-0321

The Journal Impact Factor is published each year by Thomson Reuters. It is a measure of the number of times an average paper in a particular journal is cited during the preceding two years.

For example:

A = the number of times articles published in a specific journal in 2009 and 2010 were cited by journals during 2011.

B = the total number of 'citable items' published by that journal in 2009 and 2010. ('Citable items' are usually articles, reviews, proceedings, etc.; not editorials or letters-to-the-editor.)

2011 impact factor = A/B.

ISI ranking

Journals are often ranked by Impact Factor in an appropriate Thomson Reuters subject category. As there are now two Impact Factors published – two-year and five-year Impact Factors – this rank may differ, so care is needed when assessing these ranked lists to understand which of the two metrics is being used. In addition, journals can be categorized in multiple subject categories, giving them different ranks for each subject. Consequently, a rank should always be in context to the subject category.

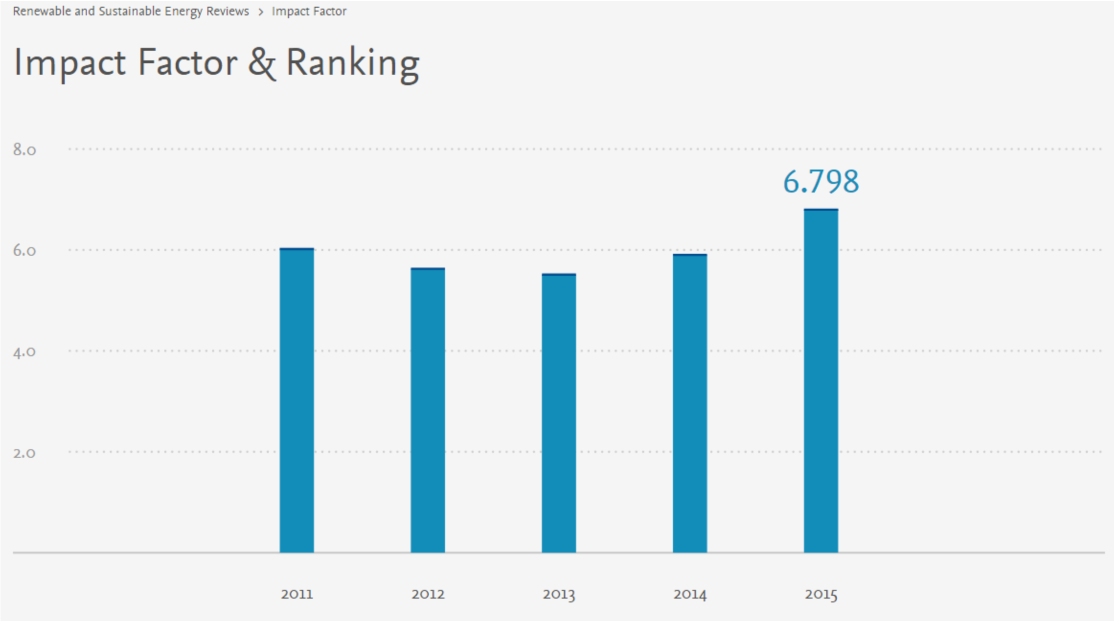


Figure 4: Impact Factor of the journal

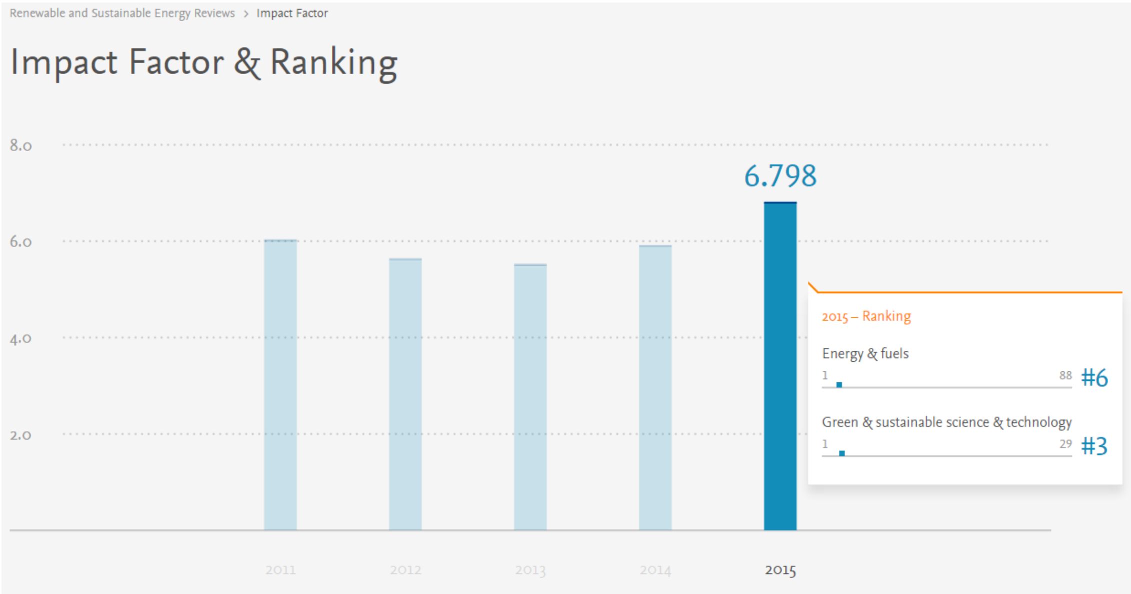


Figure 5: Ranking of the journal

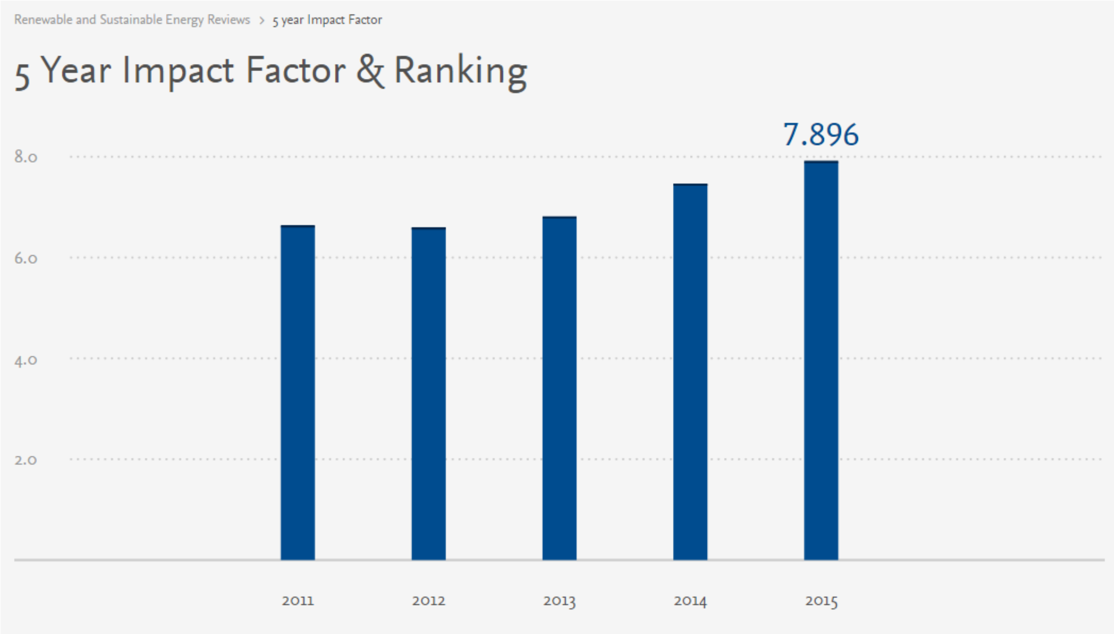


Figure 6: 5-year impact factor of the journal

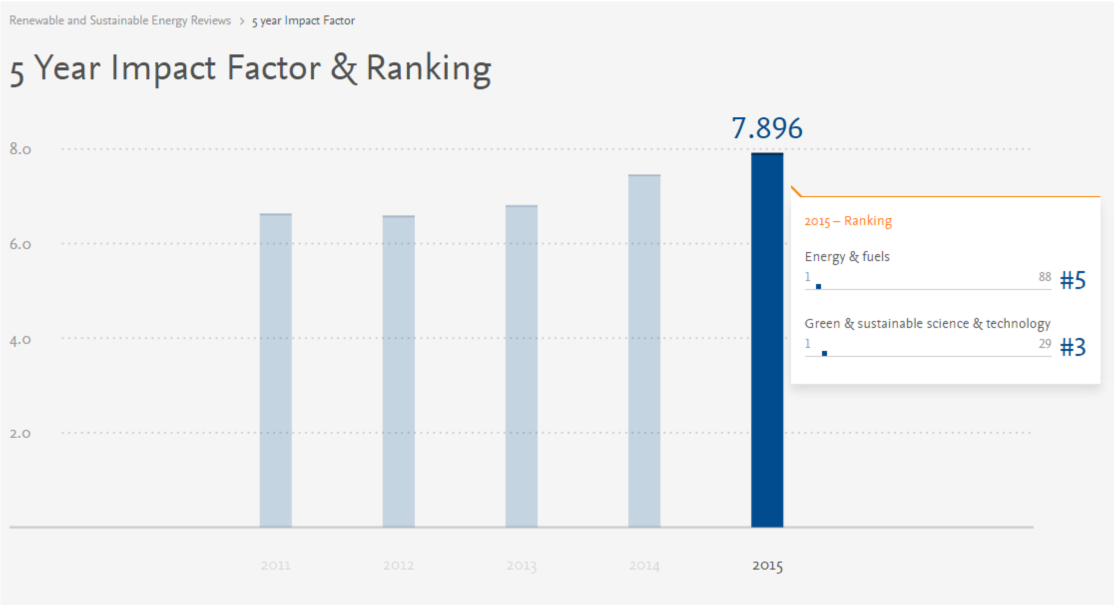


Figure 7: 5-year ranking of the journal

SJR and Quartile

Source: http://www.scimagojr.com/journalsearch.php?q=27567&tip=sid&clean=0

The SJR is a size-independent prestige indicator that ranks journals by their 'average prestige per article'. It is based on the idea that 'all citations are not created equal'. SJR is a measure of scientific influence of journals that accounts for both the number of citations received by a journal and the importance or prestige of the journals where such citations come from It measures the scientific influence of the average article in a journal, it expresses how central to the global scientific discussion an average article of the journal is.

The set of journals have been ranked according to their SJR and divided into four equal groups, four quartiles. Q1 (green) comprises the quarter of the journals with the highest values, Q2 (yellow) the second highest values, Q3 (orange) the third highest values and Q4 (red) the lowest values.

Year	SJR	Year	SJR
2006	0.954	2011	3.005
2007	2.135	2012	2.927
2008	2.632	2013	3.213
2009	2.653	2014	3.272
2010	2.476	2015	3.120

Table 15: SJR of RSER since 2006

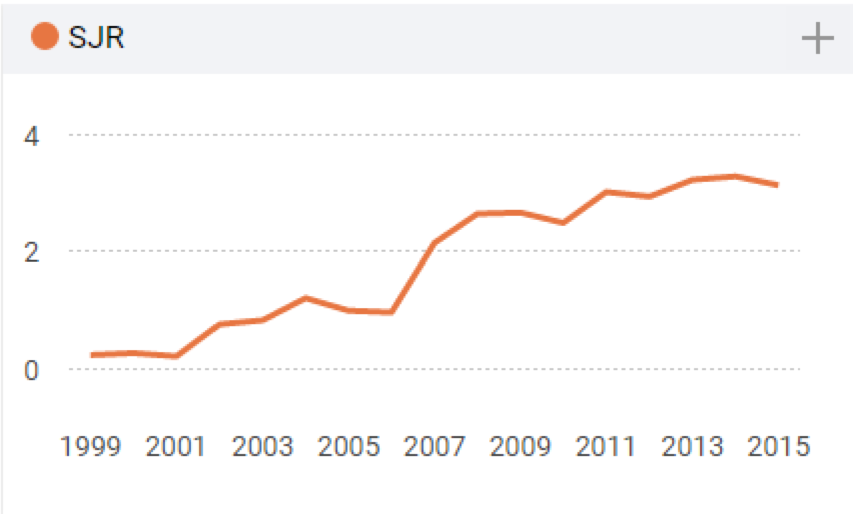


Figure 8: RSER SJR since 1999

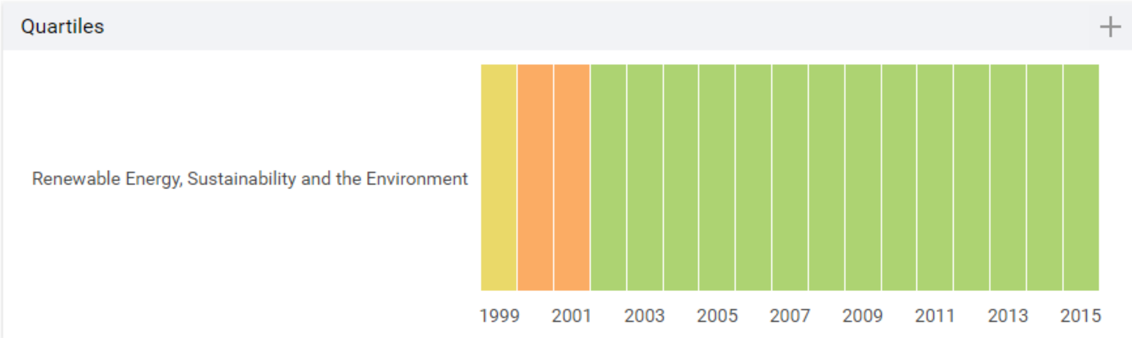


Figure 9: RSER in Q1 since 2002

h5 index and ranking under Sustainable Energy by Google Scholar

Source:

https://scholar.google.com/citations?hl=es&view_op=list_hcore&venue=ZSbkjLcARiEJ.2016

According to Google Scholar, h5-index is the h-index for articles published in the last 5 complete years. It is the largest number h such that h articles published in 2011-2015 have at least h citations each and h5-median for a publication is the median number of citations for the articles that make up its h5-index.

According to this index, RSER is ranked #1 under Sustainable Energy.

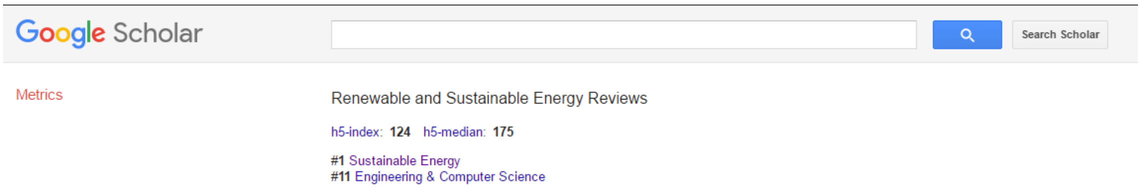
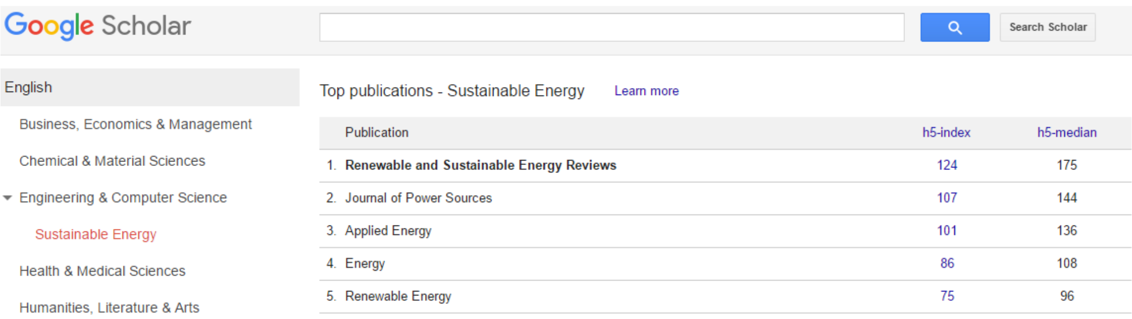
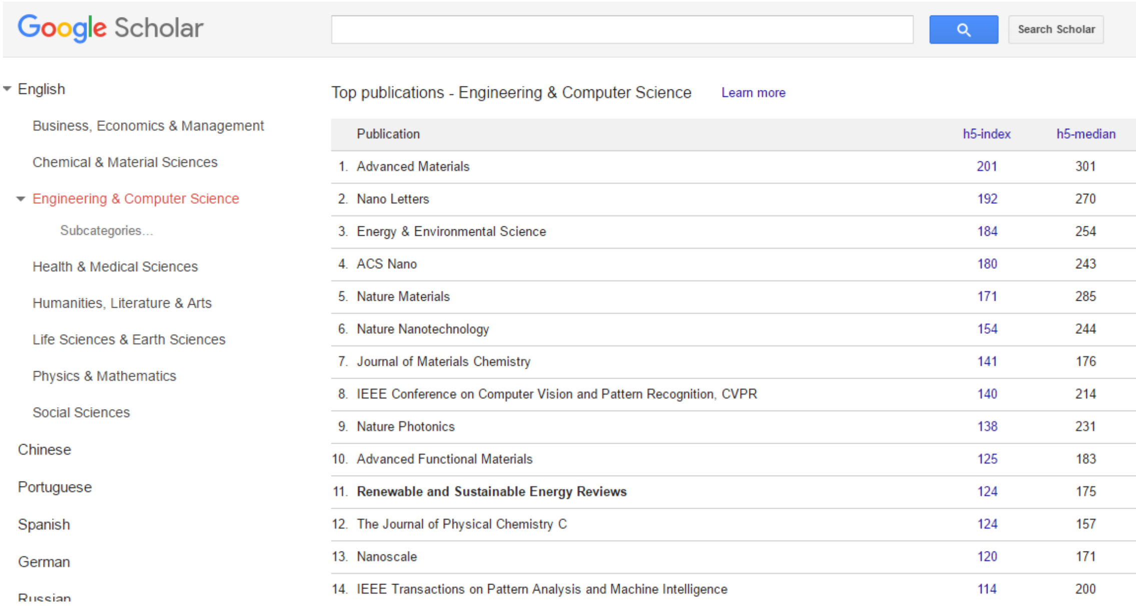


Figure 10: Google Scholar metrics



	Publication	h5-index	h5-median
1.	**Renewable and Sustainable Energy Reviews**	124	175
2.	Journal of Power Sources	107	144
3.	Applied Energy	101	136
4.	Energy	86	108
5.	Renewable Energy	75	96

Figure 11: RSER is ranked #1 under Sustainable Energy by Google Scholar according to h5 index



Google Scholar

Search Scholar

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  - Engineering & Computer Science
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  - Life Sciences & Earth Sciences
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  - Social Sciences
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- Portuguese
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- German
- Russian

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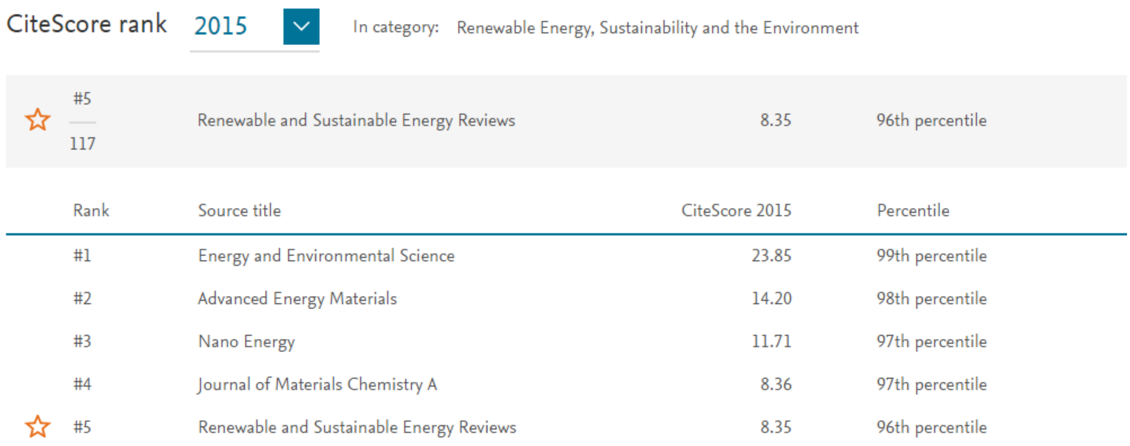
	Publication	h5-index	h5-median
1.	Advanced Materials	201	301
2.	Nano Letters	192	270
3.	Energy & Environmental Science	184	254
4.	ACS Nano	180	243
5.	Nature Materials	171	285
6.	Nature Nanotechnology	154	244
7.	Journal of Materials Chemistry	141	176
8.	IEEE Conference on Computer Vision and Pattern Recognition, CVPR	140	214
9.	Nature Photonics	138	231
10.	Advanced Functional Materials	125	183
11.	**Renewable and Sustainable Energy Reviews**	124	175
12.	The Journal of Physical Chemistry C	124	157
13.	Nanoscale	120	171
14.	IEEE Transactions on Pattern Analysis and Machine Intelligence	114	200

Figure 12: RSER is ranked #11 under Engineering and Computer Science by Google Scholar according to h5 index

CiteScore and percentile

Source: https://www.scopus.com/sourceid/27567?origin=sourceInfo&zone=refpointrank

CiteScore 2015 counts the citations received in 2015 to documents published in 2012, 2013 or 2014, and divides this by the number of documents published in 2012, 2013 and 2014.



CiteScore rank 2015 In category: Renewable Energy, Sustainability and the Environment

#5 / 117 Renewable and Sustainable Energy Reviews 8.35 96th percentile

Rank	Source title	CiteScore 2015	Percentile
#1	Energy and Environmental Science	23.85	99th percentile
#2	Advanced Energy Materials	14.20	98th percentile
#3	Nano Energy	11.71	97th percentile
#4	Journal of Materials Chemistry A	8.36	97th percentile
#5	Renewable and Sustainable Energy Reviews	8.35	96th percentile

Figure 13: RSER is ranked in the 96th percentile of Renewable Energy, Sustainability and the Environment according to CiteScore, being ranked #5 out of 117 journals.

Citations received

The first paper was published in September 2016 and has already received the following two citations:

Application of real options valuation for analysing the impact of public R&D financing on...

☐ Search within citing articles

Compound real options valuation of renewable energy projects: The case of a wind farm in Serbia
D Loncar, I Milovanovic, B Rakic... - ... and Sustainable Energy ..., 2016 - Elsevier
Abstract Renewable energy sources have become a very important issue due to environmental and sustainability concerns. In addition, most renewable energy electricity generation (RES-E) projects are characterized by considerable uncertainty and sequential
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A financial approach to renewable energy production in Greece using goal programming
E Zografidou, K Petridis, NE Petridis, G Arabatzis - Renewable Energy, 2017 - Elsevier
Abstract Investing in renewable energy production is a high interest venture considering global energy needs and the environmental impact of fossil fuel consumption. Motivated by the goals set by the European Union towards 2020, this study aims at designing a
All 2 versions Cite Save

Figure 14: Citations received on Part 1 of this doctoral thesis

ELSEVIER

Renewable and Sustainable Energy Reviews

Available online 9 November 2016

In Press, Corrected Proof — Note to users

Compound real options valuation of renewable energy projects: The case of a wind farm in Serbia

Dragan Loncar[a], Ivan Milovanovic[b], Biljana Rakic[c], Tamara Radjenovic[c]

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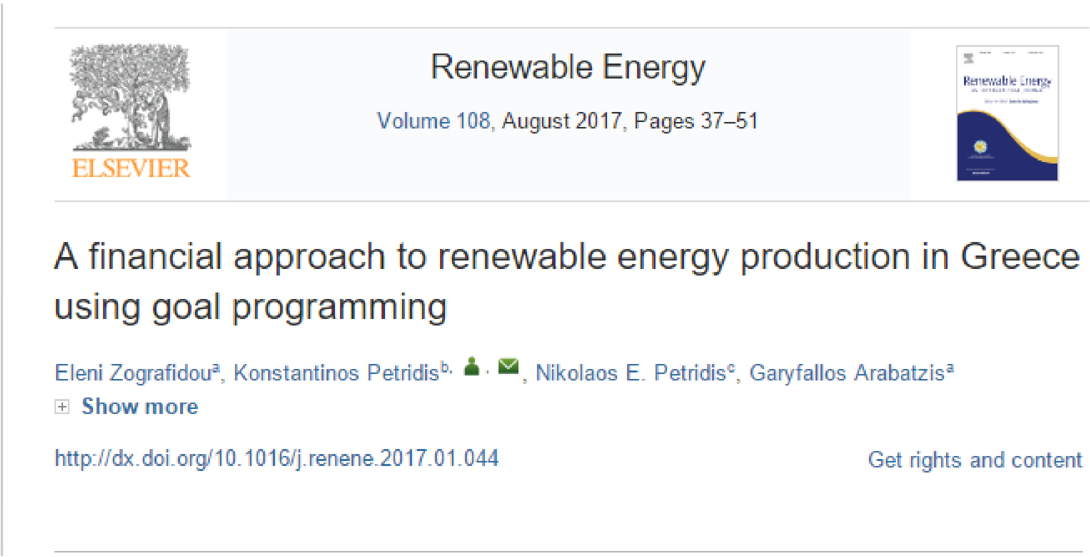
Figure 15: First citation received, published in RSER in November 2016



ELSEVIER

Renewable Energy

Volume 108, August 2017, Pages 37–51

A financial approach to renewable energy production in Greece using goal programming

Eleni Zografidou[a], Konstantinos Petridis[b], Nikolaos E. Petridis[c], Garyfallos Arabatzis[a]

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Figure 16: Second citation received, to be published in Renewable Energy in August 2017