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Valuation of a Concentrated Solar Power Project with Real Options and Discounted Cash Flow

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Affidavit

I, **Florian Schadauer**, hereby declare

1. that I am the sole author of the present Master's Thesis, "Valuation of Concentrated Solar Power with Real Options and Discounted Cash Flow", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and
2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

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ABSTRACT

Concentrated Solar Power is a exceptional renewable energy technology, as given the right conditions the energy output is subject to very little fluctuation, equal to fossil fuel fired power plants. This is the motivation to analyze the economic profitability and the impact of a Feed-in Tariff (FIT) for a plant in North Africa, a location with a high annual average of sunshine and little cloud cover. The produced electricity is sold in the Spanish market. The valuation is conducted via the application of two different methods: the Discounted Cash Flow method, to arrive at a net present value, and a Real Option Analysis (ROA). ROA can provide additional insight for projects that are subjects to high uncertainty and can valuate flexible decision-making. ROA is conducted via a binomial tree calculation. The result shows inter alia that the FIT has a high impact on the profitability of the project. No FIT results in a net present value of minus 591 million Euros for a 200MW plant, and an option value of almost zero for an eight year waiting option. A FIT that is proportional to current Spanish regulations would result in a net present value of 761 million Euros and an eight-year waiting option value of 1.066 billion Euros. Due to the high waiting value an incentive regime promoting early investments is suggested.

Keywords: Real Options, Option Theory, Project Valuation, Concentrated Solar Power.

I. INTRODUCTION

This thesis will evaluate a concentrated solar power plant (CSP) project from an economic perspective in order to explore the feasibility of financing such a plant.

Concentrated solar power is a particularly interesting and promising technology, as it is able to perform valuable services to a distributed energy supply system and therefore stands out among the renewable energy systems. The valuable services CSP can provide to an electricity grid will be presented in this introduction as they provide an answer to the question why CSP is unique among the renewable energy technologies. The valuation is of importance as can provide further insight under which circumstances the technology is profitable.

The main part of this analysis will be the application of two methods of economic evaluation. Firstly the potential economic value of a CSP project will be analyzed with the use of Discounted Cash Flow (DCF). The DCF method is a standard evaluation tool in project finance. It serves to examine the value of a project, or to compare several projects with each other, and delivers a straight-forward answer on profitability.

Secondly a Real Option Analysis (ROA) will be undertaken. This approach aims to account for the future uncertainty of the project's cash flow. The second method aims to address the shortcomings of the DCF as the DCF method faces criticism, mainly that it is a static approach (Dixit & Pindyck, 1995). It therefore can only analyze a now-or-never and all-or-nothing type of project planning. There are scholars that promote the Real Option Analysis (ROA) as an additional tool to overcome the limitations of a DCF analysis. A main argument is that ROA provides a more flexible framework that allows to plan a project in stages, hedge against down-side risks, include potential value of future expansions, and generally allows for reflecting the value that decisions can contribute to the value of a project (Copeland, Koller, & Murrin, 2000, p. 395).

It is in the very nature of a renewable energy project that the initial construction will consume the gross of the investment, as the fuel is for free. This creates an investment situation where future revenue for the whole lifetime of a plant is subject to considerable uncertainty. This uncertainty of future cash flow is increasing over the lifetime. This uncertainty can be decreased by active (e.g. prototypes) or passive learning (waiting) and a Real Option Analysis can account for the value of such procedures. Governments have the ability to provide a reliable incentive framework to promote the construction of renewable energy that will decrease the uncertainty for investors. Real Option are of particular use in resource industries, where there are reserves not yet developed and a company can choose to develop when the reserves shall be accessed, for example when the price of the resource results in maximum profit (Damodaran, 2002, p. 772). The situation for CSP is similar, as the technology is reasonably unexplored which is why there are enough available locations for developers to be able to choose when the best time of entry into a market would be. The German Aerospace Center (2009, p. 48) estimates the area in North Africa available for CSP with 3.5 million km^2, a figure which is already excludes unsuitable land due to slope, land cover, settlements, environmental impact and other factors.

I.1. The Analytical Aim and Hypotheses

The aim of this thesis is to establish whether a Real Option Analysis can reveal a significant additional value of a strategic decision-making framework for the investment in a promising renewable energy technology. Further it is of interest which investment decisions would be undertaken at which time if flexible decision-making is accounted for.

The hypotheses are:

- The technology did not yet reach a level of cost-effectiveness that would allow for the project to be financed by the revenue of the whole-sale market only.
- A governmental incentive structure is necessary to provide a basis for Engineering, Procurement and Construction (ECP) firms as well as CSP sys-

tem providers to become active. Such a governmental incentive structure will be modeled.

- The Real Option framework is better able to capture the growth potential of the technology, which will be reflected in the profitability.

In order to provide an answer for the research question and test the hypotheses the research is structured in the following way : (a) examination the two valuations models and their theory, (b) exploration which specific method of ROA is best equipped to answer the questions in this thesis, (c) framing the case and defining the input parameters, (d) the conduction and discussion of the analysis and (e) the conclusion where the findings will be presented.

I.2. Motivation

The motivation to conduct such an analysis lies with the promising aspects of the technology, which makes CSP in some ways outstanding among other renewable energy technology.

Concentrated solar power as renewable energy technology is particularly unique for several reasons. It employs to a big extent known technology, in principle it relies on a steam turbine, and uses the sun as heat source. In this way it is similar to other forms of electricity production, for example to gas or coal fired power plants or nuclear plants. The basic principle is to translate heat in mechanical movement and further to electricity (Masters, 2004, p. 191). Furthermore a CSP plant can be built in a variety of ways so that either the mid-day peak demand is answered, or the base load demand over 24 hours can be met, if the plant is equipped with heat storage.

Generation, Capacity and Electricity Demand

Power generation is categorized according to which type of demand it serves. There are certain challenges for setting up an electricity supply system. Electricity needs to be generated, fed into the transmission grid and demand and supply needs to be met at all times. This means that utilities are providing (a) base load capacity, (b) intermediate load capacity and (c) peak load capacity. Each type of demand calls for a specialized supply setup, as the base load is generally constant, and intermediate and peak loads can vary. Electricity demand changes over the course of a day as well as seasonal (Conkling, 2011, p. 303).

Conventional forms of electricity generation can be used for all demand types: base load, intermediate and peak load generation. Usually coal power plants with higher investment costs due to environmental regulation and relatively lower fuel costs are mainly providing base load capacity. Nuclear power also provides base load capacity, as the output cannot be altered. Gas turbines can be operated depending on the demand and the fuel price. For unusual high peak load demand utilities commonly make use of a way of generation that is relatively expensive in fuel, but can be switched on and off rapidly, like diesel powered generation (DLR – German Aerospace Center, 2006).

Depending on the source of renewable energy the electricity output is subject to fluctuation of energy input and therefore can contribute differently to the electricity demand. Here the *capacity factor* is important. It describes the relation of the average available load in relationship to the theoretical maximum capacity, or *nameplate capacity*. It is calculated:

$$\text{capacity factor} = \frac{\text{plant average load}}{\text{plant rated capacity}} \tag{1}$$

Normally a plant is operated below the rated capacity to reserve some peak-capacity if needed.

Some renewable energy technologies deal with a fluctuating input, which is why – if viewed *individually* without storage possibility or geographically spread overcapacity – they only provide a fluctuating range in the base load output section. The 'Trans-Mediterranean Interconnection for Concentrating Solar Power' report (Ibid.) lines out that wind power for example has a capacity factor of 15–50 percent and photovoltaic solar power 5–25 percent. However due to the fluctuation and the nature of the specific renewable source photovoltaic cannot be counted as reserve capacity. Wind power given broad geographical distribution compensating a single plants output can be counted as contribution to a reserve capacity.

Taken this figures into account it becomes clear why CSP is an attractive renewable technology. CSP has the potential to fullfil any supply function for the electricity grid in a reliable way. The type of supply depends on the plant setups. With a large turbine and no storage the plant can answer mid-day peak load demands. With a large solar field, large heat storage capacities and a small turbine a CSP plant can answer base load demand (International Energy Agency, 2010, p. 13). A hybrid plant with a gas fired turbine can be even more flexible.

There are however limitations to the realization of such a scenario, which is the availability of sunlight. To be precise the important figure here is the one of Direct Normal Irradiation (DNI) measure in kilowatt per hour per square meter per year. The Trans-CSP report (DLR – German Aerospace Center, 2006) estimates that the window to use CSP in such a reliable way closes below 2100 or 2000 kWh/m^2/year DNI.

II. TWO VALUATION TOOLS & THEIR THEORY

II.1. The Valuation of the Present Value

Investment decisions in project finance often rely on a method providing a net present value (NPV). There are several methods that essentially provide a net present value, even if the project value is expressed in a different way, for example as an Internal Rate of Return (IRR). Basically the net present value is found by calculating future incoming and outgoing cash flows and apply a value reduction the further in future a cash flow occurs via a discount rate (Brealey & Meyers, 2003, p. 15) . The main idea behind this method is the time value of money, which means the value of the money hold now is worth more than the same money in a future time (Ibid.). This is due the possibility to invest currently held money to increase its value. What adds to it as well is potential uncertainty of future money. The time value of money is a key element of finance theory (Ibid., p. 93). Not investing this money, and therefore just holding it, means to forgo this investment opportunities.

A commonly used method of calculating the net estimating the value of project finance is the Discounted Cash Flow model (Dixit & Pindyck, 1995), which is the most accurate method to arrive at the NPV.

The Discounted Cash Flow Method

The DCF method is the method of choice in this thesis to calculate the NPV of a project. As the net present value is the value of future money projected into the present time, naturally, the principle is a good tool to compare future investments. Besides the time value of money a second principle is that the net present value changes with the opportunity costs of capital. This opportunity cost is the value of the second best option one could choose as an alternative investment. As a third principle net present values compares every future cash flow at *present* value, which is why they can be added and subtracted (Brealey & Meyers, 2003, p. 93). To perform a DCF analysis one needs to predict the future cash flows for every time interval. The net present value is calculated by discounting the sum of the cash flows for each future time period at its discount factor. A simple formula for the NPV of a single future time period is the following:

$$NPV = C_0 + \frac{C_1}{1+r} \tag{2}$$

Where C_0 is the cash flow in year zero, and in case of an *investment* it is a negative figure, as it represent outgoing cash flow. C_1 is the cash flow after one time period. The value r is the discount rate. The discount rate is essential, it measures the opportunity cost of capital (Ibid., p. 15). A simple way to comprehend the discount rate is to see it as an indicator for the risk of the project. If a project does not have any risk attached, an unlikely scenario, one would use a rate reflecting secure government bonds. If a project is business as usual for a company and is neither less nor more risky than other undertaken projects, the discount rate is the weighted average cost of capital (WACC) of that company. If the project reflects a different risk however, a comparison to other projects or companies must be made to find and appropriate discount rate. The challenge in a DCF analysis is to find a fitting discount rate, and to predict future cash flows correctly. For two time intervals the NPV is calculated with:

$$NPV = C_0 + \frac{C_1}{1+r_1} + \frac{C_2}{(1+r_2)^2} \tag{3}$$

For a longer time period, with several intervals, the following formula can be used:

$$NPV = C_0 + \sum_{t=1}^{N} \frac{C_t}{(1+r_t)^t} \tag{4}$$

The formula is essentially the same as Formula 3, but is expressed in a more general manner for N time periods where C_t is the cash flow occurring in time period t, and r_t is the discount rate at time period t. This formula clearly expresses how the value of any cash flow far in the future is diminished in present value by time and risk.

This formula is made use of in the DCF analysis in this thesis. The cash flows for every year need to be predicted, which are then discounted at their respective discount factor. The sum of all Discounted Cash Flow of all future time periods are the present value (PV) of a project, and to arrive at the net present value one simply adds the initial cash flow at time zero. In case of an investment the initial cash flow is negative, in such a case the NPV will be less than the PV.

The Discount Rate

To proceed with a DCF a discount rate needs to be established. The chosen discount rate depends on the type of risk (market or private) and the magnitude of uncertainty of future cash flow (Kodukula & Papudesu, 2006, p. 39). It is recommended to not adjust the discount rate for private risk, but to capture it with a decision tree analysis. Some use a slightly adjusted market risk rate. A different approach to this would be as well to make use of the Weighted Average Aost of Aapital (WACC) (Copeland et al., 2000, p. 134), which represents business as usual (Kodukula & Papudesu, 2006, p. 41) and therefore the WACC reflects a mix of private and market risk. If the risk of a project is considerably different to the average project of a company the WACC does not capture the projects opportunity costs of capital correctly. Another way to estimate the discount rate is via the Capital Asset Pricing Model (CAPM), which uses a publicly traded asset as a risk proxy for the project in question. For this method a comparable security is essential (Copeland et al., 2000, p. 214).

Other Valuation Tools

Other tools to evaluate a project are the payback period, and the IRR. The payback period can only be seen as additional information, as it does not even shed light on the question if the project would have a positive NPV or not. The IRR is a very similar method to the DCF to begin with, as it compares the Internal Rate of Return with the opportunity cost of capital. However it has certain limitations, especially when comparing different project life durations, as the opportunity cost of capital changes over time (Brealey & Meyers, 2003, p. 110). It is therefore recommended to opt for the DCF method due to its strength to scrutinize different projects based on what value will they add from a present value perspective. Mun (2002, p. 58) described the benefits of the DCF method with the following characteristics: (a) it accounts for the time value of money and the risk involved, (b) accounting for this risk is independent from the risk preferences of the investor, as with higher risk future values are reduced more in value, (c) the data DCF uses is not prone to distortion by accounting convention, as it focuses on cash-flow only. With this set of qualities DCF produces consistent decision criteria, which can easily be compared and are economically rational. This criterion is solely the NPV. The simplicity and precision results in a wide acceptance for the DCF method. The DCF or different methods that are built around the NPV is used by 96 percent of the financial management in large companies (Teach, 2003).

Critique about the DCF

For the reasons explained the DCF is standard procedure when a management is faced with financial decisions (Copeland & Antikarov, 2003, p. 56). However there are certain limitations with this approach. The correct estimation of future cash flows and the estimation of the discount rates are crucial. Variations in the values can influence the outcome significantly. Obviously changes in the market environment, which are hard to foresee for a long-time project, can alter the outcome dramatically. The discount rate reflects the risk level of the investment, while the certainty of the cash flows is decreasing in the long run (Mun, 2002, p. 92).

All in all the DCF faces critique if it is the sole method decision-making is based on. One point of criticism is that DCF analysis does not allow for project finance decisions to be set in stages (Dixit & Pindyck, 1995). If the project environment changes at a later point the DCF model is not flexible enough to include the potential value of a choice at a later point.

A gradual development of a project however can have a value per se. A tool that does not incorporate such a value can limit the conception of possibilities. If the knowledge about a potential value is not assessed, alternative decisions might not be taken into account. As Leslie and Michaels (1997) point out, this might result in a more narrow and static mindset of decision makers. Instead of incorporating flexibility in the planning process, projects are assessed as given. That does not mean that reevaluation does not take place in decision-making during the lifetime of a project, the critique goes that the value of the possibility to make a decision at a certain stage is not accounted for to begin with. Myers (1984) makes a similar point with stressing the importance to find ways to bring the aspect of strategic planning into a financial analytical tool. The DCF model is discussed there as too static. Ottoo (2000) analyzes the DCF method from the cash-flow and not from the project planning viewpoint, and concluded that in reality cash-flow can display behavior, which cannot be accounted for in the DCF model correctly.

Dixit and Pindyck (1995) point out that DCF emphasizes the importance of the interest rate too much and neglects the question of how stable or risky future cash flow is. This is compensated in practical use by a higher interest rate than in economic predictions, which is not seen as an appropriate substitute for modeling the risk of the cash flow itself. A systematic risk for an investment is assumed, and the discount rate is the sole measure for it, therefore this procedure does not take into account the possibility of volatilities. This discount rate only reflects the negative side of the risk, the uncertainty of future cash flow, but the rewards of risks are not captured. Projects that despite high uncertainty can be rewarding, would be rejected without further examination (Kodukula & Papudesu, 2006, p. 10).

Copeland and Antikarov (2003) and Myers (1984), find it problematic to use the DCF method as it per definition undervalues every project, because it fails to estimate the values options have. This notion seems radical, and its validity cannot be assessed here, however we will later discover how Mun (2002) describes the theoretical relationship between the DCF and a ROA, which will provide a better understanding under which circumstances the DCF will produce a result subject to limitations. An example for the undervaluation of future flexibility would be growth options for strategic investments in, for example, high-tech companies. If such an investment is analyzed through a DCF perspective then the higher risk diminishes the project value, but underestimates the value of growth possibilities. These could be captured by setting up the projects in stages with an initial smaller scale to clear uncertainty and later expansion. A ROA can capture already the value of the whole scenario at once. In practice when evaluating a high-tech business usually a premium is paid during the acquisition to compensate for a lower assessment via DCF (Smit & Trigeorgis, 2006, p. 96).

A common work around for this limitation is to establish different scenarios and analyze the value of those (Leslie & Michaels, 1997). However this does not show the value a project can have if flexibility is incorporated. The idea here is that flexibility itself has a value. The value of flexibility cannot be incorporated in a scenario analysis, as it does not allow for flexibility within one scenario. The value of, say, three different scenarios that all by themselves are all-or-nothing and now-or-never investment is not same as the value to choose at any time between three different pathways.

A tool that aids decision-making should resemble reality as close as possible, without becoming too complicated. Therefore in addition to the critique summarized here, it shall be taken note of what Dixit and Pindyck (1994, p. 3) described as the realities of investments. Firstly many investments are partially or completely reversible (there is a salvage value at least), secondly there is always uncertainty about future revenue of investments and thirdly for many investments there is a possibility to postpone them for example in order to obtain better information. The Real Option framework is discussed by the critics of the DCF as a way to improve project and investment evaluation. It will be presented in the next section.

II.2. Real Option Analysis

At first a brief account on the benefits of the Real Option framework will be given. The theory behind it and the application will be presented at a later stage. The initial introduction is helpful to contrast the Discounted Cash Flow method with a tool that has a different approach to evaluation.

A prominent strand of Real Option theory is interested in the question how to translate strategic planning and project development into an evaluation framework that can account for this flexibility (Dixit & Pindyck, 1995). This is done by finding options to act, which represent management decisions like for example waiting with a project investment or investing now, or setting up a project in stages. Then the maximum value for those options is analyzed, which allows comparing decisions and their optimum timing. Real option analysis sees the present value (that can be calculated by a DCF analysis), as basis to then further calculate which additional value is created by a flexible and strategic setup.

The DCF certainly did face critique, however there is consensus that the Real Option analyze is especially valuable if the NPV is relatively close to zero compared with the initial investment costs, if there is a considerable uncertainty based on market risk, and if the project can be – or already is – set up in a strategic way resembling Real Options, like expanding or deferring a project (Copeland et al., 2000, p. 395).

There may be some critique about the DCF method, this however does not change the fact that essentially it is the basis upon which a Real Option Analysis builds. The ROA therefore improves the analysis as an additional step and compensates for the limitations of the former method. The DCF is necessary as a method to calculate the value of the *underlying asset* of a Real Option – in this work this is the economic value of the power plant. Based on the calculated underlying asset value the future uncertainty can then be modeled in the ROA. The ROA analyzes the value of options and the effect of cash flow volatility. The bases of ROA are financial options and option theory, which will be discussed now.

The Option Value

The Real Option approach is evolved from financial options and it aims to find application for the same principles in real business scenarios. Hull (2006, pp. 6-8) explains the two different kinds of financial options. The basic options are *call* and *put* options on an *underlying asset*. When talking about financial options, the underlying asset can be bonds, shares, futures, and similar financial papers. The option then gives the right, but not the obligation, to exert an action with this underlying asset. Simply put: it *reserves the right* to either buy or sell some kind of financial paper. A call option empowers the holder to buy a defined asset at a certain *time* to a certain *price*. A put option gives the holder the right to sell an asset at a defined date and price. Naturally in a market nobody grants an exclusive right to an asset for free, therefore this right to do something has a certain cost too. This is the price of having an option that is paid when buying the option. However when one wants to make use of the option for example at the date of expiration one still needs to pay for the underlying asset the agreed price. The price is referred to as the *exercise or strike price*. The date is referred to as *maturity* or *expiration date*.

Real options assume that the underlying asset of an option is not a financial paper, but a real tangible asset, like a business unit or a project (Copeland & Antikarov, 2003, p. 110). The options basically represent the possibility to *do something* with the underlying asset. In its simplest form this could be to buy an asset or invest in a project, or otherwise to abandon a project for a salvage value. To express it in theoretical terms, most Real Options can be seen as call options, which are called when the investment is made and the strike price is the cost of the investment in the project (Dixit & Pindyck, 1994). Put options like the option to abandon a project can hedge against the downside risk of future uncertainty. Further Real Option theory enables to account for the ability to defer, expand, contract, drop, change the output, or choose between several options for a project during its lifetime as a response to a changing market, and to account for the value of these choices already in advance. The deferral option is a possibility for keeping a project alive by implementing a regular reassessment procedure, if the waiting option is of high value. The option to abandon is an alteration that terminates the projects, which is easiest, as Trigeorgis (1995) concludes, if a project is set up in several stages. Expansion and contracting a project is can be applicable in for example projects dealing with natural resources or consumer cycles (Ibid.). These additional options increase the flexibility of the ROA method. The increased value can as well be calculated by adding the value of the Real Option to the NPV (Ibid.). The value of a project is then:

$$\text{strategic NPV} = \text{cash flow NPV} + \text{value of Real Option} \tag{5}$$

The added value of flexibility can be understood in the following ways: the value of the call Real Option represents a "gap" between the present value form a DCF analyzes and the current real value of a project. This gap exists if flexible decision-making is possible and there is considerable uncertainty attached to future cash flow. The question is how to arrive with a value for this gap. To model the uncertainty of future cash flow option theory assumes that the value of the underlying asset resembles a *stochastic process* – sometimes called as well *random process*. To model a stochastic process to value the "gap" between a cash flow NPV and the strategic NPV the idea of a random walk through possible future values is made use of. Black and Scholes suggested (Black & Scholes, 1973) to model after a Geometric Brownian motion, which is a widely accepted way to model stock price development as a stochastic process. The Geometric Brownian motion describes the movement of particles in a water current and is supposed to represent a kind of random walk.

In their attempt to valuate financial options along a stochastic process Black and Scholes (Ibid.) created what is now called the Black-Scholes formula. There is the argument that the precursor of this formula was described by Edward Throp (Taleb, 2010, p. 314), however the work is mostly credited to Black and Scholes. They started with describing under which condition a call option would be exercised and developed a formula to calculate its value. One will call an option if the value of the underlying asset – for example the stock price of "a single share of common stock" (Black & Scholes, 1973, p. 637) – is higher than the exercise price plus the price paid for the option itself. In this case the current value of an option is about equal the stock price minus a "pure discount bond that matures on the same date as the option" (Ibid., p. 638). The formula calculates the option value with some limitations (Ibid., p. 640).

The Development of Real Option Theory

Based on the work of Black and Scholes the idea of applying option value analysis to real assets started gain momentum. McDonald and Siegel (McDonald & Siegel, 1986) applied the principles to the timing of capital investment, which reflects a Real Option to wait. The approach was further evolved by Pindyck (1993) and Dixit and Pindyck (1994). Since the theory of financial option got established, there is a steady academic output concerning the application for real business scenarios.

Some of the earlier works on Real Options were investigating in an area where the framework can be applied intuitively, like technology development and implementation or growth potential through research and development (R&D). Here the works of Mitchell and Hamilton (1988) and Kogut and Kulatilaka (1994) were of importance. Further works followed in other areas, investigating management or investment scenarios under the perspective of Real Options and framing options of growth, waiting, switching, contracting, expanding, and other options to comprehend those scenarios (Reuer & Tong, 2007, p. 146). While there is research that follows an approach of implying options while using a less tight framework (Ibid.), in this work the more readily understood concept will be made use of, where options represent different *possibilities to act* from a management perspective. However an idea that will be drawn from is the idea of learning when later the option to expand will be taken into account. Organizational learning was investigated by Pindyck (1988), who explored the idea of planning a project in stages and possibly upscaling later on. The finding was that the opportunity cost of a firm to invest in a project is high, if the investment is irreversible and demand is uncertain. This overweighs a second effect, which is the increased value of each unit capacity. Therefore a firm's capacity would be reduced facing uncertainty, keeping an option for future demand open.

Real Option Value, Uncertainty and Strategic Decisions

To some ROA might seem paradox in the way it deals with uncertainty. In a scenario where uncertainty is high, in order to maximize the total project value, the value of the Real Option could be increased. The NPV stemming from cash flow would then be decreased (Trigeorgis & Mason, 1987). Basically this means when facing uncertainty, to develop the possibility to alter future operations, concerning output and costs, and reducing current operations. Damodaran explains the phenomena (2002, p. 779) that uncertainty about the size of a market and the magnitude of excess return decreases the value in a static analysis as the project is more risky, but if the project is seen as an *option*, then having this option is valuable in a volatile market, as one can capture the upside potential of the risk, and is not exposed to the downside risk.

Some examples can give a more complete picture of what Trigeorgis and Mason (1987) described. A prominent one is Hewlett Packard (Brealey & Meyers, 2003), which at the end of the 1980s were shipping country customized printers from their manufacturing site directly to the destination country, a process where supply and demand were often mismatched, creating a financial burden due to high inventory holding costs and other costs. Then HP chose to alter their assembling process. The goods were manufactured in a way that allowed for on spot customization in the destination country. The result was to reduce the time from months to weeks between a demand estimation was made and selling the printers on-spot. The printers could be sold anywhere in the world with changeable customization, although initial manufacturing and decentralizing the completion was more expansive. This effect was small compared to the new ability of HP to adjust supply better to demand. In essence they created a Real Option to wait, as HP bought itself time to investigate demand, and therefore reduced demand uncertainty. The cost of the option was the additional cost of operation. By delaying the process HP did protect itself against demand uncertainties through more accurate forecasts and the flexibility to interchange printers between countries.

Different examples (Mun, 2002, p. 27) are the oil and gas industry investing in equipment that enable their (partly older) refineries to alter the balance of outputs of various petrochemicals in order to match demand better, which reflects a real *switch option*. Another example is the telecommunication industry investing in infrastructure years ahead of demand to ensure capacity and speed, in order to create a first mover advantage and a high barrier to enter for the competition. This is a decision at a point when the NPV was clearly negative for the *known* cash flow. The ROA can capture the growth potential.

As these examples highlight the companies chose a strategy that comes with a costs (the option cost) in face of uncertainty to enable a different type of future operations. The option cost of course reduces the current cash flow. In this sense the examples are in line with Trigeorgis and Mason, (Trigeorgis & Mason, 1987). Due to high uncertainty a higher value is created – compared to business as usual – through the upside potential of future operations, or the downside risk is hedged. In this case, the question is how to deal with a risky situation, which might result in a higher total value of the project. To decrease current output is a strategy that might seem paradox. The model implies that the flexibility will at a later stage result in better investment decisions. An analog comparison between the Real Option method and the process of learning is made by Durand et al. (2001), who stress the importance of learning processes over time, which can be incorporated into the Real Option model by time series and path dependencies (Kodukula & Papudesu, 2006).

A good way to understand uncertainty and the Real Option framework is to see the result of the Discounted Cash Flow as the more specific case of a Real Option application. This will be further explained in the third chapter of this thesis. It shall be briefly mentioned that if uncertainty were zero the modeling of the asset value will develop along a single pathways, instead of many different potential future pathways. This means that future cash flow is known with certainty and there were no option value (Damodaran, 2002, p. 773). However with existing uncertainty the Real Option value cannot be neglected as it might be a considerable share of the total project value and therefore needs to be evaluated and implemented in the decision framework. This explains the paradox mentioned in the beginning of this section, the idea of Trigeorgis and Mason (1987) to maximize flexibility in decision-making process. It simply aims to capture the Real Option value.

Exercising an Option: Two Different Ways

Aside from the type of option describing *what to choose*, be it a call (wait) or a put (abandon) option, or the Real Options to contract, expand or other options, there is another quality used to describe the nature of an option. This distinction concerns *when* they can be exercised. There are so-called *American* options (Copeland & Antikarov, 2003, p. 12), which can be exercised at any time before the maturity date and as well at the maturity date. The decision is solely with the option holder and the right to exercise the option at any time is part of the option. On the other hand there are options, which can only be exercised at the date of maturity, the so-called *European* options (Ibid.). In many Real Option scenarios the European options are of less importance, as many options represent management decisions that can be made at any given time (Ibid.). The mere fact that a decision needs time for implementations does not make a difference of course. If for example decision, planning, engineering and construction are seen as a series of options they all can have an individual duration for implementation. They may be path depending on the earlier stage to be exercised, but once that earlier stage is completed, there is the possibility to wait with the next stage if necessary to clear uncertainty and waiting could increase the value of the project. The duration of implementation only restricts the time at which the next option can be opened, but does not determine the date of maturity. Further the path dependency only restricts the possibility of having an option or not, but as well not the date of maturity.

It is important to note that in this research only American Real Options will be employed. This is due to the nature of an investment decision, because it can be undertaken at any time during the option life. European Options can only be exercised at the strike time. As we will see this does not reflect the nature of the project that is under investigation in this research. Here a decision can be undertaken at any time, not only at the end of a certain period.

Advantages of Real Options

Real option analysis can provide a theoretical basis and therefore an economic explanation for some investment decisions. This is true for cases where a strategic element is perceived by a management and a positive decision is made, sometimes despite a negative net present value. Similarly ROA also provides an explanation for the modification of traditional valuation tools. These modifications aim to account for uncertainty or growth potential, but will according to scholars of the application of Real Options not produce a reliable result in these domains. These investments cannot be theoretically explained when looked at from the perspective of a DCF model. Assuming growth potential a Real Option framework cannot only provide an explanation for the investment in projects with negative NPV (Durand et al., 2001), but can as well account for the exact value of the growth option. Within the DCF framework it is not possible to account for different developments within the same evaluation. To value different development possibilities one can apply an option to choose. A project scenario can for example be to choose between expansion, outsourcing some activity or abandoning the whole project for a salvage value. The valuation here provides the net present value of the whole strategy, not just of a single pathway.

As the Real Option model is based on the uncertainty and availability of options, it is likely that the Real Option method would find best application for business that faces a well-understood risk structure (Sick, 1989). These are likely to have most of the features Amram and Kulatilaka (1999) describe as a foundation for conducting a Real Option Analysis with useful results: (a) a contingent investment decision should be given, (b) uncertainty should be large enough so that the position to wait for more information is feasible to support, and (c) large enough that flexibility would be a beneficial factor, (d) the value of the project is more likely to be understood in possibilities of future growth, rather than in momentary cash flow, (e) it is better applicable when there are project updates and corrections of strategy during the course, and in addition (f) the DCF analysis does not arrive at a clearly positive or negative value (Kodukula & Papudesu, 2006, p. 58).

Copeland et al. present a more simple point of view, which can be used in addition to the before mentioned criteria (Copeland et al., 2000, p. 398). The additional insight ROA can provide depends on two factors: the managerial flexibility and the uncertainty of the future value of the underlying asset. High managerial flexibility allows a medium to high value of Real Options, depending on the uncertainty, while for low managerial flexibility there will be only a small or no option value. Further there is little additional insight when the NPV of a project is very high or strongly negative (Ibid.).

The downside of the Real Option model is the assumption that options can be called at any time, which means that the underlying real assets can be traded the same way as financial assets. The negative implications of this assumption are pointed out by Miller and Park (2002), which can result in problems for the calculation of volatility. For financial investors in projects or strategic investments the Real Option model normally does not play any role, as perceived too lengthy and complex (Teach, 2003).

Uncertainty in project planning can come from several sources. To account for these multiple sources of uncertainty Copeland and Antikarov (2003) coined the term *Rainbow options*. However here it is important to identify the type of risk for each source of uncertainty, whether it reflects a market or a private risk. One can always compute several market risks in a rainbow option analysis. However private risk can only be estimated individually and cannot be calculated parallel to sources of uncertainties based on market risk. The way to proceed here is to build a decision tree (Kodukula & Papudesu, 2006, p. 194). Each node of the decision tree reflects a private risk, like if a drug will receive regulatory approval or not, and at starting from each node a Real Option evaluation can be undertaken to the next point – or node – where a private risk is occurring. The principles of this procedure would apply to any kind of option analysis, rainbow or simple options. Simple options are any options that can be expressed as singular call or put options and which can be calculated with a binomial tree.

To conclude, Real Option Analysis is a very valuable tool, which results in a more appropriate value of a planned project than a simple DCF analysis. This model will be employed to analyze the investment in a concentrated solar power project.

III. METHODOLOGY

This chapter will present the procedures that are used to calculate a Real Option value in this thesis. Explaining the procedures will shed some light on the previously presented arguments that speak for the ROA, as the possibilities and limitations are easier to understand once it is clear how to conduct the calculation. The subject matters concerning underlying asset and option value development, their assessment, and uncertainty will be discussed in relationship with the applied methodology, where it promotes a better understanding of the calculations.

III.1. Real Option Calculation

When an Option Earns Money

Since an option gives the right to call or put an asset, it is logical following common economic principles that it will only be exercised if this is profitable for the option holder. The value of an option (*C* or *P*) is the maximum of two different values, one being zero and the other being the difference in value of the underlying asset when it is bought/sold at maturity (*S*) and the exercise price at maturity (*X*) (Kodukula & Papudesu, 2006, p. 194.).

$$\text{Call} \quad C = \text{MAX}\,[0, S - X] \qquad \text{Put} \quad P = \text{MAX}\,[0, X - S] \tag{6}$$

Naturally an option will be exercised if it earns money, one says the option is *in the money*, or will not be exercised if it does not earn money, where one says the option is *out of the money*. If an option does not earn or lose money, it is *at the money*. A call option earns money if $S - X > 0$ and loses money if $S - X < 0$, while it is at the money at $S - X = 0$. For a put option the situation is the opposite, it is in the money at $S - X < 0$, out of the money if $S - X > 0$ and at the money if $S - X = 0$. This will be of importance later, when the Real Option value is calculated. For example a real *call* option: if the option is *in the money* then this will mean that an investment in a project at that point of time earns more money than not investing or waiting. With American options one needs to calculate at every time interval whether the option will be exercised or not. With European options only the option value at the end of the expiration time is significant.

Real option analysis can be undertaken via various means. The three basic ways to arrive at the value of Real Options are (a) the Black-Scholes formula, (b) via computer-assisted simulation, (c) with a lattice tree analysis with a binomial tree or sometimes a trinomial tree. All the three possibilities have one thing in common, they aim to resemble a stochastic process for the value of the Real Option. All three of these procedures have limitations of some sorts, some of these limitations are relevant for academic purposes other limitations are more relevant in a business context, which includes comprehensibility. It shall now be explained how these three ways correlate and which is therefore best applicable for the present purpose.

The Black-Scholes Equation

The Black-Scholes formula was developed to calculate the option value for *financial* options and can be applied to some Real Options the same way. It has however limitations in its applicability, as it is restricted by its presumptions. If all those presumptions reflect the reality, then the Black-Scholes formula shall deliver an accurate and precise result.

$$C = N(d_1)S_0 - N(d_2)X\exp(-rT) \tag{7}$$

with d_1 and d_2 being:

$$d_1 = [\ln(S_0 / X)] + (r + 0.5\sigma^2)T / \sigma\sqrt{T} \qquad\qquad d_2 = d_1 - \sigma\sqrt{T}$$

Where σ is the annual volatility of future cash flow of the underlying asset, S_0 represents the current asset value, X is the strike price to exercise the option at or before maturity, T the time to maturity, r the risk free rate, C the value of the call option, $N(d_1)$ and $N(d_2)$ are the representing values of a standard normal distribution at d_1 and d_2 respectively. The assumptions under which the Black-Scholes model operates are (Ibid., pp. 86, 95) for one that the option is a European option that means it can only be exercised at the end of the option life. Another main assumption is that the underlying financial asset does pay dividends and the asset value changes only due to the volatility factor. The value distribution of the underlying asset follows a lognormal function. There is only one strike price of the option under Black-Scholes, however in a Real Option scenario the strike price can change over time.

Simulating Stochastic Processes

Computer assisted simulation can be done with several procedures. A stochastic process itself can be modeled via different theoretical approaches. To simulate such a process for an option value Black and Scholes (Black & Scholes, 1973) recommended making use of the Geometric Brownian Motion. This or other ways to model a stochastic process can translate into different computer assisted modeling settings (Copeland & Antikarov, 2003, p. 245). A common method is to make use of a Monte Carlo simulation.

III.2. The Binomial Tree

As Kodukula and Papudesu (2006) point out the binomial tree – or more complex lattice tree versions like a trinomial tree – as a third way to arrive at a Real Option value. This method will be the method of choice for the present case. First an explanation of Real Option Analysis with a binomial tree will be given, secondly the relationship with other methods of modeling stochastic processes will be explained, which will highlight why this method is best suited for the present purpose. The lattice tree is an approximation to a stochastic process, and therefore it is a solid way to model the development of the underlying asset value and the Real Option value over time simulating a stochastic process (Copeland & Antikarov, 2003, p. 221).

The binomial tree is a tree that shows the probability of the outcome of a certain event as steps in time. The general layout of this tree starts with the underlying asset value *So*, which branches into a higher value of *Sou* for the upper value of the next step and with *Sod* for the lower value of the next step, while in the third step the values are ordered from Sou^2, *Soud* to Sod^2:

						S_0u^5
					S_0u^4	
				S_0u^3		S_0u^4d
			S_0u^2		S_0u^3d	
		S_0u		S_0u^2d		$S_0u^3d^2$
	S_0		S_0ud		$S_0u^2d^2$	
		S_0d		S_0ud^2		$S_0u^2d^3$
			S_0d^2		S_0ud^3	
				S_0d^3		S_0ud^4
					S_0d^4	
						S_0d^5
Time-steps						
	0	1	2	3	4	5

Figure 1 – The binomial tree

To calculate the option value one can choose between two different binomial trees procedures: a tree that makes use of a market-replicating portfolios, and a tree with risk-neutral probabilities. The result of both approaches is exactly the same, and while the former is easily applicable for financial assents, the latter is less complicated for ROA (Mun, 2002, p. 143). As there are only benefits and no downsides the binomial tree that will be used here is a recombining binomial tree with risk-neutral probabilities. The principle of this tree is adjusting the probabilities of an up- and down-movement from one time-step to the next. Instead of using a 50/50 probability, the probability is modified to reflect the risk at a certain time (Copeland & Antikarov, 2003, p. 98). As the future value development is thereby already risk-adjusted one can discount future values at a risk-free rate, which is easy to obtain (Copeland et al., 2000, p. 409). The value development depends then on two factors: firstly on the chosen risk free rate, and secondly the *volatility* of the future cash flow of the underlying asset. These two factors result in said up and down movements along the nodes, representing possible values of a random walk. The term risk neutral assumes a world of indifference towards risk. The term risk-free refers to the discount rate used within the tree to discount the future cash flow. Whichever term is used, in a binomial tree context they refer to the *same* approach, but highlight different aspects. The risk neutral and the risk free tree are exactly the same procedure.

To calculate the option value of a simple option one needs two binomial trees. The first tree is employed to model the value development of the underlying asset in face of uncertainty, which is in a ROA scenario for example the value of project or a company. Only the second tree then will be used to calculate the option value on the underlying asset.

The first lattice tree starts with the *current* value of the underlying asset. This can be the value one arrives at from the DCF. Here it is evident why the ROA in principle relies on a different assessment method. It is necessary to be informed about the value of the underlying. While the value of the underlying asset of a financial option is readily available, for example the price of a single share of stock, the value of the underlying asset of a Real Option needs to be calculated. This can of course be done by various methods, but for the reasons explained when discussing the DCF, it yields the most reliable result among net present value calculations.

To model the future cash flow of the underlying asset in a binomial tree one needs the following input factors: *S, X, T, rf, b,* σ; and the following formulas:

$$u = e^{\sigma\sqrt{T}} \qquad \text{and} \qquad d = \frac{1}{u} \tag{8}$$

$$p = \frac{e^{(r_f \delta t)} - d}{u - d} \tag{9}$$

S is the present value of the underlying asset, *X* is the present value of the strike price or the implementation costs of the option so to speak, σ is the volatility of the underlying assets free cash flow returns, *T* is the time to expiration in years, *rf* is the risk-free rate of return on an asset without risk. These input factors will still be discussed in detail. For the up and down movement in the tree one needs the value of *u* and *d* as up- and down-factors, the risk-neutral probability *p*, and the stepping time δt that is the time between the periods (Mun, 2002, p. 144).

The risk-neutral binomial tree is then build by multiplying S_0 with the up and down probabilities as shown in Figure 1. The values here are path-independent. This is repeated for as many time steps as one aims to apply. One can model the value development in small discrete time steps as well as in larger ones, the more time steps one creates the more precise the result will be (Kodukula & Papudesu, 2006, Mun, 2002). Once completed the first binomial tree models the uncertainty of future cash flow.

Now the second tree needs to be built, which reflects the option value at a given point in time. One starts with the most future time interval, at the end of the option life and builds the tree in reverse from that point by a process that is called backward induction (Ibid.). First, one starts with the terminal nodes of the second tree and writes down a value that is a maximization between the execution of the option or letting the option expire. The option value is calculated using the underlying asset value of the corresponding terminal node *of the first tree*. The maximization is different for each different type of option. For a simple call option the value of the option is the value of the corresponding node of the underlying asset minus the exercise prize. For a call option this is maximized against zero, in line with Formula 6: $C = \text{MAX}\ [0, S - X\ ]$. This is undertaken for every terminal node.

The second step is to calculate the intermediate nodes at a risk-neutral probability. For American options the intermediate nodes are as well maximizations, because at any time the option can either be executed or one can wait for further development. Therefore the optimal decision is a result of a maximization between executing the option or leaving the option open, whichever value is higher (Copeland & Antikarov, 2003, p. 221). Executing the options means for a call option for example to invest in a project, here the value of execution is again in line with Formula 6, it is the value of the underlying asset at this time minus the exercise price – the investment costs (Kodukula & Papudesu, 2006, p. 79). The value of leaving the option open is derived from one time step ahead in time and is equal to:

$$[(p)up+(1-p)down]e^{(-r_f)(\delta t)} \qquad (10)$$

This value of keeping the option open is therefore the discounted weighted average of possible future values with the use of risk-neutral probabilities. In general the maximization at the intermediate steps is the result of:

$$\text{MAX}[\text{'executing the option'},\{(p)\text{up}+(1-p)\text{down}\}/\text{EXP}\{(\text{risk-free})(\delta t)\}] \qquad (11)$$

In the concrete case of a waiting option the maximization can be expressed as MAX[S - X,{(p)up+(1-p)down}/EXP{(risk-free)(δt)}]. This second step is repeated for every node until the first time step is reached. The resulting value is the present value of the Real Option. The strategic NPV that accounts for flexibility is the sum of the cash flow NPV (from the DCF analysis) and the value of Real Option. The calculation is complete.

The Real Option to call can be for example in its simples form a deferral option, which as well called option to wait. The simplest Real Option to put is the option to abandon a project. For a put option the first lattice is calculated the same way and models the development of the future cash flow of the underlying asset. The second binomial tree starts at the terminal nodes with a maximization here between the value of the underlying asset (at the corresponding node of the first tree) and the salvage value that would be created if the project is abandoned and the option exercised (Ibid., p. 102). An abandonment option hedges against the downside risk of future cash flow. The next step is the backwards induction at the intermediate nodes. The calculation needs to lead again to an optimal decision and therefore is a result of a maximization between executing the option or leaving the option open, whichever value is higher. Executing the options means for a abandonment option to sell the project at salvage value. The value of leaving the option open is again the discounted weighted average of possible future values with the use of risk-neutral probabilities. Again the same maximization procedure is used for the intermediate nodes, this time modified for a put option: MAX[X - S,{(p)up+(1-p)down}/EXP{(risk-free)(δt)}].

Option to Expand

The option to expand is as well a call option. The additional input variables that need to be known are (a) the expansion factor as a multiple of current operations, which will multiply the value of the underlying asset in future and (b) the cost of expansion, which is the exercise price of the expansion option (Mun, 2002, p. 177). The asset value tree is built and the terminal nodes give the values for the modeled future value of the cash flow of the current operations. In the second tree, the option value tree, the terminal nodes are a maximization between exercising the option and current operations. Exercising the option multiplies the underlying asset value with the expansion factor, but comes with the cost of the exercise price: MAX[‘(expansion factor × operation value) - expansion cost’, ‘operation value’]. If the result is higher than current operations the option will be exercised, if the result is lower, current operations will be continued. The intermediate nodes are calculated in the usual way, they are a maximization between exercising the option and the discounted weighted average of possible future values with the use of risk-neutral probabilities: MAX[‘(expansion factor × operation value) - expansion cost’,{(p)up+(1-p)down}/EXP{(risk-free)(δt)}]. This procedure is based on the implicit assumptions that the expansion is of the same nature as the current operations and exposed to the same business environment. If this assumption cannot be held, there are procedures to account for these differences in the referred literature, which are not needed for this work.

Sequential Compound Options – Staged Options

Compound options are options on options, there are two different forms. The one discussed here is a staged option, or sequential compound option. This is a scenario where one option will trigger a new option once the first is completed. This can be for example a project split in several phases where a probability study, design, engineering and finally construction are seen as individual options, which can only be called once the previous option is completed. In a compound option scenario the option value is derived from the value of another option, not from an underlying asset (Kodukula & Papudesu, 2006, p. 146). One builds one underlying asset tree for the underlying asset of the *longest running option.* When one option is ended, one can continue with the next option, abandon the project, or there might be a possibility to defer as well (Ibid., p. 61). In our example case of a power plant construction this is the call option on the plant construction. The option value tree for this longest running option is built in the usual way that was already discussed previously. Here as well the intermediate nodes of the option value tree are result of the same maximization as we saw it already in the previous option value trees with MAX[‘executing the option’,{(p)up+(1-p)down}/EXP{(risk-free)(δt)}]. This results in the option value tree of the first option completed to the first time step.

The next option value tree of the second longest running option, in our example it would be the engineering phase, will take the *first option value tree* as *underlying tree* for the option calculation. At first at the terminal nodes at the time step the second option ends (Mun, 2002, p. 191). The backwards induction will reveal the value of the second option. The same process is repeated for every option until one arrives at the final value of all sequential compound options together.

A compound option can be as well seen as a learning option (Kodukula & Papudesu, 2006, p. 61, Copeland et al., 2000, p. 417) where one option shall reduce uncertainty and gather information, and with cleared uncertainty one can continue to a different stage, resembling another option – therefore a compound option. Both parallel and staged options can be learning options. A learning options can be a the development of a prototype (Kodukula & Papudesu, 2006) or as it is suggested by Brealey and Meyers (2003, p. 618) the first iteration of a project, for example a product that will establish the project developer in a market, potentially create a higher barrier of entrance for the competition and results in an option on future product cycles. There are different kinds of learning, in a passive learning scenario one simply stages a project in phases and makes decisions to go ahead or to abandon as the time clears uncertainty. In an active learning scenario there is an investment in a process, the main task of which is to gather information.

All option value calculations presented in this section were for American Real Options. For European Real Options one would not perform a maximization at the intermediate nodes, but simply calculate the discounted weighted average of possible future values with the use of risk-neutral probabilities, as seen in Formula 11, for every intermediate time period until one arrives at the present value of the Real Option.

Other Options

There are several other option types (Copeland et al., 2000, pp. 401-402):

- An option to *contract* parts of the operation to reduce costs.
- An option to *choose* between several other options for example between expansion, contracting and abandonment, which allows for incorporating different decisions into one scenario.
- *Parallel compound* options are options on an option, an independent and a dependent one, which are both running at the same time.

- *Barrier* options that strike only at a barrier price above option value.
- *Sequential compound* options are options on an option, where one needs to be finished for the next option to be triggered. They are as well called staged options.
- *Rainbow* options, which deal with several types of uncertainties at once, here a binomial tree can't provide a solution.

Further there are extensions to the binomial approach for those simple options, which were discussed above. These will not find application in this work and they are covered extensively in the referred literature (Kodukula & Papudesu, 2006, Mun, 2002). Firstly the binomial tree can be adjusted for cash flow leakage, which equals a dividend for financial options (Kodukula & Papudesu, 2006, p. 126). The benefit of the binomial model is that the leakage value can vary from year to year. Secondly the strike price for an option can change over the time of the option life (Mun, 2002, p. 188), which means for example the investment in a project can become more expensive over time. This can easily be adjusted for in the binomial option tree as different strike prices will be used to calculate the maximizations at each different time step. Thirdly changing volatility can be accounted for, but this results in breaking the recombination of the tree, as with every new phase of volatility the bifurcations of the previous time step do not recombine any more. The binomial model has the benefit that it can accompany many changes, as for example growth rates for different choices in chooser options, inflations rates, strike price changes, savings or other rates, the change of the expansion or contraction factor over time and similar. For these reasons the binomial approach is more flexible than solving an option equation and these changes are easier to frame than in a simulation, where for every change a completely new simulation needs to be formed.

Uncertainty and the Binomial Tree

With a small thought experiment the binomial tree can easily be understood as an extension to the DCF method. This thought experiment (Ibid., p. 145) will highlight explain as well the benefits and limitations of the Real Option model again. If the value development of the underlying asset were without uncertainty regarding the volatility, the volatility would be zero. This could only be the case if all future cash flow can be foreseen, and does not apply to the real word. However in such a scenario the binomial model would be a straight line, and not a tree anymore. The up and down values would both produce always same result, there is no value of flexibility, and therefore no option value. The discount rate reflects a risk-neutral rate and therefore future cash flows are discounted at the rate reflecting zero uncertainty. This resembles the Discounted Cash Flow. Hence in this specific case the DCF produces a proper result. As in the real world often uncertainty is given, the ROA aims to capture this. The Real Option model relies on the volatility as uncertainty measure to model the value for the underlying asset in a future state. The up and down movement in the lattice is this uncertainty, which in return produces a value to be flexible. The volatility of future cash flow defines the corner scenarios, the highest and lowest values throughout the time-steps. A high volatility will mean that the value of both ends of the tree at a given time step will be further apart from each other, than they would be with a low volatility, where the difference between the minimum and maximum value is smaller. Therefore with a high uncertainty the lowest and highest branch are far apart and the "cone of uncertainty" (Ibid., p. 151) spreads out in a wide way.

To calculate uncertainty in a simulation a common procedure is to make use of a Geometric Brownian Motion (GBM) to simulate price development. The GBM is modeled after the movement of particles in a water current and is supposed to represent randomness. The GBM consists of a deterministic and a stochastic part (Ibid.). The first determines the general scenario. The second part is important for the simulation where the stochastic part runs though several changes in a simulation. This creates many different pathways of development within the same scenario. This can be now compared again with a binomial tree, in which all possibilities of future asset development under uncertainty (expressed in volatility) are simulated in discrete steps. This is the reason why the formula used for the lattice does not include a stochastic part, as all the values of future value development are given through building a *single* tree and the nodes represent the different possibilities. As the time steps decrease and the lattice moves from a discrete model closer to a continuous simulation model, the results are more and more the same. The up and down movements, with the formula $u = \mathrm{EXP}(\sigma\sqrt{\delta t})$ and $d = \mathrm{EXP}(-\sigma\sqrt{\delta t})$ can be understood as being related to the deterministic part of a Geometric Brownian Motion, as can be seen with Mun (Ibid., p. 161).

The use of volatility, a standard deviation, as a measure of uncertainty however does only model what can be measured with the help of this indicator. Major jumps in value, any kind of shock scenario, are not captured and thereby they are not accounted for in the Real Option model (Kodukula & Papudesu, 2006). One simply cannot predict the future besides modeling it from known data. Here the problem of induction always plays a role. Real option model can incorporate volatility only from known sources of uncertainty. This implies that these uncertainties behave like modeled ones or like historic volatility, and that no additional source of uncertainty will impact the value.

The binomial tree is an approximation to the Real Option value and (Ibid., p. 96) recommends to use four to six time intervals for an approximation that produces a reliable result. Since the accuracy of the ROA however is more likely to be influenced by the framing of the case and the input factors Kodukula and Papudesu suggest that in many cases a smaller stepping time will not increase the reliability of the result much. If possible this should be verified via the Black-Scholes equation.

IV. FRAMING THE CASE

IV.1. How to Frame a Case

Kodukula and Papudesu (2006, p. 98) give a clear guideline how to frame a case in a six-step process. *Step one* is to *frame the application*, which means to describe the processes of the problem in a simple way, to identify the options that can be used and agreeing on the rules of decisions, be they single or contingent, and determine dependencies.

Step two means to *identify the input parameters for the binomial tree,* so that the option value can be analyzed. These are at the very minimum the volatility factor, risk-free rate, the option life, the stepping time, the value of the underlying asset, and the strike price.

Step three is to prepare the binomial tree *parameters*, which will ultimately lead to the final result of the *option value*. The parameters are the up and down factors, and the risk-neutral probability.

Step four is to build the *binomial tree that models the future value of the underlying* asset facing uncertainty. The modeled value is influenced by the volatility and the risk of the project, reflected by the up and down factors. From the step S_0 onwards the underlying asset value is modeled for future uncertainties resulting in various S values. As seen in Figure 1 the bifurcations lead to more nodes in the chosen stepping time until the option life is reached. The higher the stepping time and the more nodes, the more accurate the result.

The *fifth step* is to start the *option value tree* with the terminal nodes. The chosen decision rules are applied and the most beneficial decision is selected at the terminal nodes. The value of the option is then the asset value reflecting the best set of decisions. Then with *backward induction* the intermediate nodes are for American options maximized between executing the option on the one hand and the open option value calculated via discounting the weighted up and down nodes of the next time step in future on the other hand. This process is continued until present time is reached and the present value of the option is known.

Step six is to *analyze the result*. Here the present value of the underlying asset value shall be compared to the strategic net present value, which includes the value of the Real Option. The strike price can be put into relation of the option value and the underlying value. A sensitivity analysis can be undertaken regarding factors like volatility, value of the underlying or other factors. The value of the Black-Scholes formula can be calculated to validate the result.

Copeland and Anikarov (2003, p. 220) describe the same procedure, using four steps. It describes the same tasks: framing the scenario, building an underlying and an option tree, examining the result.

IV.2. General Assumptions

In this sections the general assumptions will be presented, which will be the input data for the Discounted Cash Flow analysis. As explained in the second chapter, the DCF is a necessary step to arrive at a value for the underlying asset in the Real Option Analysis. The DCF results will be presented later.

The case investigated in this thesis is a CSP solar power tower plant with an eight hour storage capacity and a 200 MW nameplate capacity. The power plant is located in Western North Africa. The electricity generated is sold in the Spanish market. The Spanish governmental incentive regime provides an example for the Feed-in Tariff system that is modeled in this research for a North African location.

The following technical assumptions are made about the power plant:

Plant type:	Power tower with external receiver
Plant nameplate capacity:	200 MWe
Annual solar potential:	DNI 2500 kwh/m²/y
Yearly output:	850 GWh (852,816,252 kwh)
Mirror area:	2.3 km² (2,317,215.5 m²)
Heliostats:	16,050
Tower height:	283 m
Solar multiple:	2.2
Storage time:	8 hours
Storage volume:	20,000 m²

Solar to electricity efficiency:	14.7 percent
Construction time:	2 years

The following economic assumptions are made about operation and construction:

Discount rate:	8.2 percent
Project cost:	4570 € per kW_p capacity
Valuation timeframe:	25 years
Depreciation time:	25 years
Corporate tax rate:	25%
Electricity price:	0.04993 €/kwh
Feed-in Tariff:	~ 0.22 €/kwh on top of wholesale earning
E. price escalation rate:	1% per annum
O&M costs:	2% of project value initially
O&M escalation rate:	1% per annum

These assumptions will now be explained in detail.

Technical Assumptions

The plant *capacity* is chosen at free will. However the IEA (International Energy Agency, 2010, p. 19) names 200 MW nameplate capacity as a probable optimal size. The *annual solar potentia*l with a DNI of 2500 kWh/m²/y is a solid average for North Africa and is therefore chosen as the assumed potential. A study published by the Fraunhofer Institute (Kost & Schlegl, 2010) on generation costs assumes this value, a report by EASAC (2011, p. 18) reports 2400 for Tunisia and 2600 for Morocco. We assume a storage capacity of eight hours with which generation into the evening and night hours is possible.

The other technical assumptions are based on a model by the US National Renewable Energy Laboratory (NREL) by the US Department of Energy (DOE). The 2009 report by Cory et al. (Cory, Coggeshall, Coughlin, & Kreycik, 2009) describes the System Advisory Model of the NREL, with which help a variety of renewable energy plants can be modeled based on empirical research and bottom up analysis by the NREL itself. The System Advisory Model can be openly accessed (NREL, 2011; sam.nrel.gov). Starting from the specifications of a 200 MW_e plant with eight hours storage, and a location with a DNI of 2500 kWh/m²/y, the other parameters are derived from this System Advisory Model (SAM), namely annual output electricity, mirror area, number of heliostats (the mirror units with tracking), tower height, storage volume, overall efficiency.

Economic Assumptions

The discount rate is as well derived from the SAM (Ibid.) with 8.2 percent. This is in proximity to the discount rate used in the report published by the Fraunhofer Institute (Kost & Schlegl, 2010), which is 6.5 percent. The project cost per kW_p capacity is also part of the SAM, which is 6406 $. The current iteration of the software was published in the first half of 2011, therefore the currency conversion to Euro is undertaken at an exchange rate reflecting the average of the first two quarters in 2011, which is 0.7136 Euro for one US Dollar (Onada Corporation, 2011). At this conversion rate the Project costs per install kW_p capacity are 4570 Euro. The project life and depreciation time is 25 years, which reflects the time of the first phase of the Spanish FIT contribution under the Royal Decree (RD) 661 from 2007

The electricity price reflects the average of the Spanish electricity price in 2011 for the day ahead market, which is 49.93 €/MWh. This data comes from the Iberian electricity market exchange (OMEL, 2011).

The assumption of future electricity price development is taken from the International Energy Agency. In a report from 2006 (International Energy Agency, 2006, p. 38) the IEA estimates that the electricity price development for the next four decades will increase on average around one percent. This price escalation will be implemented in the Discounted Cash Flow analysis to model future cash flow. The costs for operation and maintenance are general figures for CSP and come from the Fraunhofer Institute report (Kost & Schlegl, 2010), and are two percent of the initial project value, which escalates at one percent a year. To keep the analysis sensible the costs of the infrastructure investment to feed the electricity into the Spanish grid will not be modeled. A direct current transmission would be necessary to enable this market. A further assumption is that the project is fully equity financed.

Feed-in Tariff

For the Feed-in Tariff (FIT) a tariff regime will be constructed that is assumed to be both adequate and realistic. The tariff is derived from the Spanish renewable energy policy set up by the Royal Decree 661 in 2007 which offers a tariff of 0.269375 €/

kwh for the first 25 years of operation. This is taken as a base for the fictive tariff regime for a location in North Africa. Spain is a major location for CSP investment in the current project pipeline, with 2.3 GW pre-registered for development (IHS Emerging Energy Research, 2010, p. 2). The Spanish market produced as well CSP developers (Engineering, Procurement and Construction companies – EPCs) CSP system providers. Further the Spanish market will in the next decade be the second biggest after the US market (Ibid.). Therefore one can assume that the Spanish FIT regime fulfills to enable profitable operations for CSP operations. As in Spain the FIT as governmental incentive obviously works, we model a fictive FIT regime for North Africa on basis of the Spanish FIT regime. This is done in an easily comprehensive manner; the ratio between the Spanish FIT and the electricity output of a CSP plant in Spain are applied to the electricity output the same plant would produce in North Africa to find a fitting fictive FIT for North Africa. The calculation is relatively simple: FIT(Spain) × Generation(Spain) = FIT(North Africa) × Generation(North Africa). The costs for generation are *constant* and therefore the generation itself is a proxy for the North Africa fit. According to a study by the Fraunhofer Institute (Kost & Schlegl, 2010, p. 11) a model CSP plant with 100 MW nameplate capacity would yield 3580 MWh annually in Spain (DNI 2000 kwh/m²/y) and 4420 MWh annually in Northern Africa (2500 DNI kwh/m²/y). These data are used to compute an North African equivalent of a Spanish FIT with 0.2181816 €/kwh via: (0.269375 × 3580) / 4420. The use of this North African equivalent is appropriate because the costs for generation are constant. The Fraunhofer Institute modeled the same power plant in two different locations and therefore the FIT is not in a linear relationship with the DNI but reflects the relationship of different Levelized Costs of Energy (LCOE) for the same power plant in two different location. The value 0.2181816 €/kwh is the basis for a fictive North African FIT regime, which will be added on top of the wholesale earnings.

The directive 2009/28/EC of the European Parliament and the Council of the European Union describes the renewable energy targets of the Member States until the year 2020, and it further allows a Member State to consume renewable energy from *new* installations in non EU countries and count it towards the 2020 renewable energy targets. Therefore it is possible under current regulation to install a FIT regime that would benefit installations outside the own country, if the resulting electricity is – partly or fully – consumed in an EU Member State. This possibility is the basis for the FIT regime in this thesis. Thereby the CSP plant here is assumed to deliver energy to Spain and therefore is enabled to do so via a FIT that resembles the Spanish model.

To conclude this FIT reflects (a) the economics of the Spanish FIT, which successfully created a market of developers and operators with a strong project pipeline and (b) works under the current 2009/28/EC directive. This assumed FIT adds to the revenue of electricity sold on the market and does represent a fixed regime.

IV.3. Real Option Assumptions

In this sections the assumptions will be presented, which are necessary to conduct a Real Option Analysis. Similar to the previous section only the input data will be discussed, the option value will be modeled later. Two different scenarios will be developed. The first scenario is a simple waiting option (real call option) on a project, and the second scenario aims to take into account future project possibilities once the first project is completed. Both scenarios will be discussed in the end of this section. They identify *what* the options are.

The assumptions for the Real Option Analysis are:

Source of uncertainty:	Price development of electricity market
Volatility:	36.8%
Option life:	8 years
Risk free rate:	3% annual
Asset value:	Present value of the DCF analysis
Option:	Call option on a project
Exercise price:	Capacity cost at 4570 €/kW$_p$ times capacity

Volatility

Volatility of the value of the underlying asset is a main component of a Real Option scenario. It is the parameter that defines the maximum and minimum possible value of the underlying asset in the ROA. The ROA method assumes that volatility will reflect future uncertainties. With more complex analysis methods than the binomial tree one can model as well several sources of volatility (rainbow options) and refine the method. However ultimately ROA relies on a measure or an estimation of a standard deviation. This implies that ROA models those future states captured by the volatility value only. Strong value shocks, for example through project external economical factors, are not covered by the value modeling.

There are several ways to estimate volatility, as found in Kodukula and Papudesu (2006, p. 88) and Mun (2002, p. 197). The methods emphasized are the project proxy approach, the market proxy approach and the logarithmic cash flow returns method. The latter is used for this thesis.

The volatility in option models is the volatility of the rates of return, which is calculated as the standard deviation of the natural logarithm of returns. This is done according to the following equation (Ibid., p. 198):

$$\text{volatility} = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \tag{11}$$

Where n is the number of x and $\bar{x}$ is the average value of x.

If the base of the volatility calculation has different time steps than the Real Option Analysis, the volatility needs to be adjusted. It then will be consistent with the time steps used. This can be done with the following equation:

$$\sigma(T_2) = \sigma(T_1)\sqrt{T_2 / T_1} \tag{12}$$

This chosen method of volatility is easily applicable for any analysis undertaken in the energy sector, as historic price data can be used to arrive at a volatility level. The logarithmic cash flow of returns approach has the limitation that it is not applicable when the cash flows are negative. Here this limitation does not play a role, as electricity market prices are the base for the calculation and there are no negative prices. Alternative methods however could be (Ibid., pp. 198-201) (a) a Monte Carlo simulation at DCF level, which yields as well a volatility factor, (b) market proxy approach that includes finding a set of comparable firms, (c) project proxy approach that uses the volatility of a comparable project (Kodukula & Papudesu, 2006), (d) management assumptions, and (e) a GARCH model (Generalized Autoregressive Conditional Heteroskedasticity).

For calculating volatility a dataset from the Spanish electricity market was the basis, and therefore historical prices. The assumption that future price development will reflect historical development is an accepted approach (Copeland & Antikarov, 2003, p. 257). The historical prices used are published by the Spanish regulatory agency Comisión Nacional de Energía (CNE) in their yearly reports. The dataset reflects wholesale day ahead market prices from the years 2007–2009 (Comisión Nacional de Energía, 2008, 2009, 2010). This historic dataset is used to calculate the volatility with the above mentioned Formula 11. The volatility based on logarithmic cash flow of returns for a month basis is 10.6 percent. In line with Formula 12 an annualized volatility value of $\sigma = 36.8$ percent is used for the ROA.

Option Life

The life of the option is another variable, which can influence the outcome of the calculation in a profound way. Generally the option life defines the timeframe within which a decision must be taken whether to exercise an option or not. For a call option the option life determines *for how long* an investment can be decided upon. The *project life* does not necessarily relate to the *option life* that only would be the case if the option throughout the whole lifetime of a project, like a switching option between outputs or an abandonment option. The two scenarios in this thesis will implement variations of *call* options, and therefore the option life shall provide the time restriction for the duration until which a decision needs to be made. Further investment decisions as call options are *American* options, which means that a decision can be undertaken at any time.

As already stated in the section on the Feed-in Tariff the global project pipeline for CSP is strong, as roughly 8GW capacity are in planning (CSP Today, 2011b), while the IEA predicts 148GW (International Energy Agency, 2010) until 2020. Both the scheduled projects and the predictions support the notion of a technology take off and integration into the energy mix. The installed capacity in 2011 is at 1.3GW (EASAC, 2011). From historic analysis (Stallworthy & Kharbanda, 1985, p. 146) of the development of the electricity generating industry we know a certain set of stages a new technology passes through from the start towards market integration. The stages usually take seven to ten years to peak, while the process is overlapping at times. The stages are (1) scientific feasibility, (2) engineering development, (3) engineering demonstration, (4) construction of commercial plants, which leads to utility integration. Investment into the technology at each stage is consecutively more than for previous one. In this model the engineering demonstration phase is directly followed by the construction of commercial plants, the two phases begin and peak ten years apart respectively. From start to end it takes 30 to 40 years.

If we apply this general model to the technology of CSP one needs to examine the case in detail, as here the phases are more separated from each other. An early installation was the Solar Electric Generation System I (SEGS I) in 1985 Masters, 2004, p. 186), with 13.4MW, while all SEGS Systems together have 354MW capacity. The size of this plant is of commercial proportions however apart from SEGS there was for a considerable time no noteworthy further CSP development on a commercial scale. One can interpret this as an interruption of the CSP development on a commercial level, which is picking up now again, as the project pipeline for future commercial projects indicate, with 2.7GW under construction worldwide (CSP Today, 2011b). The reasons for the pause in the development of the technology are economic factors, after overcoming the oil-crises and before the availability of governmental incentives like FIT. Interestingly enough a report by IHS Emerging Energy Research (IHS Emerging Energy Research, 2010, p. 2) describes the current setting as well in four phases: (a) no activity from the 1990s–2007, (b) "market reignition" from 2007–2009, (c) "technology development" 2009–2012 and (d) "global take off" from 2013 onwards. The technology development phase does not surprise considering the time past since the SEGS development and the advancements in areas like engineering, material chemistry, and similar that naturally occur during twenty years.

If we now apply the model of technology development for power generation again on the CSP case we see that we are at the beginning of the phase four *construction of commercial plants*. Although there was a pause in the development of CSP the now scheduled projects can be seen as proof that profitability is given for many market participants. There is no reason to assume that the future integration were any different than any other conventional power generation technology that is of course in areas with a necessary DNI annually. Therefore it is justifiable to assume that the phase four *construction of commercial plants* will last until a significant overall level of utility integration is given for the next ten years to come.

By combining the forecast of CSP development with the general timeframe for utility integration we now arrive at a timeframe of ten years within which at latest the technology should be installed by a CSP system provider in order to be present in this market. The objective is not necessarily to be a first mover, as evidence for a first-mover advantage is spotty and not conclusive in every industry and for every type of technology. Criticism of the first mover theory came from VanderWerf and Mahon (1997), Kopel and Löffler (2008), Woolley (2009), Johansson and Nilsson (2009). Although a first mover advantage is not regarded as of essential importance, the timeframe for when the technology will be at a scale of utility integration is a limiting factor none the less. One can assume that competition is important, as firstly it is a developing technology, where the competitions head-start might be expensive to overcome, secondly the complexity of the construction of CSP plants might be a large entry hurdle.

As the timeframe within which a plant should be built is ten years, and the construction takes two years time, the option life in our scenarios will be eight years. This means there is a time period of eight years until which a decision must be undertaken.

Risk Free Rate

A viable proxy for the risk free annual interest rate treasury is the interest rate on ten year US treasury bonds, according to American textbooks (Brealey & Meyers, 2003, Kodukula & Papudesu, 2006, p. 94). As the project analyzed is however closer to Europe and concerns the Spanish market, in this work the ten year interest rate will reflect the Euro and German treasury bonds will be taken as a proxy for a risk free annual interest rate. They were three percent in June 2011 (Bloomberg.com, 2011).

The First Real Option Scenario

We arrive through the DCF calculation at a cash flow based PV and NPV for the project. The investment shall be analyzed via Real Options in order to reveal the additional value that comes with a flexible decision framework. For this scenario we assume that a single project is planned and that the decision to start this project can be undertaken at any time within the coming eight years. This resembles a waiting option, which is a real call option.

The value of the underlying asset is the present value of the project in the DCF analysis. It is important to take the present value (sum of future cash flows) and not the net present value (PV minus investments). The investment costs will be accounted for (including discounting) in the Real Option Analysis later on, as they are the exercise price.

The exercise price is the cost of the investment, which is 4570 €/kWp times the capacity of the power plant, which is 200,000kW. As the construction period is two years we assume that the investment is undertaken in two parts, which means the second half needs to be discounted at the discount factor for the first year. The exercise price then is roughly 879 million Euro. The calculated value is 879,365,989 Euro.

The procedure in this scenario is usual standard procedure in Real Option Analysis and explained by Mun (2002) Kodukula and Papudesu (Kodukula & Papudesu, 2006). A call option on an investment is an easily applicable scenario. It means that the management needs to undertake measures that will ensure that the project construction can readily be undertaken once a decision is made. This may include costs for research, planning and permitting, which are not included in the present assumptions. The costs that will allow the start of a project in a timely manner are the option costs and need to be assessed by a management.

The Second Real Option Scenario

This scenario is based on the idea that future follow-up investment possibilities can be taken into account when deciding on an investment in a project. The first project is seen as a key that opens up further project possibilities of the same kind. It is therefore of strategic importance whether one will invest in the first project or not. The notion that such scenarios can be accounted for by Real Option Analysis can be found in literature (Brealey & Meyers, 2003; Kodukula & Papudesu, 2006). As ROA can account for future uncertainty based on volatility, it is a tool to analyze decisions that could previously only be understood as 'strategic' in a sense that they enable future business possibilities but do not yield immediate revenue (Damodaran, 2002, p. 802). With ROA such decisions can be analyzed in a new light. As said before these type of decisions can be seen as a 'key' for future possibilities, in other words they enable an *option* to act. However as the first decision in itself does not necessarily need to be undertaken at once, this means the first decision can be framed as an *option* too. Therefore a scenario with a *possibility* to invest in a project that consequently will open further *possibilities* can in a Real Option scenario be framed as an *option on an option*. A strategic scenario can for example be a project that enables a market entry or that accelerates technological expertise (Ibid.).

Options on options are called compound options (Kodukula & Papudesu, 2006). Not only can the strategic element of possible future successor project be seen as an option (Brealey & Meyers, 2003), compound options as such are often used for learning scenarios (Kodukula & Papudesu, 2006). Usually learning scenarios aim to clear a certain type of uncertainty for example via the development of a prototype. In this case the compound option is used for two or more stages of a single project that would aim for full operation. In our case a compound option will be used to analyze two projects and therefore two power plants. The learning scenario notion will be implemented via progress curves. In "Renewable energy policy evaluation framework using Real Option model" Shun-Chung and Li-Hsing (2010) make use of such curves in order to establish the overall cost saving benefit from a further growing industry. Similar or same concepts to learning curves are also called "improvement curve", "experience curve", "efficiency function", "product acceleration curve", "learning by doing effect" or "cost efficiency curve" (Ibid., p. S71). In its simplest form this model describes a learning by doing effect, in a more advanced approach other factors than accumulated production are included (Ibid., pp. S71-S72) namely "premium level, scale of economies, land costs, wages, and interest rates" and "accumulated premium expenditure". Experience curves were first described as learning curves in Arrow (1962), and the concept was further applied to the energy industry through Zimmerman (1982). Frank (1983) who applied experience curves to CSP.

In a report published by the Fraunhofer Institute (Kost & Schlegl, 2010) an averaged learning curve for the whole CSP power plant cost is introduced with a progress ratio of 92.5 percent. This means that with doubled capacity the costs for the next additional installation will be 7.5 percent lower (100 minus 92.5 percent). The formula used to calculate the costs at any given time is:

$$I_n = I \times n^{\log(L_r)/\log(2)} \tag{13}$$

Where I are the investment costs now, here per installed capacity, I_n are future investment costs and L_r is the learning rate (Barlow, 2005, p. 156), which is in our example 92.5 percent.

To use this learning rate we need an additional variable: the step n. As our stepping unit is the increase in capacity here, the variable n must reflect this step. The current installed global capacity of CSP is 1.3GW (EASAC, 2011). The additional capacity gained through the project is 200MW, therefore the future n state will be roughly 1.15 times more than the current state of capacity (which is the sum of 1300 and 200 divided by 1300). Given that the current cost of installation are at 4570 €/kW$_p$, we arrive at a value of 4497 €/kW$_p$ for the future value I_n.

This will be the base for the second power plant in the second scenario. It will be modeled via an expansion option of the first operation. An option to expand can be used to "rationalize investing in projects that have negative net present values but provide significant opportunities to enter new markets or to sell new products" (Damodaran, 2002, p. 802). The second power plant is equal in all aspects to the first power plant, however the investment costs are lower due to the learning effects. As it is a condition for the second power plant to be only available after the first plant is built, the investment costs are discounted in the DCF for occurring in the third and the forth year. Calculating the investment at the new cost per capacity value and discounting half of the investment for the third year and half of the value for the forth year gives us the total investment costs for the second project with 740 million Euro (calculated at 739,137,223 Euro). These investment costs are important in our Real Option scenario for the second project, they will be the cost of expansion.

For the Real Option scenario we will firstly need the expansion cost, and the expansion factor, which is a doubling of the operation. Secondly the option life needs to be determined, which is eight years for the longest running option – the expansion – and six years for the option one phase shorter, which is the construction of the first plant. The option needs to be exercised two years before the respective plant must be completed, therefore eight and six years. The input data and the procedure used will be explained in the next chapter where the calculation will be presented.

We assume in this scenario that the learning rate of 92.5 percent can be applied to the second project. Given the size of the project of 200MW for a power tower technology it is of a significant size in comparison with the so far developed capacity of CSP general with 1300MW and especially with power tower plants, which have a cumulative capacity of about 50MW (Kost & Schlegl, 2010). At this current market size and state of technology development one can assume that a second project will have significant cost reduction possibilities, which can be compared to the development of the whole industry.

V. OPTION VALUE CALCULATION

After presenting the framing of the two scenarios the calculation results shall be discussed now. We start with the Discounted Cash Flow calculation. This was undertaken via the help of spreadsheet calculation software as instructed by Holden (2002). The Formulas 4 to 13 presented in this thesis will be applied to the analysis to arrive at the strategic net present value, which includes the value of the Real Option.

The input parameters were already discussed in the previous chapter. For convenience of reading and reviewing the results they shall be introduced here again:

Yearly output:	852,816,252 kwh
Electricity price:	0.04993 €/kwh
Feed-in Tariff:	0.218181561 €/kwh on top of sale earning
Valuation timeframe:	25 years
Depreciation time:	25 years
Project cost:	at t_0: 457,000,000, at t_1: 422,365,988.9
Discount rate:	8.2 %
Corporate tax rate:	25%
E. price escalation rate:	1% per annum
O&M costs:	2% of project value initially
O&M escalation rate:	1% per annum
Construction time:	2 years

This data is used to calculate the cash flow based present value and net present value in a DCF. This can be seen in Table 1.

Table 1 – Discounted Cash Flow analysis

Period in Years	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26
Revenue																											
electricity price in €/kWh	0.050	0.050	0.051	0.051	0.052	0.052	0.053	0.054	0.054	0.055	0.055	0.056	0.056	0.057	0.057	0.058	0.059	0.059	0.060	0.060	0.061	0.062	0.062	0.063	0.063	0.064	0.065
Quantitiy sold in GWh per year			852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8	852.8
Earning through FIT in Million €			186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1	186.1
Earning from electricity in Mil. €			43.4	43.9	44.3	44.8	45.2	45.7	46.1	46.6	47.0	47.5	48.0	48.5	48.9	49.4	49.9	50.4	50.9	51.4	52.0	52.5	53.0	53.5	54.1	54.6	55.2
Investment in Million €	-457	-457																									
Total revenue in Million €	-457	-457	101.8	102.7	103.7	104.6	105.6	106.5	107.5	108.5	109.5	110.5	111.5	112.6	113.6	114.6	115.7	116.8	117.9	119.0	120.1	121.2	122.3	123.4	124.6	125.7	126.9
Costs																											
O&M in Million €			-18.3	-18.5	-18.6	-18.8	-19.0	-19.2	-19.4	-19.6	-19.8	-20.0	-20.2	-20.4	-20.6	-20.8	-21.0	-21.2	-21.4	-21.6	-21.9	-22.1	-22.3	-22.5	-22.8	-23.0	-23.2
Depreciation in Million €			-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6	-36.6
Total Fixed Costs in Million €			-54.8	-55.0	-55.2	-55.4	-55.6	-55.8	-56.0	-56.2	-56.4	-56.6	-56.8	-57.0	-57.2	-57.4	-57.6	-57.8	-58.0	-58.2	-58.4	-58.6	-58.9	-59.1	-59.3	-59.5	-59.8
EBT in Million €			174.7	174.9	175.2	175.4	175.7	175.9	176.2	176.5	176.8	177.0	177.3	177.6	177.9	178.1	178.4	178.7	179.0	179.3	179.6	179.9	180.2	180.5	180.8	181.1	181.5
Taxes in Million €			-43.7	-43.7	-43.8	-43.9	-43.9	-44.0	-44.1	-44.1	-44.2	-44.3	-44.3	-44.4	-44.5	-44.5	-44.6	-44.7	-44.8	-44.8	-44.9	-45.0	-45.1	-45.1	-45.2	-45.3	-45.4
Depreciation in Million €			36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6	36.6
Free Cash Flow in Million €	-457	-457	167.6	167.7	167.9	168.1	168.3	168.5	168.7	168.9	169.1	169.3	169.5	169.7	170.0	170.2	170.4	170.6	170.8	171.0	171.3	171.5	171.7	171.9	172.2	172.4	172.6
Discounting																											
Discount Rate (WACC)		0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082	0.082
Discount Numerator		1.082	1.171	1.267	1.371	1.483	1.605	1.736	1.879	2.033	2.199	2.38	2.575	2.786	3.014	3.261	3.529	3.818	4.131	4.47	4.837	5.233	5.662	6.127	6.629	7.173	7.761
PV of cash flow in Million €	-457	-422	143.1	132.4	122.5	113.4	104.9	97.1	89.8	83.1	76.9	71.2	65.8	60.9	56.4	52.2	48.3	44.7	41.3	38.3	35.4	32.8	30.3	28.1	26.0	24.0	22.2
PV of Project in Million €	1641																										
Net Present Value in mil. €	762																										

The DCF analysis results in a present value of 1.641 billion Euro (1,641,129,964.6 Euro) and a net present value (PV minus investment) of 761 million Euro (761,763,975.7 Euro).

V.1. The First Scenario – an Option to Wait

The first scenario is a straight forward real call option, where an investment decision can be undertaken either now or within the next eight years, in accordance with the assumptions described in the previous chapter. This is also called an option to wait or an option to defer (Mun, 2002).

In chapter three we find the instructions on how to proceed. The first step is to model the value of the underlying asset for the time of the option life. A binomial tree is built for this purpose, which is undertaken via the help of a spreadsheet calculation software. The binomial tree is constructed with a single command, which can then easily be copied in the respective cells. With this single command line the tree will not look actually like Figure 1 where the up and down movements are as well represented by a layout that correlates with the value development. In the spreadsheet the up value will be presented in the directly, *horizontally* neighboring cell of the origin value, however the down value will be presented at a lower row.

The tree is built according to the Formulas 7, 8 and 9, which model the up and down development for all *S* values. The input data are explained in the previous chapter in detail, which are again presented for convenience of reading:

Volatility:	36.8%
Option life:	8 years
Risk free rate:	3% annual
Asset value:	1,641,129,964.6 €
Option:	Call option
Exercise price:	879,365,988.9 €
Up value *u:*	0.445727019
Down value *d:*	-0.308306488
Risk neutral prob. *p:*	0.44926521

The tree is started at Period one with the command IF('cell to the left'="",IF('cell to the left, one up'="","",'cell to the left'×(1+*d*)),'cell to the left, one up'×(1+*u*)).

This command is entered all the way until the last period, which is period eight. The values in Table 2 are in million Euro.

Table 2 – Value of the underlying for waiting option

Time	0	1	2	3	4	5	6	7	8
Underlying Asset	1641.1	2372.6	3430.2	4959.1	7169.5	10365.1	14985.1	21664.4	31320.8
		1135.2	1641.1	2372.6	3430.2	4959.1	7169.5	10365.1	14985.1
			785.2	1135.2	1641.1	2372.6	3430.2	4959.1	7169.5
				543.1	785.2	1135.2	1641.1	2372.6	3430.2
					375.7	543.1	785.2	1135.2	1641.1
						259.8	375.7	543.1	785.2
							179.7	259.8	375.7
								124.3	179.7
									86.0

The next step is to built the option value tree. This is done in the same fashion as explained in chapter three with a process that is called backward induction. The start is to built the last column of the option value tree. This last column is simply a maximization between the value of executing the option and letting the option expire. In case of a call option this means that it is a maximization between the corresponding node of the first tree minus the investment cost (exercise price) and zero. This is done with MAX(S - X, 0), where *X* is the exercise price (investment) and *S* is the 'corresponding node of underlying tree'.

Since this option tree reflects an American option a decision can be undertaken at any time, which means we need to perform at every time step a maximization between exercising the option or the discounted weighted value of the up and down values ahead. This process is explained in detail in chapter three. The backwards induction is undertaken via:

IF('cell one to the right, one down'="","",MAX(('corresponding node of underlying tree'-*X*),(*p*×'cell to the right'+(1-*p*)×'cell one to the right, one down')/(EXP(*r*)×(*δt*))))

This resembles: MAX[S - X,{(*p*)up+(1-*p*)down}/EXP{(risk-free)(*δt*)}]. Exercising the option is *underlying minus investment* for a call option. This process is continued until the first cell of the tree. The result option value tree is in our case like Table 3 (values in million Euro).

Table 3 – Option value and decisions for waiting option

Time	0	1	2	3	4	5	6	7	8
Option Value	1066.6	1720.8	2718.1	4206.3	6389.6	9561.4	14157.0	20811.0	30441.5
		592.0	1002.3	1654.5	2657.9	4155.4	6341.3	9511.7	14105.8
			290.0	525.7	927.4	1583.3	2602.0	4105.7	6290.1
				113.7	227.1	443.6	839.9	1519.2	2550.8
					27.5	63.1	144.8	332.1	761.8
						0.0	0.0	0.0	0.0
							0.0	0.0	0.0
								0.0	0.0
									0.0

Time	0	1	2	3	4	5	6	7	8
Option Decision	Wait	Wait	Wait	Wait	Wait	Wait	Wait	Wait	Call
		Wait	Wait	Wait	Wait	Wait	Wait	Wait	Call
			Wait	Wait	Wait	Wait	Wait	Wait	Call
				Wait	Wait	Wait	Wait	Wait	Call
					Wait	Wait	Wait	Wait	Call
						Wait	Wait	Wait	Wait
							Wait	Wait	Wait
								Wait	Wait
									Wait

The calculated option value for the option to wait is 1,066,619,616.8 Euro, which can be rounded to 1.067 billion Euro. This is the additional value created by a flexible framework that allows for a deferral of the investment. In order to calculate the strategic net present value now, one needs to add the NPV form the DCF analysis. Doing so we calculate 1,828,383,592.5 Euro as strategic net present value for the project including an option to wait, which can be rounded to 1.828 billion Euro.

V.2. The Second Scenario – Expansion of Operations

The same basic inputs are used here:

Volatility:	36.8%
Risk free rate:	3% annual
Up value *u:*	0.445727019
Down value *d:*	-0.308306488
Risk neutral prob. *p:*	0.44926521

Expansion option	
Underlying asset value:	1,641,129,964.6 €
Option value:	Respective *underlying node* times *expansion factor* minus *exercise price*
Expansion factor:	2
Exercise price:	739,137,223.0 €
Option life:	8 years
Option to wait	
Underlying asset value:	Respective *expansion option value node*
Option value:	Respective *underlying* minus *exercise prices*
Exercise price:	879,365,988.9 €
Option life:	6 years

The exercise price of the expansion option is derived from a DCF analysis where the investment of 4497 €/kW$_p$ is undertaken in year three and four to equal parts and the cash flow is discounted with a 8.2 percent discount rate, as explained in the previous chapter.

We built now our scenario in line with a standard method for expansion scenarios and sequential compound options explained in chapter three. We are dealing with a staged compound option where the longest running option is the expansion option. This is clear as the completion of the first plant is a condition for the expansion option. The value of the longest running option will be calculated at first for an option life of eight years.

The expansion option assumes that the expansion operation will have the same uncertainty structure as the original operation. It builds on the value of the running operation and the cash flows are assumed to multiply in a linear fashion with the expansion factor (Ibid.). Therefore with a doubling of the operation the underlying asset value would double too. The option value therefore is the value of the doubled operation minus the cost for expansion. This is the reason why the first binomial tree, the underlying asset value tree is modeled for a single power plant, as the doubling is accounted for in the option value calculation. The trees of the underlying asset value development (Table 4) and the option value tree of the expansion option (Table 5) are now presented with all values in million Euro.

Table 4 – Value of the underlying for expansion option

Time	0	1	2	3	4	5	6	7	8
Underlying Asset	1641.1	2372.6	3430.2	4959.1	7169.5	10365.1	14985.1	21664.4	31320.8
		1135.2	1641.1	2372.6	3430.2	4959.1	7169.5	10365.1	14985.1
			785.2	1135.2	1641.1	2372.6	3430.2	4959.1	7169.5
				543.1	785.2	1135.2	1641.1	2372.6	3430.2
					375.7	543.1	785.2	1135.2	1641.1
						259.8	375.7	543.1	785.2
							179.7	259.8	375.7
								124.3	179.7
									86.0

Table 5 – Option value and decisions for expansion option

Time	0	1	2	3	4	5	6	7	8
Option Value	2775	4178.9	6251	9282	13683	20055	29274	42612	61902.5
		1782.4	2719	4125	6205	9242.7	13643	20013	29231.1
			1117	1723	2656	4069.7	6164.2	9200.9	13599.8
				683.5	1057	1650.3	2586.2	4028	6121.2
					416.4	631.89	978.1	1553	2543.12
						263.66	384.41	563.18	831.227
							179.73	259.84	375.662
								124.32	179.732
									85.9909

Time	0	1	2	3	4	5	6	7	8
Option by Name	Wait	Wait	Wait	Wait	Wait	Wait	Wait	Wait	Expand
		Wait	Wait	Wait	Wait	Wait	Wait	Wait	Expand
			Wait	Wait	Wait	Wait	Wait	Wait	Expand
				Wait	Wait	Wait	Wait	Wait	Expand
					Wait	Wait	Wait	Wait	Expand
						Wait	Wait	Wait	One Plant
							Wait	Wait	One Plant
								Wait	One Plant
									One Plant

The option value tree is modeled according to the instructions in chapter three. The last column is a maximization between executing the option and letting the option pass. Executing the option means 2×'corresponding underlying value' - X. The intermediate nodes are calculated again by exploring at each node, which decision is the best: waiting or exercising. Therefore the Formula 11 applies here too with MAX['executing the option',{(*p*)up+(1-*p*)down}/EXP{(risk-free)(δt)}]. This is:

IF('cell one to the right, one down'="","",MAX(('corresponding node of underlying tree'×'expansion factor'-*X*),(*p*×'cell to the right'+(1-*p*)×'cell one to the right, one down')/(EXP(*r*)×(δt))))

The option value of the expansion option is 2,774,574,913 Euro or roughly 2.774 billion Euro. The option value tree then becomes the value tree of the underlying asset of the *next* option, which is the call option on the investment. For the option with the six year option life therefore no underlying asset value tree needs to developed, the option value tree of the eight year option is the underlying for the six year option. This is modeled like in Table 6.

Table 6 – Option value and decisions for waiting option

Time	0	1	2	3	4	5	6
Option Value	2113	3443.6	5472	8478	12855	19201	28395
		1144.1	1980	3321	5377	8389.3	12764
			525.5	995.1	1828	3216.4	5284.9
				171.5	370.4	796.91	1706.8
					18.77	43.045	98.73
						0	0
							0

Time	0	1	2	3	4	5	6
Option by Name	Wait	Wait	Wait	Wait	Wait	Wait	Construct
		Wait	Wait	Wait	Wait	Wait	Construct
			Wait	Wait	Wait	Wait	Construct
				Wait	Wait	Wait	Construct
					Wait	Wait	Construct
						Wait	Forfeit Option
							Forfeit Option

The option value of the compound option, which includes the value of flexibility for two decisions, is calculated with 2,112,834,859.2 Euro, which is 2.113 billion Euro rounded.

This value is the present value of the compound option. Adding to the NPV of the DCF analysis we calculate the strategic net present value with 3,543,927,232 Euro, which is rounded 3.544 billion Euro.

One can present a combination of the both trees, which does not add additional information, and just summarizes both option values in a single tree. In such a presentation the option decisions of the individual stages do not necessarily need result in dependent pathways. It is possible that there are pathways shown where the later option node will not be possible given the result of the earlier stage. This is normal and can be found in textbook examples (Ibid.).

Table 7 – Optimal decisions for the two stage compound option

Time	0	1	2	3	4	5	6	7	8
Option by Name	Wait	Wait	Wait	Wait	Wait	Wait	Construct	Wait	Expand
		Wait	Wait	Wait	Wait	Wait	Construct	Wait	Expand
			Wait	Wait	Wait	Wait	Construct	Wait	Expand
				Wait	Wait	Wait	Construct	Wait	Expand
					Wait	Wait	Construct	Wait	Expand
						Wait	Forfeit Option	Wait	Expand
							Forfeit Option	Wait	One Plant
								Wait	One Plant
									One Plant

V.3. Discussion of the Analysis

In this work the binomial tree is used as a method to calculate the option values. As it is pointed out in the literature (Ibid.; Kodukula & Papudesu, 2006) the binomial tree produces a close approximation to more precise methods like the Black-Scholes formula or a Monte Carlo simulation. As for the reasons explained in chapter three the binomial tree is the most appropriate method for the present work. It is however recommended to test the result via a different method in order to verify the procedure. This will be done via the Black-Scholes formula as seen in Formula 7. It does produce valid results for (a) European options (b) without leakage, (c) no changing exercise price and (d) the only factor influencing the asset value shall be its volatility. In our first scenario we assumed an American option, however the other limitations do not apply to the waiting option scenario. As the result of the waiting option scenario shows in Table 3, the decision will not be undertaken until the very end in any case, which resembles the decision possibilities of a European option. Therefore the Black-Scholes formula can be applied to verify the outcome of the first scenario. We use Formula 7 and the following input data:

Asset value now (V):	1,641,129,965
Asset value volatility:	0.368612323
Risk-free rate annually:	0.03
Exercise Price (X):	879,365,988.9
Time to Maturity (t):	8

The calculated result is an option value for the waiting option in the first scenario 1,066,494,745.5 Euro. This is close to the result of the binomial tree analysis for the waiting option in the first scenario with 1,066,619,616.8 Euro. The analysis is much more likely to be influenced by the framing of the application than by the difference between the two methods.

The second scenario cannot be verified in the same way, due to the limitations of the Black-Scholes formula, however as the two scenarios rely on the same methodology and the same DCF analysis the result of the second scenario is likely to have similar accuracy as the first scenario.

Taken into account the DCF analysis alone the operations produce in both cases a positive cash flow. The cash flow based net present value of a first plant was around 760 million Euro. The option value of the waiting option is around 1.066 billion Euro, which is the added value of the flexibility to wait. The strategic net present value is the sum of both, which is around 1.828 billion Euro. The option would be exercised in year eight. The additional value comes from the potential price development of the electricity price during the time of the option life, as this is the way the application was framed.

The second scenario implies the construction of two plants with the second plant being more cost efficient to construct than the first one. The net present value of the second scenario is best expressed in a sum of both plants, as the NPV of the second depends on the existence of the first plant. This sum is about 1.431 billion Euro. The staged compound option analysis reveals the value of the scenario, which is a waiting option and an expansion option in sequence, with 2.123 billion Euro. The additional value that comes with flexibility in this scenario is mainly influenced by two factors: the development of the electricity price, and the potential to develop a second plant, as this is how the application was framed in this scenario. The strategic NPV here is around 3.544 billion Euro. The options would be exercised in the years six and eight.

Sensitivity Analysis

The work in this thesis relies on several assumptions that are necessary to establish a project environment within which a CSP project would be undertaken in North Africa. The present case however is only one and the project environments can vary quite significantly. This is the reason a sensitivity analysis for the most important parameters shall be undertaken. The underlying assumptions in this work rely on published information. However to frame the application in a way that would create a market a virtual FIT regime needed to be established. The premise of the FIT regime was to mirror the economics of the Spanish FIT and is adapted for the cost of power generation in North Africa. It will now be shown how a change in this FIT regime would alter the outcome of project, this can be seen in Figure 2.

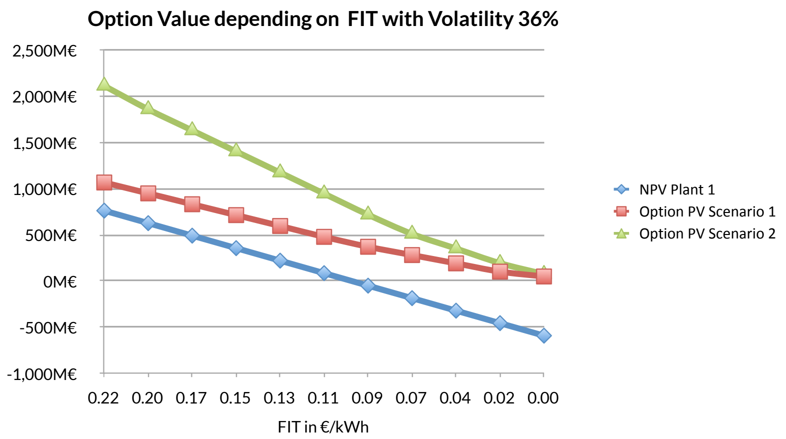

Figure 2 – Option value development with changing FIT

Here can be seen that the FIT regime has a strong influence on the profitability of the project. The NPV of the first plant is in linear relationship with the available FIT. At the assumed FIT of 0.218181561 €/kwh the NPV is 760 million Euro. The NPV reaches zero at a FIT of 0.095394531 €/kwh. If no FIT is provided the NPV were minus 590 million Euro. It is important to note that a net present value of zero does not mean the project does not make any profit. It means however that for an investment with a risk factor that requires a discount factor of 8.2 percent the project becomes unattractive compared to more profitable projects at the same level of risk, or compared to projects with a lower level of risk. This is because the discount rate represents the *opportunity cost of capital* (Brealey & Meyers, 2003). As the value of the first power plant diminishes with a lower FIT the value of the options decrease as well. The graph represents the option values alone and not the strategic NPV with added flexibility.

The result is noteworthy as even with negative underlying asset value there is still for some while a value of flexibility where the option to wait can result in a situation where calling the option would initiate a project with a positive NPV. The option value steadily diminishes and is approaching zero without a Feed-in Tariff regime. This means without a FIT even the option to wait does not result in better prospects for profitability.

Once again, the value of flexibility added is the *strategic NPV*, which is the sum of the option present value and the NPV of the underlying. While Figure 2 aimed to highlight the option value development, which approaches zero as the FIT value decreases, the next presented Figure 3 highlights the strategic NPV.

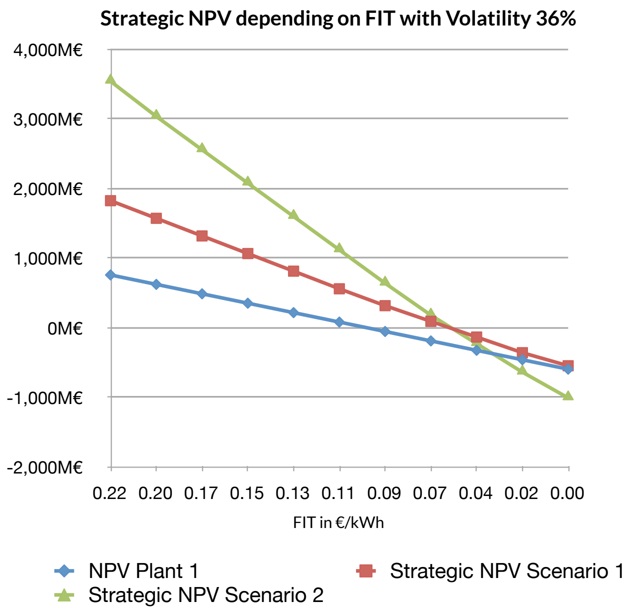

Figure 3 – Strategic NPV development with changing FIT

In Figure 3 it is interesting to note where the option present value does not produce enough additional value and therefore the total strategic NPV becomes negative despite the option. This occurs in the proximity of a FIT of 0.05623 €/kwh for both option scenarios. While the second scenario still produces a positive result at this FIT, the simple waiting option is already negative here.

The value of a Real Option Analysis is driven to a significant extent by the volatility. Volatility of the underlying cash flow defines the corner scenarios in the binomial tree, the spread between the lowest and highest values at every given time step. Therefore we now take a closer look at how the present value of the Real Options depends on the volatility. Firstly we shall have a look at how the option PV is dependent on the volatility at the assumed FIT of 0.21818 €/kWh. This can be seen in Figure 4.

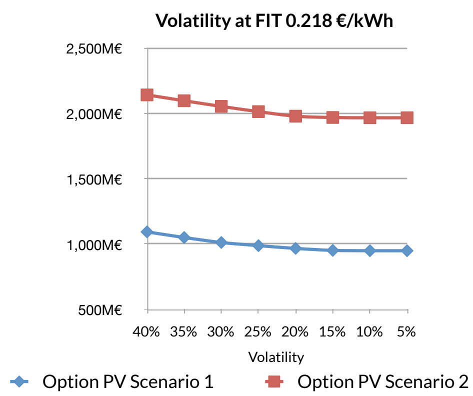

Figure 4 – Changes of option PV depending on volatility

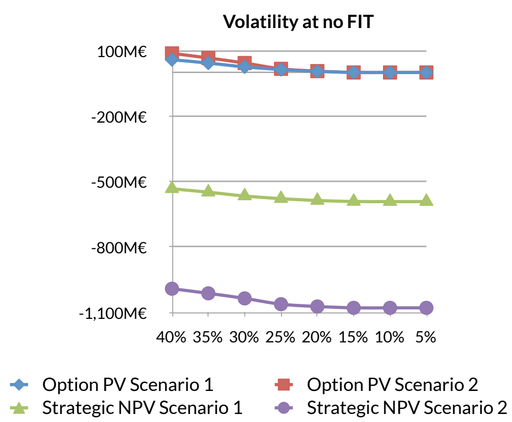

Figure 5 – Volatility at no FIT

As one can see the volatility has a certain impact, the slope of the curve however decreases with lower volatility and does overall not change much compared to the NPV of the first plant, which is 760 million Euro. Volatility does not seem to have a strong impact on the outcome if there were no FIT at all. This is the case in Figure 5 where the strategic value of the added flexibility is clearly negative at any volatility rate. This indicates again that the profitability in North Africa for a CSP project does need a FIT regime. Even the option to wait does not change the project economics significantly at the current cost for the technology. One can note in Figure 5 only small changes of option value with changing of the volatility. This means that without a FIT project economics are hopeless. Even a strong electricity price volatility does not result in a different outlook.

At last we shall have a look on the effect of volatility change at an FIT of about 0.09539 €/kwh. This FIT is chosen at a level at which the NPV of the first power plant is zero. This means for the first scenario the option value equals the strategic NPV (strategic NPV = option value + zero). For the second scenario there is a distinct strategic NPV. Figure 6 shows a stronger change in volatility than Figure 4.

The volatility change from five to 40 percent at the FIT regime of 0.21818 €/kwh results in option present value changes of 144 million Euro for the first scenario and a difference of 175 million Euro for the second scenario. With a FIT of about 0.09539 €/kwh the result depends much more on the price development of electricity in the wholesale market. With this FIT the option PV difference at five and 40 percent volatility is 238 million Euro for the first scenario and 400 million Euro for the second scenario.

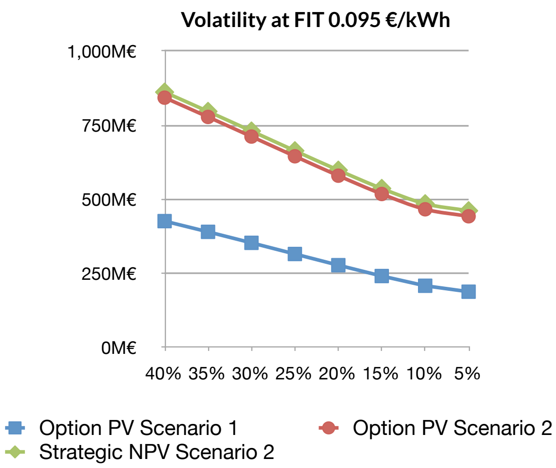

Figure 6 – Change of option PV depending on Volatility at "NPV zero FIT"

VI. CONCLUSION

In the present thesis a concentrated solar power (CSP) project was evaluated via two different valuation tools, the Discounted Cash Flow (DCF) method and a Real Option Analysis (ROA). The result of a DCF calculation does produce an accurate result for a now-or-never and all-or-nothing investment situation and is well equipped to compare several projects with each other. However the DCF method has an inherently static perspective, which can undervalue the profitability potential of a project. One can assume this is likely to be the case for new technologies, for contingent decision scenarios, for situations with high market uncertainties, and in a setting where the net present value (NPV) from a DCF is comparatively close to zero compared to the investment (Amram & Kulatilaka, 1999, Copeland et al., 2000, p. 398). In line with other research that applied the ROA framework to renewable energy valuation, this thesis aims to find out whether ROA can reveal an additional value of a flexible decision-making process for investments in CSP or if the profitability of a CSP project does change only little with the option to wait with a project.

The Real Option evaluation was undertaken via a risk neutral binomial tree model, which is a very flexible method, as several input parameters can be changed at different time steps, and therefore it can be adapted to a wide range of applications. The binomial tree therefore was well suited to answer the questions in this thesis.

The analysis shows that for a North African location an Feed-in Tariff (FIT) regime that is modeled after the Spanish FIT regulations would ensure profitability of a CSP project at a discount rate of 8.2 percent. This research assumes a power plant featuring a nameplate capacity of 200MW, a power tower setup, eight hour heat storage, capital costs per capacity of 4,570 €/kWp and a location with a Direct Normal Irradiation (DNI) of 2500 kwh/m²/year. The FIT is fixed with 0.218 €/kwh on top of the wholesale price that starts at 0.04993 and escalates with one percent annually. This results in a project with an NPV of 761 million Euro. The ROA reveals that a simple eight year waiting option can increase the strategic value of the project to 1.828 billion Euro, with the Real Option present value being 1.067 billion Euro. There strategic NPV is 1.828 billion Euro.

In a second scenario a successive power plant is accounted for as well, based on the assumption that it is in the interest of the utility company to explore this energy source further. In this setting a learning effect is accounted for, which decreases the costs of the second plant by a 92.5 percent learning rate. Entering a market allows for the possibility to develop additional projects in the future, this future potential can be accounted for. The option application is set up as a staged compound option with an expansion (the second plant) and a waiting option (the first plant). The second scenario reveals that the option present value of construction and expansion is 2.113 billion Euro and the consequent strategic net present value is 3.544 billion Euro.

Sensitivity analysis highlights that the FIT is a very significant parameter for this type of CSP plant. Without a FIT there is a distinctively negative net present value and the value of the option to wait is close to zero, which means that even with time the profitability will not change (given same technology costs). During the sensitivity analysis it was also shown that given a FIT that produces an cash flow NPV of zero for the first plant, there is a significant Real Option value in the option to wait, and even more so in the option to wait and later expand. This FIT has a value of roughly 0.09539 €/kwh. There the option value for the first scenario (one plant) is about 404 million Euro and for the second scenario about 802 million Euro. This option value is the strategic value to keep the option open for future investment until a more beneficial electricity price development, or a further drop in technology costs.

The Discounted Cash Flow method shows that a FIT is necessary to ensure profitability. The Real Option Analysis shows that without a FIT the project will not reach profitability in future (at current cost of technology). The ROA further shows that even with a smaller FIT compared to Spain there is a significant Real Option value. This means there would be a benefit for investors to ensure that a decision to invest can be undertaken at any time once the uncertainty clears. The ROA also shows that with a relatively high FIT an investor would still wait with the investment. How long this waiting period would be, depends on the interpretation of the ideal market entry time. In our analysis we assumed from historic patterns of power generation industry and predictions of industry reports (Stallworthy & Kharbanda, 1985, IHS Emerging Energy Research, 2010) that a market integration of CSP will be given within the next ten years and therefore within this time a company would need to enter the market. However it is possible to reduce the option time depending on competition.

Two aspects of the CSP market are reflected in the findings in this thesis. Firstly the global project pipeline does not seem to take off immediately. A report from IHS Emerging Energy Research (Ibid.) does see a take off phase around 2014, where 17,000 MW and more are scheduled for yearly construction onwards. This seems to indicate that we currently are in a 'waiting and preparing' and first development phase. This is as well described by the same report as a "technology and deployment" phase. The findings in this thesis resemble this waiting period, as waiting increases the future value of construction, once the option to invest (for example technology design, engineering, permitting and similar preparations) is secured. However this waiting period might not be desirable by political decision makers, depending on the policy priorities. If a government were keen on promoting CSP technology, it can encounter the waiting value by granting certain incentives only for projects starting before a certain deadline, as it is the case in the US with some tax credits for CSP becoming active only in case of a construction before 2017 (CSP Today, 2011a).

Secondly the most active CSP markets will be the United States and Spain. Spain has for a European country relatively areas of acceptable Direct Normal Irradiation (DNI) with around 2000 kWh/m^2/y. Further there is a promising FIT regime for CSP operators. In the US there is a range of incentives available, from a loan guarantee to a short depreciation time, to tax credits, to incentives for manufacturing facilities, and R&D funding partnerships (Ibid.). Therefore the global market seems to develop first in those countries that provide the necessary incentives. The results in this thesis show that the profitability of a CSP plan in North Africa is not profitable without a FIT.

However the Real Option framework did prove to be a better equipped tool to understand the potential and limitations of the technology at current costs per capacity. It reveals under which conditions a waiting option becomes interesting for utilities. ROA therefore can capture the dynamic development of the technology better than a DCF analysis. The main limitation of this research is that only one project is assessed which depends on the availability of direct current transmission infrastructure between North Africa and Spain. In reality this infrastructure needs investment.

For a future analysis the Real Option framework can be applied to analyze how steadily decreasing costs per capacity would alter the project profitability. This can be undertaken in a ROA analysis with a steadily reducing strike price (the investment) along the time steps in a binomial tree. For such an analysis the strike price would be reduced for every time step in line with the learning rate for CSP and the globally installed additional capacity according to detailed projections for each time step and registered projects. Consequently the availability of technological breakthroughs as for example found in (EASAC, 2011, pp. 20–21) for CSP at estimated time points can be modelled in a similar fashion, instead using a generalized learning curve.

VII. BIBLIOGRAPHY

Amram, M., & Kulatilaka, N. (1999). *Real Options Managing Strategic Investment in an Uncertain World*. Boston: Harvard Business School Press.

Arrow, K. J. (1962). The Economic Implications of Learning by Doing. *The Review of Economic Studies*, 29(3), 155–173. doi:10.2307/2295952

Barlow, J. F. (2005). *Excel models for business and operations management*. John Wiley & Sons.

Black, F., & Scholes, M. (1973). The Pricing of Options and Corporate Liabilities. *Journal of Political Economy*, *81*(3, May-June), 637–654.

Bloomberg.com. (2011). German Government Bonds 10 Yr Dbr. Retrieved 11.12.2011, from http://www.bloomberg.com/apps/quote?ticker=GDBR10:IND

Brealey, R. A., & Meyers, S. C. (2003). *Principles of Corporate Finance* (7 ed.). New York: McGraw-Hill.

Comisión Nacional de Energía. (2008). Annual Report 2007. Retrieved 20.10.2011, from www.cne.es/cne/doc/publicaciones/PA004_08ingles.pdf

Comisión Nacional de Energía. (2009). Annual Report 2008. Retrieved 20.10.2011, from www.cne.es/cne/doc/publicaciones/PA004_09_ing.pdf

Comisíon Nacional de Energía. (2010). Annual Report 2009. Retrieved 20.10.2011, from www.cne.es/cne/doc/publicaciones/PA004_10_ing.pdf

Conkling, R. L. (2011). *Energy Pricing, Economics and Principles*. Heidelberg: Springer.

Copeland, T., Koller, T., & Murrin, J. (2000). *Valuation, Measuring and Managing the Values of Companies* (3 ed.). New York: John Wiley & Sons, Inc.

Copeland, T., & Antikarov, V. (2003). *Real Options, A Practitioner's Guide*. New York: Thomson.

Cory, K., Coggeshall, C., Coughlin, J., & Kreycik, C. (2009). Solar Photovoltaic Financing: Deployment by Federal Government Agencies. Retrieved 4.11.2011, from https://sam.nrel.gov/content/reports-featuring-sam

CSP Today. (2011a). CSP FIT Guide. Retrieved 18.11.2011, from www.csptoday.com/csp/pdf/CSPFITGUIDE.pdf

CSP Today. (2011b). The concentrated solar power markets report 2011–2012. Retrieved 21.10.2011, from http://www.csptoday.com/csp-markets-report/

Damodaran, A. (2002). *Investment Valuation: Tools and Techniques for Determining the Value of any Asset* (2 ed.). New York: John Wiley and Sons Inc.

Dixit, A. K., & Pindyck, R. S. (1994). *Investment under Uncertainty*. Princeton: Princeton University Press.

Dixit, A. K., & Pindyck, R. S. (1995). The Options Approach to Capital Investment. *Harvard Business Review, 73*, 105–115.

DLR – German Aerospace Center. (2006). Trans-Mediterranean Interconnection for Concentrating Solar Power, Final Report. Retrieved 25.5.2011, from http://www.dlr.de/tt/trans-csp

Durand, R., Gomez, P. Y., & Monin, P. (2001). Real Options Strategies. *European Entrepreneurial Learning, 1*, 1–21.

EASAC – European Academies Science Advisory Council. (2011). Concentrating solar power: its potential contribution to a sustainable energy future. Retrieved 20.11.2011, from http://www.easac.eu/fileadmin/Reports/Easac_CSP_Web-Final.pdf

Holden, C. W. (2002). *Spreadsheet Modeling in Corporate Finance.* Prentice Hall.

Hull, J. C. (2006). *Options, Futures, and Other Derivatives* (6 ed.). Prentice Hall: Pearson.

IHS Emerging Energy Research. (2010). Global Concentrated Solar Power Markets and Strategies: 2010–2025. Retrieved 20.10.2011, from http://emerging-energy.com/uploadDocs/Excerpt_GlobalConcentratedSolarPowerMarketsandStrategies2010.pdf

International Energy Agency. (2006). World Energy Outlook. Retrieved 16.6.2011, from http://www.iea.org/weo/2006.asp

International Energy Agency. (2010). Technology Roadmap, Concentrated Solar Power. Retrieved 9.6.2011, from www.iea.org/papers/2010/pv_roadmap.pdf

Johansson, T., & Nilsson, M. (2009). First mover disadvantages? A brief inquiry into investment dynamics in wind power and grids. *Energy Market – 6th International Conference on the European Energy Market,*.

Kodukula, P., & Papudesu, C. (2006). *Project Valuation Using Real Options, A Practitioner's Guide.* Fort Lauderdale: J. Ross Publishing.

Kogut, B., & Kulatilaka, N. (1994). Operating flexibility, global manufacturing, and the option value of a multinational network. *Management Science, 40*(1), 123–140.

Kopel, M., & Löffler, C. (2008). Commitment, first-mover-, and second-mover advantage. *Journal of Economics, 94}, issue = {2*, 143-166. Retrieved from http://dx.doi.org/10.1007/s00712-008-0004-4

Kost, C., & Schlegl, T. (2010). Studie Stromgestehungskosten Erneuerbare Energien. Retrieved 28.8.2011, from http:// www.ise.fraunhofer.de/veroeffentlichungen/studie-stromgestehungskosten-erneuerbare-energien

Leslie, K. J., & Michaels, M. P. (1997). The Real Power of Real Options. *The McKinsey Quarterly, 3*, 4–22.

Masters, G. M. (2004). *Renewable and Efficient Electric Power System.* Hoboken: John Wiley & Sons Inc.

McDonald, R., & Siegel, D. (1986). The Value of Waiting to Invest. *Quarterly Journal of Economics, 101*, 707–728.

Miller, L., & Park, C. (2002). Decision-Making Under Uncertainty, Real Options to the Rescue? *Engineering Economist, 47*(2).

Mitchell, G. R., & Hamilton, W. F. (1988). Managing R&D as a strategic option. *Research Technology Management, 31*, 15–22.

Mun, J. (2002). *Real Option Analysis, Tools and Techniques for Valuing Strategic Investments and Decisions*. Hoboken: John Wiley & Sons.

Myers, S. C. (1984). Finance Theory and Financial Strategy. *Interfaces*, *14*, 126–137.

NREL – National Renewable Energy Laboratory. (2011). System Advisory Model. Retrieved 20.11.2011, from https://sam.nrel.gov/

OMEL. (2011). OMEL Electricity Market Data. Retrieved 12.11.2011, from http://www.omel.com/files/flash/ResultadosMercado.swf

Onada Corporation. (2011). Onada Historical Exchange Rates. Retrieved 08.09.2011, from www.oanda.com/currency/historical-rates/

Ottoo, R. E. (2000). *Valuation of Corporate Growth Opportunities, A Real Options Approach*. New York: Garland Publishing.

Pindyck, R. S. (1988). Irreversible investment, capacity choice, and the value of the firm. *The American Economic Review*, *78*(5), 969–985.

Pindyck, R. S. (1993). Investment of Uncertain Cost. *Journal of Financial Economics*, *Aug. 34*, 53–76.

Reuer, J. J., & Tong, T. W. (2007). *Real Option Theory* (1 ed.). Oxford: Elsevier.

Shun-Chung, L., & Li-Hsing, S. (2010). Renewable energy policy evaluation using Real Option model – The case of Taiwan. *Energy Economics*, *32*, S67–S78.

Sick, G. (1989). Capital Budgeting with Real Options. *Monograph Series in Finance and Economics*, *3*.

Smit H. T. J., & Trigeorgis, L. (2006). Real options and games: Competition, alliances and other applications of valuation and strategy. *Review of Financial Economics*, *15*, 95–112.

Stallworthy, E. A., & Kharbanda, O. P. (1985). *International construction : and the role of project management*. Brookfield: Gower Pub Co.

Taleb, N. N. (2010). *The Black Swan: The Impact of the Highly Improbable* (2 ed.). Random House.

Teach, E. (2003). Will Real Options Take Root? Why companies have been slow to adopt the valuation technique. *CFO Magazine*, *July*.

Trigeorgis, L. (1995). *Real Options in Capital Investment, Models, Strategies, and Applications*. Westport, Connecticut: Praeger Publishers.

Trigeorgis, L., & Mason, S. P. (1987). Valuing Managerial Flexibility. *Midland Corporate Finance*, *5*.

VanderWerf, P. A., & Mahon, J. F. (1997). Meta-Analysis of the Impact of Research Methods on Findings of First-Mover Advantage. *Management Science*, *43*(11), 1510–1519.

Woolley, J. (2009). Innovation policy in emerging domains of activity: First-mover advantage or curse? *2009 Atlanta Conference on Science and Innovation Policy*,.

Zimmerman, M. B. (1982). Learning Effects and the Commercialization of New Energy Technologies: The Case of Nuclear Power. *The Bell Journal of Economics*, 13(2), 297-310.

VIII. LIST OF TABLE AND FIGURES

IX. LIST OF ACRONYMS

CSP	Concentrated Solar Power
DCF	Discounted Cash Flow
DNI	Direct Normal Irradiation
CAPM	Capital Asset Pricing Model
EASAC	European Academics Science Advisory Council
EC	European Commission
EPC	Engineering, Procurement and Construction firms
FIT	Feed-in Tariff
GARCH	Generalized Autoregressive Conditional Heteroskedasticity Model
GW	Gigawatt
HP	Hewlett Packard
IEA	International Energy Agency,
IRR	Internal Rate of Return
kwh	Kilowatt-hour
kW_p	Kilowatt potential
LCOE	Levelized Costs of Energy
MW_e	Megawatt electrical
MWh	Megawatt-hour
NPV	Net Present Value
NREL	National Renewable Energy Laboratory
PV	Present Value
RD	Royal Decree
R&D	Research and Development
ROA	Real Option Analysis
SAM	System Advisory Model
SEGS	Solar Electric Generation System
US	United States
WACC	Weighted Average Cost of Capital