E.ON Energy Research Center
FCN | Institute for Future Energy Consumer Needs and Behavior

FCN Working Paper No. 21/2010

Power Plant Investments in the Turkish Electricity Sector: A Real Options Approach Taking into Account Market Liberalization

Reinhard Madlener and Simon Stoverink

December 2010
Revised July 2011

Institute for Future Energy Consumer Needs and Behavior (FCN)

School of Business and Economics / E.ON ERC

RWTH AACHEN UNIVERSITY

FCN Working Paper No. 21/2010

Power Plant Investments in the Turkish Electricity Sector: A Real Options Approach Taking into Account Market Liberalization

December 2010
Revised July 2011

Authors' addresses:

Reinhard Madlener
Institute for Future Energy Consumer Needs and Behavior (FCN)
Faculty of Business and Economics / E.ON Energy Research Center
RWTH Aachen University
Mathieustrasse 6
52074 Aachen, Germany
E-mail: rmadlener@eonerc.rwth-aachen.de

Simon Stoverink
Evonik Steag GmbH
Rellinghauser Straße 1-11, Haus 5
45128 Essen, Germany
E-mail: simon.stoverink@evonik.com

Publisher: Prof. Dr. Reinhard Madlener
Chair of Energy Economics and Management
Director, Institute for Future Energy Consumer Needs and Behavior (FCN)
E.ON Energy Research Center (E.ON ERC)
RWTH Aachen University
Mathieustrasse 6, 52074 Aachen, Germany
Phone: +49 (0) 241-80 49820
Fax: +49 (0) 241-80 49829
Web: www.eonerc.rwth-aachen.de/fcn
E-mail: post_fcn@eonerc.rwth-aachen.de

Power plant investments in the Turkish electricity sector: A real options approach taking into account market liberalization

Reinhard Madlener[a,*], Simon Stoverink[b]

[a] *RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), School of Business and Economics / E.ON Energy Research Center, Mathieustrasse 6, 52074 Aachen, Germany*

[b] *RWTH Aachen University, Templergraben 55, 52056 Aachen, Germany*

December 2010, revised version July 2011

Abstract

In this paper we study the economic feasibility of constructing a 560 MW coal-fired power plant in Turkey, using real options theory [1]. We start from a short review of the Turkish electricity market as well as the literature on real options theory and power plant investment. We then investigate the peculiarities and uncertainties related to large-scale power generation. Our special research focus is on the determination of the real options value of the sequential nature of the power plant project considered. To this end, we develop a sequential investment model based on the binomial tree model of Cox, Ross and Rubinstein [2]. The four stages considered are (1) initial project development; (2) detailed planning and permitting; (3) first major project payments; and (4) release of final order. We find that especially for the strategic planning of projects the application of the real options analysis (ROA) can be very useful. The relatively high option value compared to the net present value (NPV) of the project makes clear that the flexibilities of reacting during project realization, depending on the market developments, can be assigned an immense value. A further advantage of the ROA for a staged or sequential investment lies in the fact that it also delivers, besides the option value of the investment, the optimal strategy for exercising the option (i.e. if and when to invest). The revelation of action possibilities and their examination sheds new light on the conventional calculation of the NPV of such projects.

Keywords: Real options, Liberalized market, Sequential investment, Turkey

* Corresponding author: Tel.: +49 241 80 49 820; fax: +49 241 80 49 829; *E-mail address:* RMadlener@eonerc.rwth-aachen.de (R. Madlener).

1. Introduction

In recent years it has increasingly been recognized that in liberalized energy markets traditional investment calculations, such as discounted cash flow approaches, are inadequate. Real options analysis (ROA) is a more sophisticated approach that enables to take into account the “value of waiting” that accrues from the irreversibility of an investment (sunk cost), uncertainty, and the flexibility of postponing an investment in order to obtain more information about the future. This flexibility of waiting can be considered as an option that is forfeited when the investment is made. Keeping the option alive, i.e. to maintain the flexibility to invest or not to invest, has a value that can be calculated. In this paper we apply ROA to the case of a large coal power plant in Turkey. Our specific interest is in the sequential nature of the investment that passes through certain planning and construction phases at which the project can be stopped if the relevant markets develop in an unfavorable direction. Additionally to the options’ values of the investment considered, we also want to determine the optimal strategy for exercising the options.

The Turkish electricity market has been considerably restructured in recent years. In order to open it further for private sector participation, the formerly vertically integrated companies have been unbundled, leaving only the transmission grid as a natural monopoly. During the last two decades, the Turkish electricity market has been rapidly growing, with an average annual growth rate of more than 6% [3]. In 2007, total electricity generation reached 191.6 TWh. Natural gas accounted for 50% (95.0 TWh) of total power generation in 2007, lignite for 20% (38.3 TWh), renewables for 19% (36.4 TWh), and hard coal for about 8% (15.1 TWh). The 19% share of renewables was strongly dominated by hydroelectric energy [3]. According to IEA forecasts, it is expected that electricity consumption will double by 2020. Unless major changes in electricity imports take place, this will require at least doubling the installed generation capacity within a decade, which constitutes a tremendous challenge [4].

The remainder of this paper is organized as follows. Section 2 contains a review of relevant literature, section 3 the methodology used, section 4 the main results, and section 5 concludes.

2. Literature review

Real options analysis (ROA) has its origins in the article “Determinants of Corporate Borrowing” published by Stewart C. Myers in the Journal of Financial Economics in 1977 [5]. In this paper Myers points out that the value of an enterprise not only depends on the NPV of existing investment projects, but that it is also influenced by the NPV of future growth options.

Since the value of these options cannot be determined by classic investment calculation, Myers [6, p.136] proposes to apply the principles of financial options theory to real assets. The foundation of modern option valuation is the work of Black and Scholes [7] and Merton [8]. Specifically, the approach developed by Black and Scholes yields a closed form solution for the value of a financial option. An alternative valuation approach is the binomial tree model developed by Cox, Ross and Rubinstein [2]. Today, this model for the valuation of financial options is used mainly for real options valuation in practical applications. A useful overview of ROA by solving partial differential equations, which is mathematically somewhat more demanding, can be found in Dixit and Pindyck [1].

In the early 1980s the number of publications on the empirical application of ROA has soared. Many studies at that time focused on optimal strategies for the exploitation of natural resources [9]. Another study is Paddock, Siegel and Smith [10], who use ROA for the valuation of offshore oil production licenses.

The use of ROA in the electricity sector has received an increasing interest over the last decade. Attractive application areas are the planning of power generation investment and the use of options in power plant operation. Hundt et al. [11] provide an introduction on applying ROA to power plant investments and consider the prerequisites for their use in the electricity industry. They point out that most electricity markets are still no complete and arbitrage-free markets, as it is required in ROA. At the same time they deliver an approach to surmount this dilemma. Gollier et al. [12] use options valuation for the comparison of two nuclear power plant projects, where one consists of a series of smaller units and the other one is a large nuclear power station with the same installed capacity as all modular units taken together. The authors show that the value of modularity has a decisive impact on the investment strategy. Another interesting application of ROA has been introduced by Siddiqui and Maribu [13]. The authors consider investments in decentralized power supply units and their expansion possibilities. By applying ROA they are able to determine the optimal investment strategy for distributed generation in dependence of the volatility of the natural gas price.

An example for the application of ROA to power plant operation is de Moraes et al. [14], in which the Brazilian electricity supply industry is investigated. The Brazilian electricity sector is highly influenced by precipitation, since 99% of the electricity is produced in hydropower plants. De Moraes et al. [14] use ROA in order to determine the value of flexibility attached to the construction of additional conventional power plants. A more general application of ROA for power plants in liberalized markets, with a particular focus on Germany, is described in Hartmann [15].

Keppo and Lu [16] investigate the impact of large producers, as they are common in the electricity market, on real options theory. They emphasize that large producers have an influence on the market supply that cannot be underestimated, and thus might affect electricity price. Crampes and Creti [17] take this influence and employ a game-theoretic approach for analyzing the way the restraint of production capacity can be utilized for strengthening market power.

The works of Hommel and Pritsch [18], Amram and Kulatilaka [19] and Trigeorgis [20] are especially suited as an introduction to ROA. Useful discussions for practitioners are provided by Copeland and Antikarov [21] and by Kodukula and Papudesu [22].

3. Option value of a hard coal power plant

In this section we provide a detailed description of the power plant investment considered in our study. First, we describe the project considered and in particular the time structure of project realization. Second, we analyze the uncertainties attached to the investment and the real options inherent in the project. Finally, we compute the real options value and provide a detailed analysis of the results obtained.

3.1. Project description

We consider the investment in a conventional hard-coal power plant located in Turkey, with a declared net capacity of 560 MW. Regarding the investment on the Turkish energy market considered, the investing company acts as an Independent Power Producer (IPP). The electricity produced by the power plant shall be sold to a Turkish energy provider on the basis of a long-term power purchase agreement (PPA). Investment decisions on power plants are characterized by a multi-stage process. These stages have the characteristic feature that their completion takes time. Paybacks from the project only accrue when all stages are fully accomplished. The real options valuation that follows is based on the explicit consideration of these sequential stages of investment. Hence the process stages of the large-scale power plant investment considered is described next.

At the beginning of the investment process is the initial project development phase (IPD). Its duration depends strongly on the type of power plant considered. For a hard coal plant, as it is considered in our study, the duration of this stage is about two years, whereas for nuclear power plants the planning phase usually takes much longer. During the IPD, the acquisition of market knowledge and an environmental audit take place. Also, a detailed elaboration of the technical details as well as negotiations with technology providers about the commissioning of the delivery contracts is conducted. At the end of the initial project development phase, a concept for the construction of the power plant exists. Subsequently to the planning, typically a delivery contract is concluded with one or more of the technology providers for supplying the power plant's components. For the project considered here the goal for the end of the planning phase is the conclusion of an EPC[1] contract. If such a contract is signed, and thus the project realization can be continued, the next stage is the detailed planning and permitting (DPP). In this stage, site acquisition, final planning and permitting as well as preliminary site preparations are carried out. For the considered power plant the investment for this stage add up to US$ 30 million. The EPC contract between the technology provider and the investing enterprise normally contains two distinct paragraphs, in which it is stipulated that the continuation of the activities on the side of the technology provider requires a deliberative invitation on the side of the investing firm. On the one hand, this is the first major project payment (MPP) and, on the other hand, the release of the final order (RFO) These dates, at which the decision about the continuation has to be taken, are determined by the EPC contract. For the project considered in our study these dates are 6 and 12 months, respectively, after signing the EPC contract. These two dates deliver the deadlines for the last stages. Six months after signing the EPC contract the first major project payments are due. The costs for this stage comprise those for the continuation of site preparation, detailed engineering by the technology provider, final site preparations (foundation etc.), the reservation of production capacities, finalization of permitting work as well as financial engineering and related advisory costs. In contrast to the signing of the EPC contract the provision at the end of stage three (MPP) is linked to high payments to the technology manufacturer that (largely) represent sunk costs in case of a cancellation of the project. As mentioned above the release of the final order (RFO) has to be made six months after the first major project payments (MPP). With the RFO 12 months after signing the EPC contract the investing firm decides about the complete realization of the power plant investment. A cancellation during construction is possible, but would result in very high forgone costs due to the design of the contract. For the project considered, a construction period of 42 months after the release of the final order is foreseen. Therefore, the first repayments from the project can only be realized four years and a half year after signing the EPC contract.

[1] *Engineering, Procurement and Construction* (EPC) refers to a form of project realization, where the customer acts as general contractor. He is obliged to deliver a plant or construction turnkey ready to the contractor, usually at a fixed price and at a fixed point in time, safeguarded by means of penalty payments. The EPC supplier provides all necessary services, especially the entire engineering, the procurement or manufacturing of the necessary materials and components, on-site assembly, and turnkey-ready putting into operation.

Following the construction time, commercial operation of the plant starts, assumed to have a duration of 20 years.

3.2. Determination of the real options

In order to meaningfully apply ROA, the real asset considered (described in section 3.1 in some detail) has to feature flexibility, uncertainty, and irreversibility. In the previous subsection we described the various stages of the investment decision. We emphasized that the decision for ultimate project realization is not taken during the planning phase, but instead repeatedly over the course of the entire process at the beginning of each new stage. Therefore, the project type features the necessary flexibility. Net revenues from the project depend strongly on the development of the electricity, coal and oil prices, which are characterized by substantial uncertainty. Finally, since the investment costs as well as a large portion of the pre-investment costs are sunk costs, also the criterion of irreversibility is fulfilled.

For the ROA a detailed analysis of the options connected to the project is required. The presentation of the investment sequencing has shown that the project is characterized by a sequential process. For the further considerations, due to the contractual arrangement of the relationship between the investing firm and the technology provider, the assumption is made that the decision about continuation of the project realization is made in discrete points in time.

The company considered owns an operation license, which allows the construction of a 560 MW power plant. According to the license, construction has to begin within five years, after which it expires. The operation license can thus be regarded as an American call option with a duration of five years on the construction of a power plant. The value of this option is determined by the value of the sequential options on the basis of the stages of the investment process. “Sequentially” in this context means that the next option only becomes relevant if the previous one is actually exercised. The analysis of the project under consideration, with the above-described structure over time, has shown that the duration of the operation license can be divided into four sequential options. In particular, these are (1) the option on the initial project development (IPD); (2) the option on the detailed planning and permitting (DPD); (3) the option on the provision of the first major project payments (MPP); and (4) the option on the release of the final order (RFO).

Chronologically, the first option bears the right to purchase the second option. The same applies to the subsequent options. The risk-laden underlying[2] of the first three options is the value of the following option. The risk-laden underlying of the last option are the expected revenues from the investment project itself. From an economic perspective, the chronologically last option is de facto the first one. As the operation license expires at the end of its five-year lifetime, the company has to take the decision in favor or against the release of the final order (RFO) at t = 5 years at the latest. Due to the design of the EPC contract the option on providing the first major project payments has a duration of six months. The second option from an economic perspective is the option on providing the first major project payments (MPP). This one also features a duration of six months due to the contractual stipulations.

The third option is the option for the detailed planning and permitting (DPP) and signing of the EPC contract. The duration of this option is determined by the length of the initial project development, which in our case is two years. The first three options from an economic viewpoint are European call options, which can be exercised at the end of their lifetime. The last option from an economic perspective is the option on the initial project development (IPP). The initial project development of our project takes two years, and development has to start at least three years before expiry of the operation license. Hence the duration of the lifetime of the initial project development phase (IPP) option is two years. Within these two years, development can start at any arbitrary moment in time. The option on the initial project development is thus equivalent to an American call option that, in contrast to a European call option, can be exercised any time until expiry.

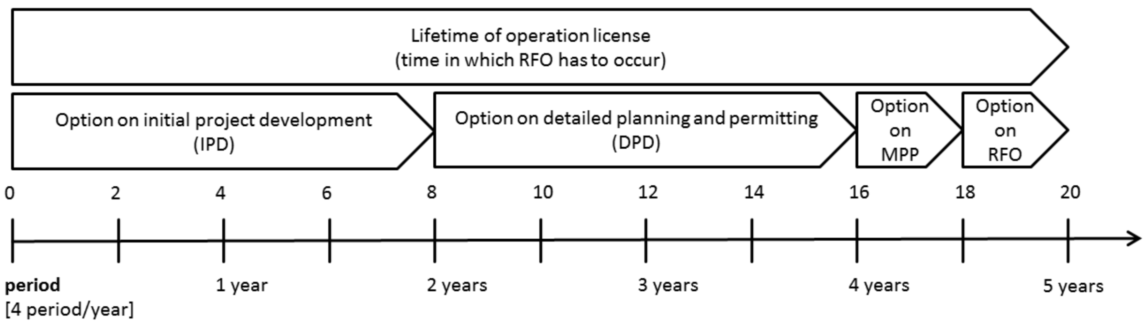

Fig. 1. Overview of sequential options

[2] A term used in the trading of derivatives (e.g. options). A derivative is a financial instrument whose price is based (derived) from a different asset, the so-called ‘underlying’. In other words, the underlying is the asset (e.g., stock, futures, commodity, currency, index) on which a derivative’s pricing is based.

3.3. Dealing with uncertainty

In the following, we discuss the uncertainties related to the power plant investment. Here we distinguish between uncertainties that enter the decision model, and those that are ignored. The uncertainties considered in the decision model are those of the prices of the input fuels (coal, oil), of the electricity price, and of the costs of transporting the imported coal. The price volatilities are determined from historical data, as described in section 4.1.

The development of the electricity prices is one of the most important impacts on our project. The investing firm wants to conclude a power purchase agreement (PPA) with a Turkish customer at the latest when the provision of the release of the final order is made. The electricity price fixed in this contract is, however, unknown at the beginning of this option's lifetime. The same is true for the development of the input fuel prices for coal and oil[3]. The change in the freight rate is also unknown, but correlates highly with the oil price. The development of the coal and oil prices after signing the PPA is for the further considerations negligible, since these risks are directly passed on to the customers by contract design. The electricity price fixed represents the market expectations at the time of exercising the option.

When dealing with power plant investments in Turkey, large uncertainties also arise from possible changes in the regulatory and political framework conditions. However, by nature these can only be insufficiently considered in a decision-making model. As Copeland emphasizes, for instance, with increasing uncertainty in an economy, investment activities often slow down, since it becomes increasingly attractive to wait and see [19, p.107]. Due to the ongoing liberalization process in the electricity industry in Turkey, in the coming years a number of changes can be expected [4]. The related risks also offer some business opportunities that should be scrutinized thoroughly before realizing a project.

3.4. Present value calculation

The aim of this section is to compute the net present value (NPV) of the power plant investment at time $t = 0$. Given that the traditional discounted cash flow approach is unable to account for the value of flexibility, it may serve as a reference value for the case of no flexibility.

For the calculation of the NPV we first have to identify the payment streams connected to project realization. The cost of the first three stages of the project can be estimated with sufficient accuracy by the project participants. Specifically, the cost of the initial project

[3] Oil is used in the considered power plant for ramping up of the plant, and a small amount also during operation.

development including the cost of the acquisition of market knowledge amount to an estimated US$5 million. For the detailed planning and permitting, site acquisition and preliminary site preparation some US$30 million are required. At the provision of the first major project payments US$86 million are due, a sum that is determined in part by the EPC price and in part by the estimated project realization costs. The EPC contract stipulates in detail at which points in time payments have to be made to the technology provider. Finally, when calculating the NPV we assume that the costs at the various stages of project realization are due at discrete points in time.

The determination of the present value of the construction costs after granting the release of the final order requires the consideration of the time structure of the investment payments. A characteristic of power plant investments is their long construction time. Consequently, the time structure of the investment expenditures has a significant impact on their present value. Specifically, we spread the investment costs according to the stipulations in the EPC contract over the 42 months of construction and discount them to the time of the release of the final order. The risk-adjusted discount rate r_{risk} is assumed to be 11.28% (based on company information). This rate consists of a risk-free interest rate of 8.2% and a risk premium of 3.08%. The risk premium is calculated by multiplying the market risk premium for Turkey (4.0%) by a specific risk coefficient of $\beta_i = 0.77$ for investments in the Turkish electricity sector. The total investment costs are composed of the EPC price, the cost of the components not covered by the EPC contract, the cost of spare parts, the cost of filling the coal storage facility, the working capital at the beginning, the project realization cost, cost of putting into operation, and the cost provision for unforeseen items. According to the details in the EPC contract the EPC costs are spread over the duration of the construction phase. All other expenditures are spread according to the project planning. The result from this calculation is the NPV of the investment expenditures at the time of the release of the final order and amounts to US$ -801 million.

As a next step we compute the positive cash flow from the operating phase of the planned power plant. These are also discounted to the point in time when the release of the final order is provided. The first revenues from the project can be expected at the end of the construction period with a duration of 3.5 years (42 months). When calculating the project's NPV, a lifetime of the plant of 20 years is assumed. The free cash flows FCF_t at time t are calculated according to eq. (1)

$$FCF_t = R_t - c_{\text{var}} - c_{\text{fix}} - \tau_t, \tag{1}$$

where FCF_t is the payment stream, R_t the revenues, c_{var} the variable costs, c_{fix} the fixed costs, and τ_t taxes, all at time t (the time index is dropped for the costs as these are assumed constant over time). The sales revenues R_t per period are given as the product of the amount of electricity sold times the electricity price. The electricity sales are dependent on the net capacity of the power plant and its non-availability, which comprises both planned and unplanned outages of the plant[4]. Hence we can specify the sales revenues as

$$R_t = p_t \cdot 8760 \frac{h}{a} \cdot (100\% - nonav_t), \quad (2)$$

where p_t denotes the electricity price at time t, and $nonav_t$ the non-availability at time t.

The variable costs c_{var} per period depend on the amount of electricity produced. They include all expenditures for fuel and auxiliary materials that correlate directly with the amount of electricity produced. The fuel expenditures are composed of the costs for the coal, the freight costs for the coal, and the amount of oil used.[5] As during ramp-up of the power plant a significantly higher share of heating oil is required, the share rises depending on the number of ramp-ups. The costs for the operating materials comprise the costs of the Denox system, the flue gas desulphurization, as well as the ash disposal costs.

The fixed costs c_{fix} per period comprise the costs for personnel, maintenance, administration, operation of the disposal site, insurance and other expenditures. The planning of these costs is done on the basis of the prices at the point in time of the release of the final order. Its temporal dynamics depends on the cost type and on the development of the Local and Foreign Consumer Price Index, respectively. Due to the high inflation rate the growth rate of the National Consumer Price Index in Turkey is about 10%. However, note that all calculations made in our study are made in US Dollars. Due to the development of the exchange rate between the Turkish Lira and the US Dollar, the rise of the Local Consumer Price Index in US Dollars is much more moderate. In the following, we assume for both indices an annual growth rate of 2%.

[4] For each time period the planned outages are determined on the basis of a detailed revision plan. The non-availability due to unplanned outages is considered as a percentage figure. Specifically, for the project considered we assume an unplanned non-availability of between 7-8%, the exact value depending on the age of the plant. This percentage figure refers to 8760h/a minus the planned outages.

[5] For safeguarding an optimal combustion in the boiler, a small amount of the thermal energy for producing electricity is provided by light heating oil. Because of the high tax rates in Turkey the price of a ton of heating oil is about US$1400. This implies that despite the modest share of the thermal energy of only 0.34% a minimum of 3% of total fuel costs are attributable to the use of heating oil.

The tax rate for the calculation of the tax amount τ_t per period is 20%. The basis for the computation of the taxes is the sales revenues, reduced by depreciation and by variable and fixed costs. The depreciation of the investment expenditures activated in the balance sheet is linear over the entire planned operating time of the plant.

After computing the free cash flows per period these are discounted to the point in time of the release of the final order by using the risk-adjusted discount rate δ_{risk}. The result is the present value of the project's returns, which amount to US$939 million.

At this point all payment requirements connected to project realization are known and the NPV at time *t = 0* of the plant investment can be determined. In table 1the calculation is shown for the case that the investing firm starts the initial project development in *t = 0* or in *t = 2* years, respectively. An enterprise taking the investment decision on the basis of the NPV criterion would, therefore, prefer the immediate start of the planning phase to that at some later point in time (4.85 > 3.92 million US$).

The option value is largest when the NPV is near zero [23]. Measured by the total project volume this is also true for the project considered here, which can serve as an indicator for the attractiveness of the ROA. As mentioned above, the NPV calculation neglects the value of flexibility. In the following section, the valuation of the investment project is thus done with a real options model.

Table 1

NPV calculation.

[million US$]	Payment implication at time *t*	Present value in *t*=0 (start of planning in *t*=0)	Present value in *t*=0 (start planning in *t*=2)
Initial project development	-5	-5	-4.04
Detailed planning and permitting	-30	-24.23	-19.56
First major project payments	-86	-66.19	-53.46
Release of final order	-801	-581.55	-469.62
Operation	939	681.82	550.60
NPV		**4.85**	**3.92**

4. Real options analysis

4.1. Determination of the real options value

ROA is intuitively clear and superior to the NPV approach, but also computationally more demanding and complex. Numerical approaches for the calculation of the option value on partial differential equations (PDE) and the use of finite difference methods make a practice-oriented application relatively difficult. In the following, we therefore pursue the real options value determination with the help of the binomial model developed by Cox et al. [2], which can be easier understood. The required basic qualifications for doing so, such as spreadsheet calculation, algebra and Monte Carlo analysis, are often already available in companies. An implementation on this basis is thus markedly easier than the application of an approach where partial differential equations are needed.

Cox et al. [2] assume that the stock price can be described by a multiplicative binomial process in discrete time intervals. At the end of each time interval, the stock price either shows an upward or downward movement relative to the base value S_0. The probability for an upward movement is described by q and for a downward movement by $1-q$. This implies that the stock value after one time interval for an upward movement is uS_0 and for a downward movement dS_0.

To describe a geometric Brownian motion the up and down factors are calculated using the following formula [see 4]

$$u = e^{\sigma\sqrt{\frac{T}{n}}} \tag{3}$$

$$d = \frac{1}{u} = e^{-\sigma\sqrt{\frac{T}{n}}}, \tag{4}$$

where σ denotes the underlying volatility, T the options lifetime, and n the number of time intervals. The option value can then be calculated as

$$V = \frac{\left[\sum_{j=0}^{n}\left(\frac{n!}{j!(n-j)!}\right)pr^{j}(1-pr)^{n-j}\max\left[0, u^{j}d^{n-j}S_0 - K\right]\right]}{(1+r_{\mathrm{f}})^{n}}, \tag{5}$$

where V is the option value, pr the risk-neutral probability and K the strike price of the underlying asset.

Before computing the option value a determination of the input variables is required. The present value of the underlying and the investment costs that are linked with the exercising of the sequential options are already known from section 3.4. Still unknown is the project value risk, which in the real options consideration is described by the volatility of the project value return [22, p.86]. Following Hartmann [24, p.97] essentially three methods can be distinguished for the determination of the volatility. The first method is based on the determination of historical values for comparison. The aim is to find a firm registered at the capital market, whose business activities largely match with the project in question. The volatility of the stock price of this enterprise would then serve as a proxy for the volatility of the considered project. Thanks to the specific characteristics of power plant investments this is highly problematic for the enterprise studied. The second method for the determination of the volatility is based on estimates. Following this procedure, the stakeholders of the project are asked to state the volatility of the project considered. However, for the individual assessor it is almost impossible to correctly incorporate the interrelations between the various project uncertainties. Hence the estimation of the volatility cannot be considered as a systematic method for the determination of the volatility. In the third method, the volatility is determined by modeling. Normally, the volatility of the underlying does not result from a single factor, but is rather determined by a plethora of individual uncertainty factors. In the modeling process, these individual sources of uncertainty are identified and assigned a probability distribution. Subsequently, with the help of Monte Carlo simulation, they are summarized to a value that reflects the project's volatility. For the power plant investment considered in this paper, we identified the sources of volatility of the electricity price, coal price, oil price and the freight rate for coal in section 3.3. These four factors are then bundled into a single value by Monte Carlo simulation. For the computations we have applied Oracle's software Crystal Ball®.

As a starting point for the modeling of the uncertainties we use the calculation of the free cash flows for the operating phase described in section 3.4. In the Excel spreadsheet, by employing Crystal Ball, we can state for each of the four uncertainty variables the probability distribution, the mean value and the standard deviation. All uncertain variables are prices, so that we can assume that their values will be non-negative. Hence we can choose the log-normal distribution as a suitable probability distribution. For the mean values the same values are taken that were used in the present value calculation in section 3.4. The determination of the standard value is based on historical data for the prices of electricity, coal and oil as well as transport of coal. As a reference value for the standard deviation of the electricity price, we first use the development of the system imbalance price (SIP) for electricity on the Turkish market (cf. Figure 2). These have been published by TEIAS since August 2006. A weakness of considering the SIP prices is their short published history, which precludes special influences of certain environmental conditions from being averaged out. Especially with respect to the strong fluctuations in the primary energy prices in 2008 this short observation period is critical for the use as a reference. Moreover, from figure 2 we get the impression that electricity prices were limited by price caps during the period of maximum coal prices. The exclusive consideration of the SIP prices is thus only to a limited extent suited as a reference for determining the standard deviation of the electricity prices. For this reason we additionally consider the electricity prices for private households and industry in Turkey for the period 1996–2007 as a reference. From figure 2 it becomes evident that annual electricity prices fluctuate less than the SIP prices and that their development follows a positive time trend.

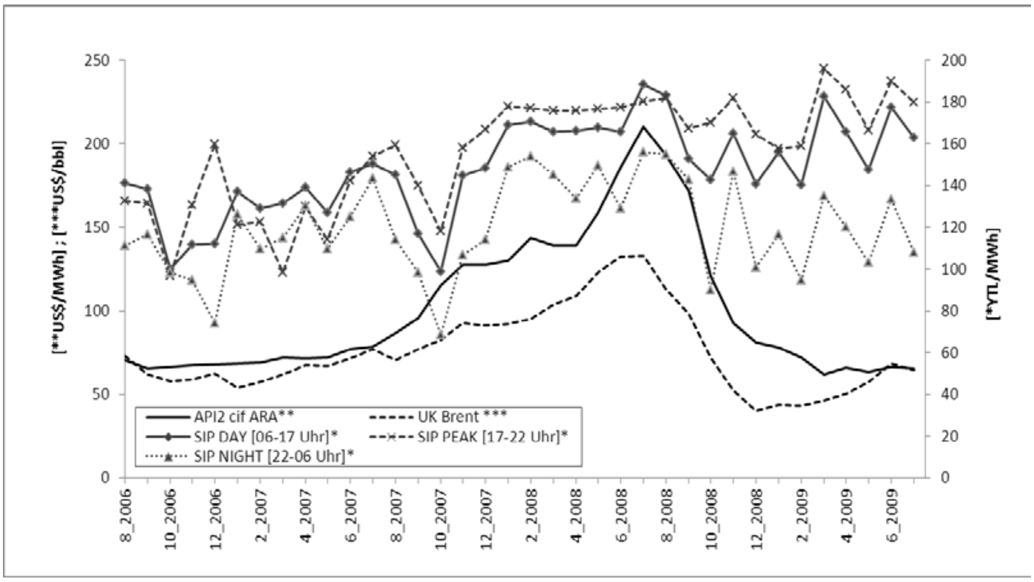

Fig. 2. Price development of electricity, coal, and oil, 2006-2009

Source: ** Coal Trader International [25]; * TEIAS [3]; *** MWV [26], own illustration

Besides the development of the SIP prices, figure 2 also depicts the development of API 2 CIF ARA[6] prices for coal and the development of freight rates for coal transport. In the previous section we have pointed out the strong fluctuations of primary energy prices in 2008, which makes predictions difficult. Hence we use the period 1996–2007 also for the coal price (cf. Figure 3). The fourth input parameter for the Monte Carlo simulation is the probability distribution of the oil price. As a reference for the determination of the standard deviation we have used the price development of the crude oil sorts Brent Dated and West Texas Intermediate, respectively (cf. Figure 3). Transportation of hard coal is effected by using oil, which is used as a fuel for transport by ship. Hence for the simulation that follows a correlation of the freight costs with the oil price is taken into account (correlation coefficient = 0.8[7]). Moreover, a correlation between electricity and coal prices could be accounted for. However, the share of hard coal in electricity production in Turkey is low (8% in 2007; TEIAS [3]; see

[6] Hard coal price incl. freight and insurance Amsterdam/Rotterdam/Antwerp.

[7] A comparison between the development of the oil price (Brent) and the physical freight rates shows that these are highly correlated (Figure 2). For the time period April 2008 until July 2009 the correlation coefficient is 0.97.

also [4]). Therefore, we refrain from considering a correlation between the electricity and coal prices in the analysis that follows.

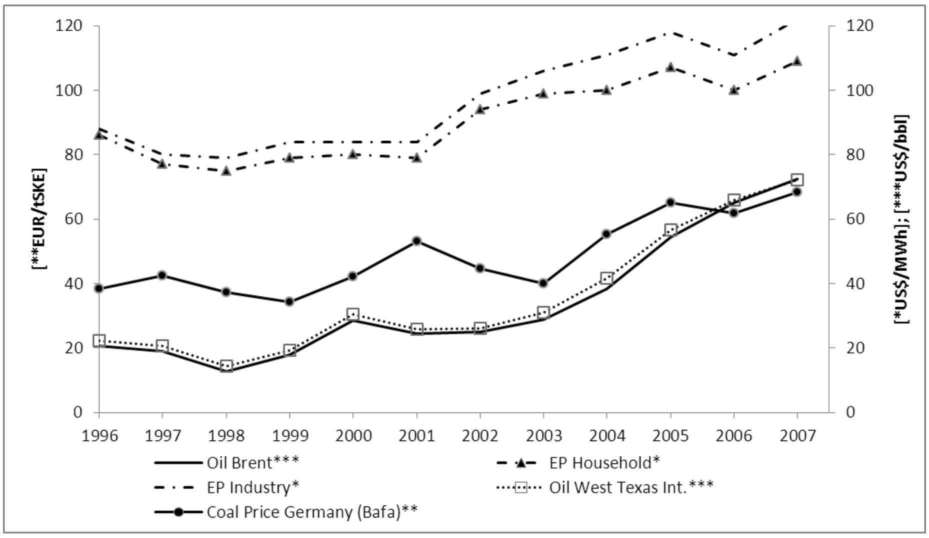

Fig. 3. Price development electricity, coal, oil 1996-2007

Data sources: ** Bafa [27]; *** BP [28]; * IEA Statistics [29]; own illustration

The prices described in the previous section partly have a different level than those prices considered in the calculation. For this reason the relative standard deviation of the prices are considered as a reference value for the computation of standard deviations, which enter the Monte Carlo simulation (MCS). Table 2 provides an overview of the parameters used for the simulation.

Table 2

Parameterization for the Monte Carlo simulation.

	Rel. standard dev.	Mean	Standard dev.	Correlation
Electricity price	0.10	95.67	9.57	
Coal price	0.20	81.02	16.20	
Freight costs	0.40	11.96	4.78	0.80 with oil
Oil price	0.30	1393.30	417.99	

At the beginning of section 4.1 we already mentioned that the project's value risk in a RO model is characterized by the standard deviation of the project's value risk. The MCS computes for 10,000 value pairs of the four uncertain factors the respective project value return r_p, by using the following formula (cf. Copeland and Antikarov, [21] p.268)

$$r_p = \ln\left(\frac{S_1 + FCF_1}{S_0}\right), \qquad (6)$$

where S_t denotes the project value at time *t* and FCF_1 the free cash flow at time *t*=1.

For the calculation of the project value return the denominator of the ratio remains constant, whereas the numerator is simulated. The simulation yields the frequency distribution of the project value return (cf. Figure 4). The standard deviation of this distribution describing the project value risk is $\sigma = 0.25$, which is used in the following for determining the parameters *u* and *d* in the modeling of the binomial tree.

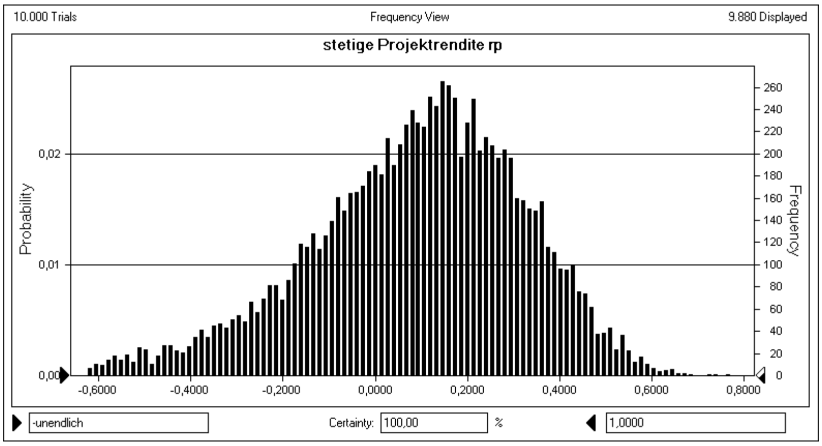

Fig. 4. Frequency plot for ROI

After having determined all input variables for the ROA, we can now proceed to compute the option value. To this end, in a first step and analogously to the procedure described by Cox et al. [2], the required input variables and option parameters can be summarized as follows:

Input variables:

Present value of the underlying:	$V_0 = US\$939 million$
Present value of the cost release of final order:	$I_0 = US\$801$ million
Present value of the cost first major project payments:	$I_1 = US\$86$ million
Present value of the cost detailed planning & permitting:	$I_2 = US\$30$ million
Present value of the cost initial project development:	$I_3 = US\$5$ million
Option lifetime:	$T = 5\ years$
Number of intervals:	$n = 20$
Risk-free interest rate:	$r_f = 0.082 = 8.2\%$
Standard deviation of the ROI:	$\sigma = 0.25$

Option parameters:

Upward movements: $u = e^{\sigma\sqrt{\frac{T}{n}}} = e^{0.25\sqrt{\frac{5}{20}}} = 1.133$

Downward movements: $d = e^{-\sigma\sqrt{\frac{T}{n}}} = e^{-0.25\sqrt{\frac{5}{20}}} = 0.882$

Risk-neutral probability: $pr = \frac{(1+r_f)-d}{u-d} = \frac{(1+0.082)-0.882}{1.133-0.882} = 0.548$

As a next step, we show the development of the value of the underlying by means of a binomial tree. To this end, we divide the entire option's lifetime of five years into 20 intervals. The duration of each interval is thus three months. Note that the standard deviation, which we have calculated in the previous section for the duration of one year, has to be adapted to the interval length considered. The start value is given by the present value of the underlying V_0. By means of the above-calculated parameters *u* and *d* we get the binomial tree shown in table 3[8]. It does not yet take flexibility into account, but represents the uncertain value development of the underlying over time, taking into account the standard deviation of the return computed above.

Table 3

Excerpt from the value development of the underlying.

t	0	1	2	3	4	…	18	19	20
0	939.55	1064.65	1206.41	1367.04	1549.06	…	8914.25	10101.16	11446.12
1		829.15	939.55	1064.65	1206.41	…	6942.42	7866.79	8914.25
2			731.73	829.15	939.55	…	5406.76	6126.67	6942.42
3				645.75	731.73	…	4210.79	4771.45	5406.76
4					569.87	…	3279.37	3716.01	4210.79
5							2553.97	2894.03	3279.37
6							1989.04	2253.87	2553.97
7							1549.06	1755.32	1989.04
8							1206.41	1367.04	1549.06
…							…	…	…

The next step is to adequately represent the existing flexibility of the firm with respect to the sequencing of the project realization phases. As described in section 3.2, determination of the options value is determined by the last option in the chronological order. The determination of the options value of the release of final order is based on the value development of the underlying shown in table 3. The valuation starts at the end of the option duration in $t = 20$ and

[8] Due to the size of the binomial trees we only depict excerpts here. For the computation of the option value we use MS Excel. For the analysis of the results we have additionally implemented the option value calculation in Matlab.

is then continued backwards until $t = 0$. At time $t = 20$ the firm has to decide in favor or against the release of the final order. A positive decision is taken if the value of the underlying at time exceeds the value I_0. For the option value of the release of the final order ($t = 20$ with $i + j = 20$) we get

$$V_{u^i d^j \mathrm{ROF}} = \max\left[V_0 \cdot u^i \cdot d^j - I_0; 0\right], \tag{7}$$

where i denotes the number of upward movements and j the number of downward movements of the underlying.

Contrary to time period $t = 20$ the firm additionally has the possibility before expiry of the option to postpone the granting of the release of the final order to the next period. For the option value of the release of the final order for $t = 1,\ldots,19$ we thus get:

$$\mathrm{V}_{\mathrm{u^i d^j ROF}} = \max\left[\mathrm{V_0} \cdot \mathrm{u^i} \cdot \mathrm{d^j}\text{-}\mathrm{I_0}; \frac{\mathrm{pr} \cdot \mathrm{V}_{\mathrm{u^{i+1} d^j ROF}} + (1\text{-}\mathrm{pr}) \cdot \mathrm{V}_{\mathrm{u^I d^{j+1} ROF}}}{1 + \mathrm{r_{f_{period}}}}\right]. \tag{8}$$

By applying this formula in each node of the binomial tree (from right to left) the option value of the release of the final order is determined. The risk-free interest rate per period is given by $r_{f_{period}} = \sqrt[4]{1 + r_f} - 1 = 0.020$.

An overview of the results is given in Table 4. The colors of the cells provide some information about the optimal strategy in the respective node. For cells highlighted in dark gray it is optimal to postpone the decision, whereas cells highlighted in light gray means that the option is exercised and shaded means that the project is cancelled.

The computation of further option values is done analogously to the procedure described above. It has to be considered, though, that the options that follow have other lifetime ends and that the valuation is based on the value of the preceding option, and not on the value development of the underlying. For the first major project payment (MPP) option value at the end of the lifetime ($t = 18$ with $i + j = 18$) we can write:

$$V_{u^i d^j \mathrm{MPP}} = \max\left[V_{u^i d^j \mathrm{ROF}} - I_1; 0\right] \tag{9}$$

and for $t = 0,\ldots,17$ we get:

$$V_{u^i d^j \mathrm{MPP}} = \max\left[V_{u^i d^j \mathrm{MPP}} - I_1; \frac{pr \cdot V_{u^{i+1} d^j \mathrm{MPP}} + (1 - pr) \cdot V_{u^i d^{j+1} \mathrm{MPP}}}{1 + r_{f_{\mathrm{period}}}}\right] \tag{10}$$

Table 4
Event tree for the options value initial project development (excerpt).

t	0	1	2	3	4	5	6	7	8
0	361.07	458.63	575.73	714.56	877.35	1066.44	1284.42	1534.33	1819.79
1		258.62	336.75	432.64	548.52	686.58	848.94	1037.79	1255.56
2			175.21	235.25	311.10	405.18	519.84	657.20	819.27
3				110.07	153.58	210.66	283.93	376.07	489.52
4					62.13	91.10	131.03	184.64	254.99
5						29.73	46.66	71.76	107.43
6							10.49	18.27	31.64
7								1.53	2.84
8									0.00

The option value of the power plant investment considered here is V_{IPD} = US$361.07 million and hence markedly higher than the present value of US$4.85 million calculated in section 3.4 (start of the initial project development at t = 0) and US$3.92 million (start of the detailed planning and permitting phase in t = 8). Apart from the calculation of the option value the real options valuation simultaneously also yields the optimal strategy for exercising the option. For the power plant investment considered the decision to invest is optimal at the end of the lifetime of each of the individual options. The decision about the initial project development phase is done at time t = 8, that of the detailed planning and permitting in t = 16, that of the first major project payments in t = 18, and the decision of granting the final release order at the end of the option's lifetime.

4.2. Sensitivity analysis of the real options value

The ROA done in the previous section is based on a number of assumptions regarding the option parameters. For the investing company it is important to properly understand how sensitive the real options value reacts to the assumptions made. To this end, we analyze the impact of the main value drivers. First, we study the influence of the number of periods, the standard deviation of the returns and the risk-free interest rate. Second, we use the software Crystal Ball® for determining the frequency distribution of the real options value for different scenarios.

In section 4.1, for computing the options value, we have divided the duration into 3-month intervals. In order to analyze the influence this arbitrary choice of the interval length has on the option values, the calculation from section 4.1 is implemented in Matlab®. In this calculation the number of intervals is considered as being variable. The longest interval length is, due to the structure of the sequential options, six months. Figure 5 shows the calculation of the real options value for 1-15 periods per half year. As can be seen clearly, the option value for 1-4 periods per half year shows a distinct variation. When increasing the number of periods, the variation of the option value diminishes and converges to the limit value, which for the project considered is at approximately US$360.6 million. The calculation of section 4.1 is based on two periods per half year. This implies that the option value is overestimated by about US$0.5 million, and that by choosing four periods per half year this deviation can indeed be reduced markedly.

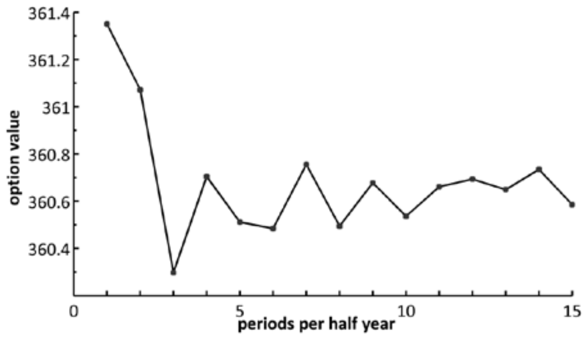

Fig. 5. Option value depending on the number of periods per half-year

In figure 6 the variation of the standard deviation is combined with the variation of the risk-free interest rate r_f between 5% and 10%. If the risk-free interest rate rises, then the option value rises as well, since due to the achievable monetary advantage it becomes advantageous to postpone the investment. This only applies, however, under the assumption that the present value of the underlying is independent of the risk-free interest rate. If we consider that for the project considered this value is determined by a present value calculation, which depends crucially on the risk-free interest rate, a countervailing effect can be observed. Figure 6 shows that the influence of the standard deviation on the level of the option value of the project decreases when the risk-free interest rate rises.

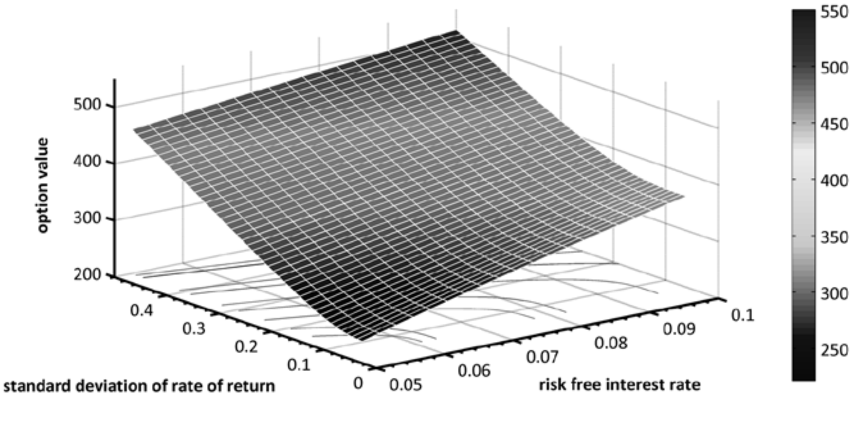

Fig. 6. Option value depending on the standard deviation and risk-free interest rate (in million US$)

In a next step, frequency distributions of the real option values for six different scenarios are determined. The scenarios are based on different assumptions about the probability distributions for the standard deviation of the return and/or the present value of the underlying. By means of these scenarios it is determined how robust the computation of the option value is against variations of the standard deviation and the present value of the underlying.

The following scenarios are considered (Scenarios 3 and 6 are combinations):

- *Scenario 1*: The standard deviation of return σ varies between 0.2 and 0.3 and underlies a triangular distribution with a mean value of 0.25.
- *Scenario 2*: The present value of the underlying varies between US$800-1000 million and underlies a uniform distribution.
- *Scenario 3*: Combination of Scenarios 1 and 2.
- *Scenario 4*: The standard deviation of the return σ underlies a normal distribution with a mean value of 0.25 and a standard deviation of 0.05.
- *Scenario 5*: The present value of the underlying underlies a normal distribution with a mean value of US$939.555 million and a standard deviation of US$93.95 million.
- *Scenario 6*: Combination of Scenarios 4 and 5.

Figure 7 depicts the results from the MCS. The distribution of the option values by scenario is shown in steps of 10%. From figure 7we can see that the option value for all six scenarios varies between US$60 million and US$724 million. It can be seen that for the scenarios considered the option value lies above US$277 million, with a probability of 80% and with a probability of 60% even above US$310 million. This illustrates that the calculation of the option value is relatively robust against the considered variation of the standard deviation of return σ and the variation of the present value of the underlying.

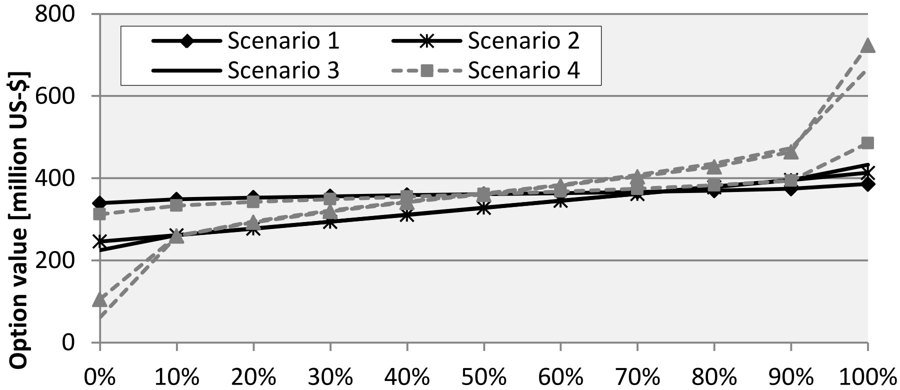

Fig. 7. Option values by scenario

5. Conclusions

Investments in new power plant capacity are prone to high uncertainty and, due to the amount of capital required, can have far-reaching impacts on the future of the investing enterprise. Not least for this reason the investment decision requires a detailed project analysis. In this study the real options approach has been introduced as a further tool of analysis. To this end, we have first discussed the peculiarities of power plant investments and related uncertainties. After that we have argued that the Turkish power market shows considerable uncertainty, especially with respect to future framework conditions due to regulation. As a next step, we have introduced the traditional approaches for calculating the cost-effectiveness of an investment project. We have shown that static and dynamic approaches have conceptual weaknesses for the valuation of flexibility to postponing investment action. For solving this dilemma we have introduced ROA as an alternative in which financial options theory is transferred to real assets. In section 4 we have calculated the real options values for a sequential power plant investment. The relatively high option value compared to the present value of this project makes clear that the possibilities of acting during project realization can be assigned an immense value. The analysis of the real options value shows also that the value is relatively insensitive with respect to the considered variation of the standard deviation value of the return and the present value of the underlying project.

Especially for the strategic planning of projects the application of ROA seems particularly useful. A valuation solely on the basis of the NPV criteria bears the risk that economically interesting projects are possibly not pursued any further, since no adequate value is assigned to the possibilities of taking future action. However, ROA should not be interpreted as an approach that completely replaces the far simpler NPV calculation. Rather, the ROA can be used additionally to critically reflect on the results gained from simple NPV calculations. Also, it helps to assign a specific value to flexibility that often occurs. ROA provides the management with quantifiable arguments to pursue a project for which, due to future action opportunities, an economically attractive option value can be found. The often opaque ‘feeling’ concerning future chances prevalent in such decision-making situations under uncertainty can be expressed by means of RO valuation in monetary terms and thus put on a sound and transparent basis.

A further advantage of ROA lies in the fact that it also delivers, besides the option value of the investment, the optimal strategy for exercising the option. Moreover, it helps action possibilities and risks of a project and to take it into account in the valuation. The revelation of action possibilities and their examination leads to a situation where the calculated NPV is seen in a different light. Especially in the power plant business real options can be found in many instances. In the framework of this study we pointed out that the ROA can be applied in a useful way both for strategic investment decisions and also in power plant operation. It can be expected that, above all, the latter field of application will gain in importance in the future on the Turkish electricity market. The introduction of spot markets for energy commodities in Turkey will likely increase the volatility of the market price. An approach to consider the chances of increasing volatility is delivered by options theory. In markets that have been liberalized years ago, options theory is applied frequently for optimizing power plant operation planning.

An option that has not been considered yet in section 4 so far is the growth option that arises through construction of the plant. The current investment may serve the firm to secure future growth opportunities. The existing location of the power plant and the know-how gained in dealing with Turkish authorities can constitute a great advantage for follow-up projects. These examples show that for the object considered in section 4 apart from the option value through sequential investment also an attractive option value can be determined for further growth possibilities.

By the deregulation of the Turkish electricity market the environment of decision-makers has been significantly changed. By these changes they are increasingly confronted with uncertainties that so far did not enter the decision-making models to the same extent as today. The results of our study show that the real options model is well suited for addressing these new requirements to the valuation process. Companies are thus well advised to grapple in detail with ROA, which can help to reveal previously undetected flexibility leeways and to critically assess their values. In this respect ROA can significantly contribute to the strategic optimization of a company.

Further research could investigate the threshold value of the option beyond which a company will exercise the option rather than keeping the option value alive. Approaches from the Behavioral Finance literature seem to be promising to answer this question. Still another important question is how the high share of hydropower plants affects the electricity price when a day-ahead market is being introduced. As Weber [30, p.15] states, the indirect storage of electricity by hydropower plants contributes to the smoothening of price peaks. It would be interesting to see whether this effect can also be observed for the Turkish power market, and whether this is desired on the side of the mostly state-owned hydropower plants.

Nomenclature

V:	option value
d:	parameter for the downward movement of the option
FCF_t:	free cash flow
I_i:	present value of cost, i={1=release of final order, 2=first major project payment, 3=planning/permitting, 4=initial project development}
K:	strike price
c_{fix}:	fixed costs
c_{var}:	variable costs
n:	number of intervals
$nonav_t$:	non-availability at time t
pr:	risk-neutral probability
p_t:	electricity price at time t
$q, (1-q)$:	probability of an upward movement, probability of a downward movement
r_p:	return on investment (ROI)
r_{f}	risk-free interest rate
δ_{risk}:	risk-adjusted discount rate
R_t:	revenues
S_o, S_t:	project value
t, T:	time, option lifetime
τ_t:	taxes
u:	parameter for the upward movement of the option
V_{o}:	present value of underlying
σ:	underlying volatility

References

[1] Dixit AK, Pindyck RS. Investment under Uncertainty. Princeton: Princeton University Press; 1994.

[2] Cox JC, Ross SA, Rubinstein M. Option Pricing: A Simplified Approach. Journal of Financial Economics 1979;7(3):229-63.

[3] TEİAŞ. Electricity Generation - Transmission Statistics of Turkey. 2009 (accessed May 23, 2009 at http://www.teias.gov.tr/ist2007/).

[4] IEA. Energy Policy of IEA Countries. Turkey 2009 Review, OECD/IEA, Paris; 2010.

[5] Myers SC. Determinants of Corporate Borrowing. Journal of Financial Economics 1977;5(2):147-75.

[6] Myers SC. Finance Theory and Financial Strategy. Interfaces 1984;14(1):126-37.

[7] Black F, Scholes M. The Pricing of Options and Corporate Liabilities. The Journal of Political Economy 1973;81(3):637-54.

[8] Merton RC. Theory of Rational Option Pricing. The Bell Journal of Economics and Management Science 1973;4(1):141-83.

[9] Brennan MJ, Schwartz ES. Evaluating Natural Resource Investments. The Journal of Business 1985;58(2):135-57.

[10] Paddock JL, Siegel DR, Smith JL. Option Valuation of Claims on Real Assets: The Case of Offshore Petroleum Leases. The Quarterly Journal of Economics 1988;103(3):479-508.

[11] Hundt M, Swider DJ, Voß A. Einfluß von Unsicherheiten und Flexibilität auf den Wert von Kraftwerksinvestitionen – Reale Optionen in der Elektrizitätswirtschaft. Arbeitspapier, Universität Stuttgart, Institut für Energiewirtschaft und Rationelle Energieanwendung, Stuttgart; 2006.

[12] Gollier C, Proult D, Thais F, Walgenwitz G. Choice of nuclear power investments under price uncertainty: Valuing modularity. Energy Economics 2005;27(4):667-85.

[13] Siddiqui A, Maribu K. Investment and upgrade in distributed generation under uncertainty. Energy Economics 2009;31(1):25-37.

[14] de Moraes Marreco J, Carpio LG. Flexibility valuation in the Brazilian power system: A real options approach. Energy Policy 2006;34(18):3749-56.

[15] Hartmann T. Bewertung von Kraftwerken und Verträgen im liberalisierten Strommarkt. Aachen: Klinkenberger Verlag; 2007.

[16] Keppo J, Lu H, 2003. Real options and a large producer: the case of electricity markets. Energy Economics 2007;25(5):459-72.

[17] Crampes C, Creti A. Capacity Competition in Electricity Markets. Université des Sciences Sociales, Toulouse; 2006.

[18] Hommel U, Pritsch G. Marktorientierte Investitionsbewertung mit dem Realoptionsansatz. Finanzmarkt und Portfoliomanagement, 1999;13(2):121-44.

[19] Amram M, Kulatilaka N. Real Options Managing Strategic Investment in an Uncertain World. Boston: Harvard Business School Press; 1999.

[20] Trigeorgis L. Real Options. Cambridge: The MIT Press; 1996.

[21] Copeland T, Antikarov V. Realoptionen: Das Handbuch für Finanzpraktiker. Weinheim: WILEY-VCH Verlag GmbH & Co. KGaA; 2002.

[22] Kodukula P, Papudesu C. Project Valuation Using Real Options. Fort Lauderdale: J. Ross PublishingM; 2006.
[23] Mun J. Real Options Analysis. New Jersey: John Wiley & Sons, Inc; 2006.
[24] Hartmann M. Realoptionen als Bewertungsinstrument für frühe Phasen der Forschung und Entwicklung in der pharmazeutischen Industrie. Dissertation, Technische Universität Berlin, Fakultät II - Mathematik und Naturwissenschaften, Berlin; 2006.
[25] Coal Trader International. The McGraw-Hill Companies; 2009. (accessed August 20, 2009 at http://www.platts.com).
[26] MWV. Mineralölwirtschaftsverband e.V.; 2009 (accessed September 16, 2009 at Association of the German Petroleum Industry: http://www.mwv.de/cms/front_content .php?idcat=14&idart=62).
[27] Bafa (Bundesamt für Wirtschaft und Ausfuhrkontrolle); 2009 (accessed September 8, 2009 at http://www.bafa.de/bafa/de/energie/steinkohle/preise.xls).
[28] BP. BP Statistical Review of World Energy June 2009. London; 2009.
[29] IEA Statistics, 2008, *Electricity Information 2008*. Paris: International Energy Agency.
[30] Weber C. Uncertainty in the electric power industry - Methods and Models für Decision Support. New York: Springer Science+Business Media, Inc.; 2005.

E.ON Energy Research Center

fcn Institute for Future Energy Consumer Needs and Behavior

RWTH AACHEN UNIVERSITY

List of FCN Working Papers

2010

Lang J., Madlener R. (2010). Relevance of Risk Capital and Margining for the Valuation of Power Plants: Cash Requirements for Credit Risk Mitigation, FCN Working Paper No. 1/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Michelsen C.C., Madlener R. (2010). Integrated Theoretical Framework for a Homeowner's Decision in Favor of an Innovative Residential Heating System, FCN Working Paper No. 2/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, February.

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). The Structure of Online Consumer Communication Networks, FCN Working Paper No. 3/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, March.

Madlener R., Neustadt I. (2010). Renewable Energy Policy in the Presence of Innovation: Does Government Pre-Commitment Matter?, FCN Working Paper No. 4/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, April (revised June 2010).

Harmsen-van Hout M.J.W., Dellaert B.G.C., Herings, P.J.-J. (2010). Behavioral Effects in Individual Decisions of Network Formation: Complexity Reduces Payoff Orientation and Social Preferences, FCN Working Paper No. 5/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, May.

Lohwasser R., Madlener R. (2010). Relating R&D and Investment Policies to CCS Market Diffusion Through Two-Factor Learning, FCN Working Paper No. 6/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, June.

Rohlfs W., Madlener R. (2010). Valuation of CCS-Ready Coal-Fired Power Plants: A Multi-Dimensional Real Options Approach, FCN Working Paper No. 7/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July.

Rohlfs W., Madlener R. (2010). Cost Effectiveness of Carbon Capture-Ready Coal Power Plants with Delayed Retrofit, FCN Working Paper No. 8/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Gampert M., Madlener R. (2010). Pan-European Management of Electricity Portfolios: Risks and Opportunities of Contract Bundling, FCN Working Paper No. 9/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Glensk B., Madlener R. (2010). Fuzzy Portfolio Optimization for Power Generation Assets, FCN Working Paper No. 10/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Lang J., Madlener R. (2010). Portfolio Optimization for Power Plants: The Impact of Credit Risk Mitigation and Margining, FCN Working Paper No. 11/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Westner G., Madlener R. (2010). Investment in New Power Generation Under Uncertainty: Benefits of CHP vs. Condensing Plants in a Copula-Based Analysis, FCN Working Paper No. 12/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Bellmann E., Lang J., Madlener R. (2010). Cost Evaluation of Credit Risk Securitization in the Electricity Industry: Credit Default Acceptance vs. Margining Costs, FCN Working Paper No. 13/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September (revised May 2011).

Ernst C.-S., Lunz B., Hackbarth A., Madlener R., Sauer D.-U., Eckstein L. (2010). Optimal Battery Size for Serial Plug-in Hybrid Vehicles: A Model-Based Economic Analysis for Germany, FCN Working Paper No. 14/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, October(revised June 2011).

Harmsen - van Hout M.J.W., Herings P.J.-J., Dellaert B.G.C. (2010). Communication Network Formation with Link Specificity and Value Transferability, FCN Working Paper No. 15/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Paulun T., Feess E., Madlener R. (2010). Why Higher Price Sensitivity of Consumers May Increase Average Prices: An Analysis of the European Electricity Market, FCN Working Paper No. 16/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B. (2010). Portfolio Impact of New Power Generation Investments of E.ON in Germany, Sweden and the UK, FCN Working Paper No. 17/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Kwasnica A., Shortle J. (2010). A Laboratory Experiment to Compare Two Market Institutions for Emissions Trading, FCN Working Paper No. 18/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Bernstein R., Madlener R. (2010). Short- and Long-Run Electricity Demand Elasticities at the Subsectoral Level: A Cointegration Analysis for German Manufacturing Industries, FCN Working Paper No. 19/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Mazur C., Madlener R. (2010). Impact of Plug-in Hybrid Electric Vehicles and Charging Regimes on Power Generation Costs and Emissions in Germany, FCN Working Paper No. 20/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Stoverink S. (2010). Power Plant Investments in the Turkish Electricity Sector: A Real Options Approach Taking into Account Market Liberalization, FCN Working Paper No. 21/2010, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, December (revised July 2011).

2009

Madlener R., Mathar T. (2009). Development Trends and Economics of Concentrating Solar Power Generation Technologies: A Comparative Analysis, FCN Working Paper No. 1/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Madlener R., Latz J. (2009). Centralized and Integrated Decentralized Compressed Air Energy Storage for Enhanced Grid Integration of Wind Power, FCN Working Paper No. 2/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised September 2010).

Kraemer C., Madlener R. (2009). Using Fuzzy Real Options Valuation for Assessing Investments in NGCC and CCS Energy Conversion Technology, FCN Working Paper No. 3/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Westner G., Madlener R. (2009). Development of Cogeneration in Germany: A Dynamic Portfolio Analysis Based on the New Regulatory Framework, FCN Working Paper No. 4/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Westner G., Madlener R. (2009). The Benefit of Regional Diversification of Cogeneration Investments in Europe: A Mean-Variance Portfolio Analysis, FCN Working Paper No. 5/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November (revised March 2010).

Lohwasser R., Madlener R. (2009). Simulation of the European Electricity Market and CCS Development with the HECTOR Model, FCN Working Paper No. 6/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Lohwasser R., Madlener R. (2009). Impact of CCS on the Economics of Coal-Fired Power Plants – Why Investment Costs Do and Efficiency Doesn't Matter, FCN Working Paper No. 7/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Holtermann T., Madlener R. (2009). Assessment of the Technological Development and Economic Potential of Photobioreactors, FCN Working Paper No. 8/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Carriazo F. (2009). A Comparison of Three Methods of Estimation in the Context of Spatial Modeling, FCN Working Paper No. 9/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Shortle J. (2009). Water Quality Trading when Nonpoint Pollution Loads are Stochastic, FCN Working Paper No. 10/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Ghosh G., Ribaudo M., Shortle J. (2009). Do Baseline Requirements hinder Trades in Water Quality Trading Programs?, FCN Working Paper No. 11/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

Madlener R., Glensk B., Raymond P. (2009). Investigation of E.ON's Power Generation Assets by Using Mean-Variance Portfolio Analysis, FCN Working Paper No. 12/2009, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, November.

2008

Madlener R., Gao W., Neustadt I., Zweifel P. (2008). Promoting Renewable Electricity Generation in Imperfect Markets: Price vs. Quantity Policies, FCN Working Paper No. 1/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, July (revised May 2009).

Madlener R., Wenk C. (2008). Efficient Investment Portfolios for the Swiss Electricity Supply Sector, FCN Working Paper No. 2/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Omann I., Kowalski K., Bohunovsky L., Madlener R., Stagl S. (2008). The Influence of Social Preferences on Multi-Criteria Evaluation of Energy Scenarios, FCN Working Paper No. 3/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, August.

Bernstein R., Madlener R. (2008). The Impact of Disaggregated ICT Capital on Electricity Intensity of Production: Econometric Analysis of Major European Industries, FCN Working Paper No. 4/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

Erber G., Madlener R. (2008). Impact of ICT and Human Skills on the European Financial Intermediation Sector, FCN Working Paper No. 5/2008, Institute for Future Energy Consumer Needs and Behavior, RWTH Aachen University, September.

FCN Working Papers are free of charge. They can mostly be downloaded in pdf format from the FCN / E.ON ERC Website (www.eonerc.rwth-aachen.de/fcn) and the SSRN Website (www.ssrn.com), respectively. Alternatively, they may also be ordered as hardcopies from Ms Sabine Schill (Phone: +49 (0) 241-80 49820, E-mail: post_fcn@eonerc.rwth-aachen.de), RWTH Aachen University, Institute for Future Energy Consumer Needs and Behavior (FCN), Chair of Energy Economics and Management (Prof. Dr. Reinhard Madlener), Mathieustrasse 6, 52074 Aachen, Germany.