Real options analysis and its application in the energy sector

Prof. Dr. Reinhard Madlener

FCN | Future Energy Consumer Needs and Behavior

E.ON Energy Research Center

RWTH AACHEN UNIVERSITY

Presentation outline

1. Evaluation methods for investment projects
2. Net present value vs. real options analysis
3. Real options
    2.1. Financial options
    2.2. Financial options vs. real options
    2.3. Evaluation methods
4. Applications of real options to the energy sector – selected examples

1. Evaluation methods for investment projects

Project evaluation is a systematic assessment of a project's design and its implementation with the goal

to provide information that can **guide decision-making process**, improve project performance, ensure accountability, and contribute to knowledge for future projects

Evaluation of investment projects, specifically means to assess their potential **profitability**, **risks**, and overall **viability**

1. Evaluation methods for investment projects

Evaluation of investment projects can be conducted using:

Return on Investment (ROI):

- one of the **most widely recognized and employed** methods for project evaluation
- offers a simple yet powerful way to **assess the economic success or failure** of a project
- compares the initial outlay with the ultimate revenue generated
- presents a clear picture of a **project's financial viability**
- quantifies the profit or loss made on a project relative to the amount of money invested
- positive value of ROI means benefits exceed costs, a negative value means costs overshadowed the benefits

1. Evaluation methods for investment projects

Evaluation of investment projects can be conducted using:

Net Present Value (NPV):

- calculate the present value of **expected cash flows minus initial investment** costs
- measures the present value of all cash flows in terms of a project's benefits and costs
- used **for long-term projects** where some cash flows are received in the future
- considers the **time value of money** (the fact that money today is worths more than money tomorrow)
- considers the **risks associated with future cash flows**
- positive value means the present value of all benefits exceeds the current value of all costs, a negative value means the opposite

1. Evaluation methods for investment projects

Evaluation of investment projects can be conducted using:

Internal Rate of Return (IRR):

- popular metric used to **estimate the profitability of potential investments**
- represents the interest rate at which NPV of a project's cash flows amounts to zero, means is the rate at which a project **breaks even** in terms of NPV
- helps stakeholders decide whether to proceed with a project, take a loan, or compare it with other potential investments
- project with a **higher IRR** is considered as a **better investment**

1. Evaluation methods for investment projects

Evaluation of investment projects can be conducted using:

Payback Period:

- helps to determine the **time required for a project to recoup** its initial investment in terms of net cash inflows
- gives a straightforward view of **how quickly an investment can pay back** its initial cost but doesn't consider any cash flows after the payback period
- **shorter payback period** is typically **more favorable**, especially when facing an uncertain future or evaluating multiple investment opportunities

1. Evaluation methods for investment projects

Evaluation of investment projects can be conducted using:

Real Option Analysis (ROA):

- recognizes the **value of flexibility** in investment decisions
- extends traditional discounted cash flow (DCF) analysis by incorporating the **value of managerial flexibility** to adapt decisions in response to unexpected market developments or new information
- particularly useful when dealing with projects that have **uncertain future cash flows**
- considers the **ability to adapt or change an investment strategy** as new information becomes available
- incorporating some options (to expand, delay, or abandon a project) provides a **more accurate assessment** of its value

2. Net Present Value vs. Real Options Analysis

- **Investment projects** – are a capital investment opportunities **in real assets** – such as lands, buildings, plants or equipment etc.

- In most investment projects the **options are already embedded** e.g.:
  - ✓ the **option to expand** the investment project – i.e. to make further investments and increase the output if conditions are favorable
  - ✓ the **option to abandon** the investment project – i.e. means to sell or shut down a project
  - ✓ the **option to contract** the investment project – i.e. to reduce the scale of a project's operation

These options are very difficult to evaluate using <u>traditional capital investment techniques</u> <u>(such as NPV)</u>

2. Net Present Value vs. Real Options Analysis

Net Present Value vs. Real Options Analysis	
Single decision pathway with **fixed outcome**	Multiple decision pathways – consequence of **high uncertainty** in future cash flows
Static in nature; tends to systematically **undervalue investments**	Builds upon traditional discounted cash-flow analysis, providing **value-adding insights to decision making**
All decisions are made at the beginning **without the ability to change** or develop over time	Flexibility of **investment timing**
Decision should be made when the expected discounted future cash-flows **match the investment costs**	Decision could be made even the expected discounted future cash flows **are significantly above the investment costs**

2. Net Present Value vs. Real Options Analysis

- The **NPV approach ignores the benefits** which managers may obtain from **exercising their judgment** and making decisions as **future events unfold**
- **Real options analysis** is an attempt to **extend the state of the art**, but **not** even the most complex real options models are **able to fully capture** the **competitive dynamics** and **interactions** inherent in most compound real options

NPV "…cannot properly capture management's flexibility to adopt and revise later decisions in response to unexpected market developments."

(Trigeorgis L., 2000, Real Options: Managerial Flexibility and Strategy in Resource Allocation, MIT Press)

3. Real options

- Real options represent certain **types of management decisions**
- Real options are **decision choices** about real assets that a **manager may exercise in the future**
- Many real options are contingent on **more than one source of uncertainty** and so should be classified as **compound real options** or options on an option
- **Real-life investment projects** often include a **collection of these compound real options** whose values may interact (e.g., a R&D project investment)
- Real options are on the **frontiers of strategic management and finance**

3. Real options

- The **option models** used to value real options are **borrowed from financial options pricing models but:**
  - ✓ The **underlying assumptions** of these financial models **do not strictly apply to real assets**
  - ✓ The **standard models** used to value financial options **do not strictly apply to the conditions of most real options**

Example:

Black-Scholes option pricing formula (Black and Scholes,1973)

- ✓ applies when there is a single source of uncertainty, as measured by the volatility of the underlying asset (technically the squared standard deviation of the asset's returns)
- ✓ and a single decision date (the time of exercising the option is fixed on a certain date)

E.ON Energy Research Center

RWTHAACHEN UNIVERSITY

3. Real options

- Consider **uncertainty** in future cash flows and the **irreversibility** of investment projects
- This analysis enables to value **real options** (e.g., the value of a power plant based on the option to invest)
- Allows to determine the **value of flexibility,** e.g., from:
  - ✓ delaying the construction of an electric power plant
  - ✓ installing new equipment or components (e.g. retrofit measures) in a power plant
  - ✓ stop the operation of the power plant (*dis*investment)

The crucial point of real options analysis is the modeling of uncertainty in the future project’s value

Financial options

- Common **assets on the finance market** include: stocks, bonds, commodities, currencies, interest rates and market indices (traded assets)
- A **derivative** can be defined as a **financial instrument** whose value depends on (or derives from) the values of other basic underlying assets
- The derivative itself is a **contract between two or more** parties based on the asset or assets (the ‘underlying’)
- The value of a derivative is determined by fluctuations in the **underlying asset** Examples of derivatives:
  - ✓ option - is a derivative whose value is dependent on the price of a stock
  - ✓ futures
  - ✓ forwards
  - ✓ swaps
  - ✓ credit derivatives

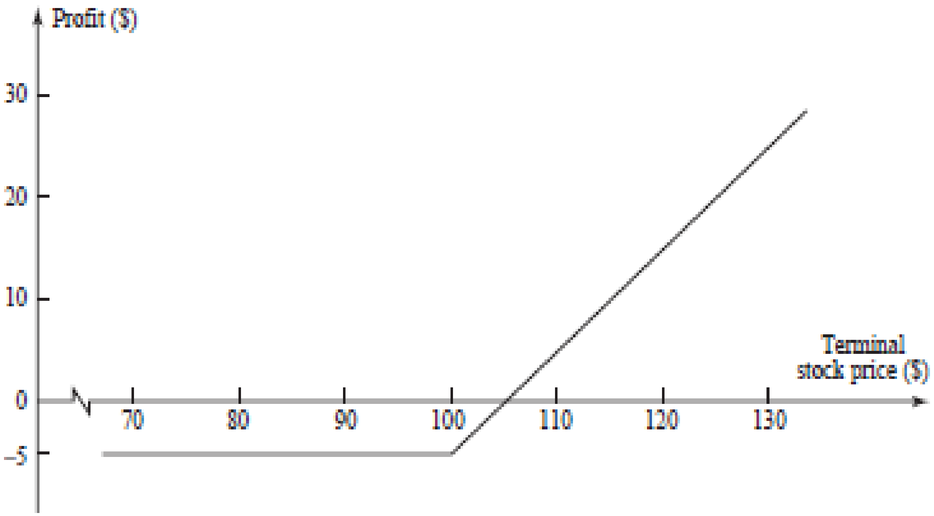
3.1. Financial options

Financial options – the common form of derivatives

- An **option** is a contract in that it is an **agreement between two parties** granting one party the **opportunity to buy or sell a security** or **other financial asset** from the other party **at a predetermined future date**
- The contract **offers the buyer the right, but not the obligation**, to buy (**call option**) or sell (**put option**) a security or other financial asset at an agreed-upon price (**the strike price**) during a certain period of time, or on a specific date (**exercise date or maturity**)
- Options are traded both on **exchanges and in the over-the-counter (OTC)** market
- **American options** can be exercised at any time up to the expiration date
- **European options** can be exercised only on the expiration date itself
- Different **evaluation methods**

European call option

Figure 9.1 Profit from buying a European call option on one share of a stock. Option price = \$5; strike price = \$100.



Source: Hull C. (2012). Options, futures, and other derivatives. Prentice Hall, p.195

A **call option** gives the holder the right **to buy** the underlying asset by a **certain date** and at a **certain price**

Situation: investor buys a European call option (the investor can exercise only on the expiration date) with a strike price of \$100 to purchase 100 shares of a certain stock:

- Current stock price is \$98
- Expiration date of the option is in 4 months
- Price of an option to purchase one share is \$5
- Initial investment is \$500

European call option

At the expiration date:

(1) Stock price is less than $100

- the investor will not exercise the option
- the investor loses the whole of the initial investment of $500

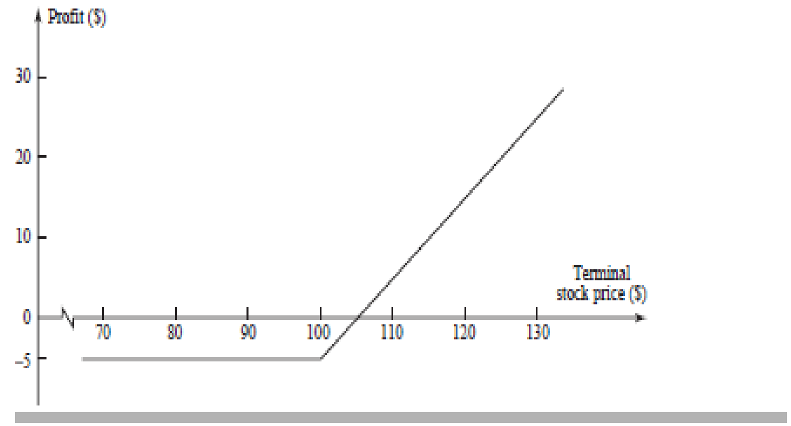
(2) Stock price is, e.g., $115

- the investor will exercise the option
- the investor buys 100 shares for $100 per share
- the investor sells immediately and makes a gain of $15 per share ($1,500, ignoring transaction costs)
- net profit to the investor is $1,000 ($1,500 - $500)

(3) Stock price is e.g. $102

- the investor would exercise the option
- contract for a gain of 100*($102 - $100) = $200
- but realizes a loss overall of $300 when the initial cost of the option is taken into account

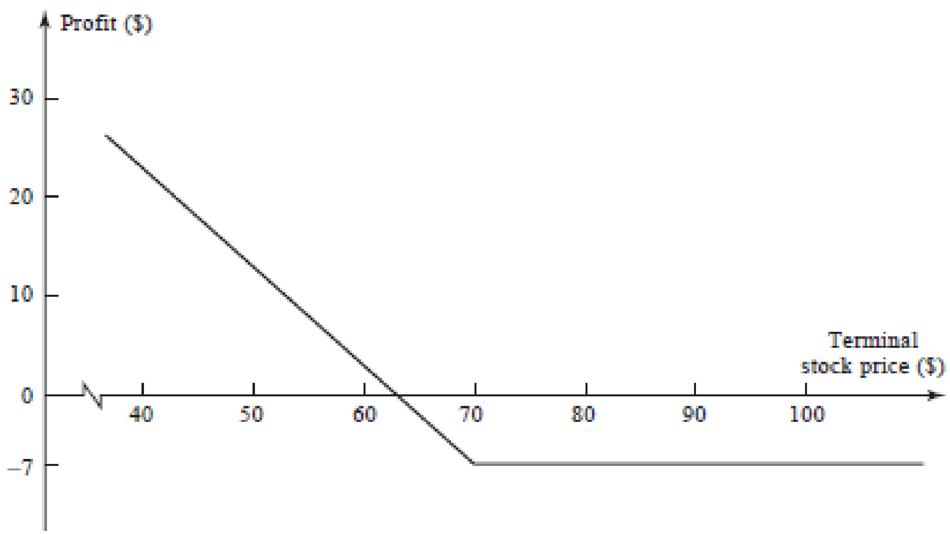
Figure 9.1 Profit from buying a European call option on one share of a stock. Option price = $5; strike price = $100.



Source: Hull C. (2012). Options, futures, and other derivatives. Prentice Hall, p.195

European put option

Figure 9.2 Profit from buying a European put option on one share of a stock. Option price = $7; strike price = $70.



Source: Hull C. (2012). Options, futures, and other derivatives. Prentice Hall, p.196

A **put option** gives the holder the right **to sell** the underlying asset by a **certain date** and at a **certain price**

Situation: investor buys a European put option (the investor can exercise only on the expiration date) at a strike price of $70 to purchase 100 shares of a certain stock:

- Current stock price is $65
- Expiration date of the option is in 3 months
- Price of an option to purchase one share is $7
- Initial investment is $700

European put option

At the expiration date:

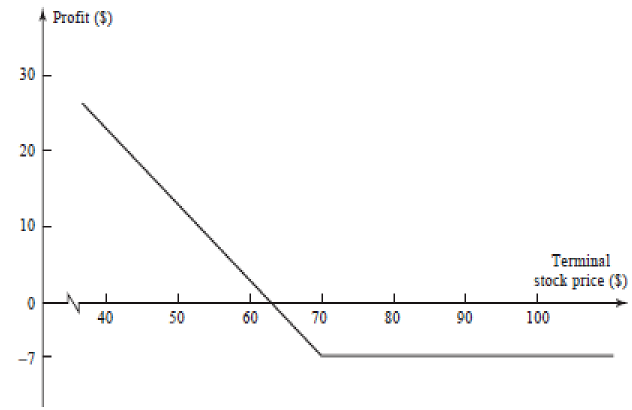
(1) Stock price is above $70

- the investor will not exercise the option
- the investor loses the whole of the initial investment of $700

(2) Stock price is e.g. $55

- the investor will exercise the option
- the investor buys 100 shares for $55 per share
- the investor sells at $70 per share ($1,500, ignoring transactions costs)
- net profit to the investor is $800 ($1,500 - $500)

Figure 9.2 Profit from buying a European put option on one share of a stock. Option price = $7; strike price = $70.



Source: Hull C. (2012). Options, futures, and other derivatives. Prentice Hall, p.196

3.2. Financial options vs. real options

Option parameter (characteristic)	Financial option	Real option
Underlying asset	✓ financial assets (such as: stocks, bonds, currencies, commodities, interest rates or market indices) ✓ traded on the stock exchange or OTC ✓ value (=price of the financial asset)	✓ real assets (such as: land, buildings, plants or equipment) ✓ are not traded on financial exchange ✓ illiquid and hard to trade ✓ more sources of uncertainty ✓ value (=present value of project's or investment's cash-flows)
Strike price	exercise price	amount of money to be invested or received in a launching (exercising) the action (option)
Exercise date or maturity	time until the option expires	time until the decision must be made
Volatility	standard deviation of the value of the underlying asset	uncertainty about the future value (probability distribution)

Source: Haahtela T. (2012). Differences between financial options and real options. Lecture Notes in Management Science, Vol. 4: 169-178

3.2. Financial options vs. real options

Financial option	Real option
Short maturity (usually months)	Longer maturity with several years
Volatility sufficiently stable	Time-varying, usually diminishing, volatility
Follows better process gBM	Follows rather a mean-reverting process in the long run
No possibility to control and manipulate option value	Managerial decisions and flexibility increase the option value
Management assumption have no effect on valuation	Management assumptions and actions drive the value of the real option
Competition and market value do not affect valuation	Competition and market value drive the value of the strategic option
Often single options	Often compound options (parallel and sequential) with interactions
Solved usually using closed-form PDE's and simulation / variance reduction techniques	Closed-form solutions and binomial lattices with simulation of the underlying variables

Source: Haahtela T. (2012). Differences between financial options and real options. Lecture Notes in Management Science, Vol. 4: 169-178

PDE – partial differential equation, gBM –geometric Brownian motion

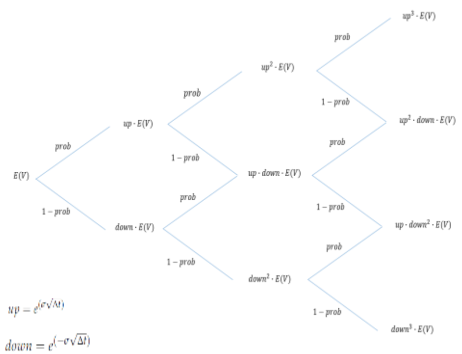
3.2. Financial options vs. real options

Financial option	Real option
Depends only on the risk-free interest rate	Dependent on both risk-free interest rate and risk-adjusted premium or equilibrium rate in dynamic programming context
Option value is known at exercise	Expected value may be known, but it may still have fluctuations in the future
Exercise time or time period (for American options) is known in the beginning	Exercise time, especially the optimal one, not necessarily known
Strike price is often known	Strike price may also be stochastic
May not have negative values	Underlying asset may have negative values
Mostly European by nature	Mostly American by nature
Computational efficiency is important	Computational efficiency is less important
Valuation parameters mostly primary and observable variables	Valuation parameters are often secondary, derived and estimated from the primary parameters of the cash-flow simulation

Source: Haahtela T. (2012). Differences between financial options and real options. Lecture Notes in Management Science, Vol. 4: 169-178

A) Binomial or multinomial lattice models

- ✓ the **binomial lattice** as an option pricing model that is based on the simple formulation that the price of the **underlying**, in any time period, **can move to one of two possible new stages** (“up” and “down”) with certain probabilities
- ✓ it is a **common method** applied **to American-style options**
- ✓ the major **advantages** of the binomial lattice method are:
    - its ease of use and better tractability
    - its flexible use for different types of real options problems



- ✓ lattice and tree-based methods **are accurate, robust, and intuitively appealing** tools to value financial and real options
- ✓ lattices are also more **easily to be explained to and accepted by management**, because the methodology is straightforward to understand
- ✓ assumption: price of underlying asset follows a random walk
- ✓ **European option** price given by the binomial tree **converges** to the Black–Scholes–Merton price as the **time step becomes smaller**

E.ON Energy Research Center | RWTH AACHEN UNIVERSITY

B) Closed-form models with partial-differential equations (Black-Scholes approach)

- ✓ can **only** be applied **to European-style options**
- ✓ is also considered as the **limiting case of the binomial approach**
- ✓ is **justified when the distribution of the underlying is normal** and if the price trajectory of the underlying is continuous and without jumps
- ✓ Black and Scholes used the **capital asset pricing model** to determine the relationship between the market's required return on the option and the required return on the stock

$$CALL_t(T) = p_t \cdot N(d_1) - e_T \cdot e^{-i(T-t)} \cdot N(d_2)$$

$$d_1 = \frac{\ln\left(\frac{p_t}{e_T}\right) + \left(i + \frac{\sigma^2}{2}\right) \cdot (T-t)}{\sigma \cdot \sqrt{T-t}}$$

$$d_2 = d_1 - \sigma \cdot \sqrt{T-t}$$

p_t	present spot market price of the underlying
e_T	exercise price of the option at maturity T (strike price)
i	risk-free interest rate
σ	annualized volatility of p_t (underlying)
T	time of maturity (in years)

3.3. Evaluation methods

C) Path-dependent stochastic simulations (simulation-based methods)

- ✓ Monte Carlo simulation methods are used especially **for high-dimensional option models**, i.e. when the model incorporates multiple sources of uncertainties
- ✓ Monte Carlo simulation can be **used to consolidate cash-flow calculation uncertainties**
- ✓ **differential equations** to describe the process of the sources of uncertainties are **no longer needed** because their “physical” processes can be directly simulated
- ✓ this method is **computationally expensive**

D) Fuzzy pay-off method for real options valuation (Collan et al., 2009)

- ✓ combines the use of **fuzzy logic** with the idea of the payoff method
- ✓ the approach **uses fuzzy numbers** to represent the **future distribution of the expected option value** and applies **fuzzy sets theory** to calculate the **option value**

4. Applications of real options for energy sector – selected examples

Real options disinvestment model – OPTION TO ABANDON

STEP 1

Tree of underlying asset

Capacity factor of the power plant as underlying asset influence the output as well as the current value of the power plant

STEP 2

Tree of discounted cash-flow

Simulation of the power plant's discounted cash-flow using Monte Carlo Simulation

STEP 3

Tree of project value

Backward calculation of the project values and decision to continue or abandon the generation – **option to abandon**

4. Applications of real options for energy sector – selected examples

Real options disinvestment model – OPTION TO ABANDON

- **Dynamic programming** – used approach
- The **multi-period optimization problem** is broken down into a sequence of simpler problems, where at each date the decision on the action to be taken is made
- All relevant information about the past – summarized by the **current state of the project**
- All relevant information about the future – summarized by the **market values of the project** after up and down moves
- **Main question**: shut-down or continue power generation?
- Crucial point – the optimal timing of the **shut-down**
- **Project value** is calculated for each period and depends on the **level of the capacity factor**
- The **shut-down option** is taken when the present project value for the given capacity factor level is less than the **decommissioning costs (residual value of the plant)**

4. Applications of real options for energy sector – selected examples

Real options reinvestment model – OPTION TO EXPAND

STEP 1

Definition of the operation strategy of the power plant

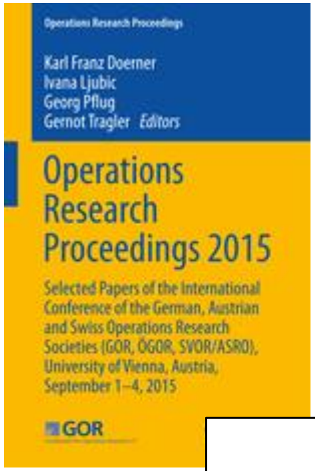
Comparison of the profitability indicator and source of uncertainty **(1-electricity price and 2-spark spread)** estimated via the arithmetic Brownian motion (ABM) process with **marginal cost of technology (MCT)**

STEP 2

Valuation of expected project value E(PV) applying a stochastic dynamic programming

STEP 3

Real options analysis for option to expand

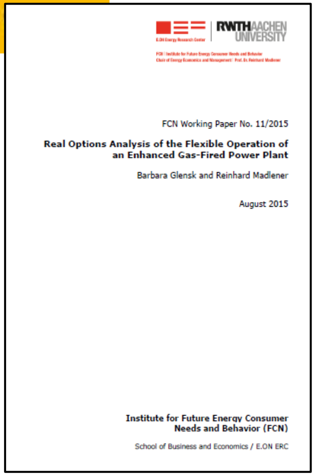

Operations Research Proceedings

Karl Franz Doerner
Ivana Ljubic
Georg Pflug
Gernot Tragler *Editors*

Operations Research Proceedings 2015

Selected Papers of the International Conference of the German, Austrian and Swiss Operations Research Societies (GOR, ÖGOR, SVOR/ASRO), University of Vienna, Austria, September 1–4, 2015

GOR


FCN Working Paper No. 11/2015

Real Options Analysis of the Flexible Operation of an Enhanced Gas-Fired Power Plant

Barbara Glensk and Reinhard Madlener

August 2015

Institute for Future Energy Consumer Needs and Behavior (FCN)

School of Business and Economics / E.ON ERC

4. Applications of real options for energy sector – selected examples

Real options reinvestment model – OPTION TO EXPAND

Module 1: Definition of the operation strategy
Profitability indicator and source of uncertainty is:

Electricity price | Spark spread

Module 2: Project value calculation for:

Power plant without retrofit measure | Power plant with retrofit measure

Module 3: Main real options analysis

4. Applications of real options for energy sector – selected examples

Real options reinvestment model – OPTION TO CHOOSE

STEP 1

Definition of the operation strategy of the power plant

Comparison of **spark spread** (the profitability indicator and source of uncertainty, estimated via the arithmetic Brownian motion (ABM) process) with **marginal cost of technology (MCT)**

STEP 2

Monte Carlo Simulation of expected project value E(V)

STEP 3

Binomial lattice approach for option to choose between continuation, abandonment and expansion

Licensing

Case study "Application of real options analysis for repowering of wind power plants"

Chair of Energy Economics and Management
Institute for Future Energy Consumer Needs and Behavior
Prof. Dr. Reinhard Madlener, Dr. Barbara Glensk, Qinghan Yu M.Sc.
RWTH Aachen University October 2023

Participating universities:

Funded by:

Ministerium für Kultur und Wissenschaft des Landes Nordrhein-Westfalen

Contact

E.ON Energy Research Center,
Institute for Future Energy Consumer Needs and Behavior (FCN)
Mathieustraße 10
52074 Aachen
Germany

Prof. Dr. Reinhard Madlener
T +49 241 80 49820
F +49 241 80 49829
RMadlener@eonerc.rwth-aachen.de

Further Information:

http://www.eonerc.rwth-aachen.de/fcn

Selected references

- Dixit A.K., Pindyck R.S. (1994). *Investment under Uncertainty*. Princeton University Press, Princeton
- Glensk B., Madlener R. (2015). Investments in Flexibility Measures for Gas-Fired Power Plants: A Real Options Approach in: Operations Research Proceedings 2015. Selected Papers of the International Conference of the German, Austrian and Swiss Operations Research Societies (GOR, ÖGOR, SVOR/ASRO), University of Vienna, Austria, September 1-4, 2015, Springer 2017, pp: 637-643
- Glensk B., Madlener R. (2015). Real Options Analysis of the Flexible Operation of an Enhanced Gas-Fired Power Plant, FCN Working Paper No.11/2015
- Glensk B., Madlener R. (2016). Evaluating the Enhanced Flexibility of Lignite-Fired Power Plants: A Real Options Analysis, FCN Working Paper No.10/2016
- Glensk B., Madlener R. (2016). Flexibility Options for Lignite-Fired Power Plants: A Real Options Approach in: Operations Research Proceedings 2016. Selected Papers of the Annual International Conference of the German Operations Research Societies (GOR) Helmut Schmidt University Hamburg, Germany, August 30 - September 2, 2016, Springer 2018, pp: 157-163
- Glensk B., Madlener R. (2018). Evaluating the Enhanced Flexibility of Lignite-Fired Power Plants: A Real Options Analysis, *Energy Conversion and Management*, 177: 737-749
- Glensk B., Madlener R. (2019). The Value of Enhanced Flexibility of Gas-Fired Power Plants: A Real Options Analysis. *Applied Energy*, 251: 113-125
- Glensk B., Rosen C., Madlener R. (2014). A Real Options Model for the Disinvestment in Conventional Power Plants in: Operations Research Proceedings 2014. Selected Papers of the Annual International Conference of the German Operations Research Society (GOR), RWTH Aachen University, Germany, September 2-5, 2014, Springer 2016, pp: 173-179
- Haahtela T. (2012). Differences between financial options and real options. *Lecture Notes in Management Science*, Vol. 4: 169-178
- Hull, J. (2012). *Options, Futures, and Other Derivatives, Global Edition*. (11th ed.). Pearson Education
- Trigeorgis, L. (2000). *Real Options: Managerial Flexibility and Strategy in Resource Allocation*. The MIT Press: Cambridge, Massachusetts/London, England