MSc Program
Renewable Energy in Central and Eastern Europe

# APPLICATION OF REAL OPTIONS VALUATION IN CORPORATE RENEWABLE ENERGY ELECTRICITY (RES-E) PORTFOLIO STRATEGIES

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Andreas Müller

Ivan Milovanović

1027596

18.11.2013, Vienna

# Affidavit

I, **IVAN MILOVANOVIĆ**, hereby declare

1. that I am the sole author of the present Master's Thesis, "**APPLICATION OF REAL OPTIONS VALUATION IN CORPORATE RENEWABLE ENERGY ELECTRICITY (RES-E) PORTFOLIO STRATEGIES"**, 186 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or toll, and

2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 18.11.2013

Signature

# ABSTRACT

*Decisions on investment in capital projects, such as those based on renewable energy sources – electricity generation technologies (RES-E), are associated with the future uncertainties that affect the present value of the considered projects. One of implications of uncertain business environment to corporate finance and strategy is increased interest in sophisticated strategic valuation tools and techniques, which involve valuation of risk, i.e. uncertainty, as well as managerial flexibility in the strategic decision making process.*

*The thesis examines the applicability of real options valuation (ROV) in RES-E greenfield projects, namely on-shore wind and solar photovoltaic (PV) technologies. The case study of multi-phased compound mutually exclusive path-dependent real options applied to the on-shore wind farm and PV plant projects in Serbia, evaluates different real options and their interactions.*

*The strategy tree model covers a period of 14 years – two years of investment period and next twelve years of operation period, which is protected by Feed-in-Tariffs (FiT), according to the Serbian RES regulation. The model examines two mutually exclusive strategic paths – the blue path (expand/abandon) and the red path (don't expand/abandon), as a result of the bifurcation of the basic path in the 3rd year of the plant operation.*

*In the case study, the author demonstrates the ROV of more complex (blue) path, consisting of following options: sequential option to invest in the plant construction (European call), option to expand the plant capacity in the 3rd year of operation (European call) depending on the results of previous two years of operation, as well as options to repower (European call) in case of favorable or to contract (European put) in case of unfavorable conditions after the expiration of protective FiT period in the 13th year of operation, depending on the market conditions at that time. Abandon option (American put) is permanently present in the model from the start of the project until $12^{th}$ plant operation year. It is shown that, due to scalability and modularity of on-shore wind and PV technologies, options to alter the scale (expand/contract) can be easily executed from a technical point of view.*

*The ROV follows the framework based on the IRMP (Integrated Risk management Process) approach. Volatility is calculated according to the logarithmic present value returns approach. It is shown that the volatility of the project cash flow is dominantly sensitive to the capacity factor forecasted as modified Weibull's probability distribution and simulated with Monte Carlo simulation (MCS), together with the other uncertainties affecting the project value. The author has developed an MS Excel tool for binomial tree option pricing which is used for the ROV process. Obtained results have been proven by comparison with the results in the SLS (Super Lattice Solver) software.*

*Considering calculated real option values in the final binomial tree, as well as its four moments (mean, standard deviation, skew and kurtosis), it is shown that the proposed sequence of options, after being optimized, increases project value by transforming higher risk and lower returns in the initial discounted cash flow (DCF) model – to lower risk and higher returns in the optimized RO model. The final RO value obtained after optimization is sensitive only to risk-free rate change, which enables easier risk management and decision making process over the examined ROV period.*

*Furthermore, the analysis of the real options interactions shows that incremental of the American abandon option in the presence of other options increases the project value, while there is no benefit out of interactions of other options included in the RO model.*

*As a final point, the portfolio of real options has been examined in two different ways: on intra-project level (combinations of different real options within a single project, considering their interactions) and on inter-project level (optimization of the RES-E projects portfolio consisting of combinations of six wind and six PV projects, under budget and diversification constraints). The 3D options space metrics in the "Tomato garden" approach has been applied on intra-project level, showing the optimal development path of the real options, which corresponds to the above mentioned results of the binomial tree options pricing model. On the inter-project level, basic principles of the efficient frontier approach for project portfolio optimization have been demonstrated, as well as ranking of different portfolios according to the Sharpe ratio.*

**Key words:** investment project, renewable energy, electricity, real options valuation, compound options, Monte Carlo simulation, portfolio, strategy, binomial tree, interactions, DCF, NPV, risk, uncertainty, volatility, risk-free rate, underlying asset, RES-E, Weibull's probability distribution, capacity factor, wind farm, PV plant, IRMP, "Tomato garden", efficient frontier, Sharpe ratio.

## ACKNOWLEDGEMENTS

I would like to thank my supervisor, Andreas Müller (TU Wien - Energy Economics Group), for all his support, guidance and inspiration given during my thesis research.

I am greatly thankful to Johnathan Mun, author of numerous books in the field of real options, for his support in the application of the Risk simulator and SLS software tools in the case study in this work.

My special thanks to Tamara Rađenović (Faculty of Economics, University of Niš) and to Dragan Lončar (Faculty of Economics, University of Belgrade) for their suggestions on real options modelling and valuation.

Finally, a great thanks to my family for their everyday support and faith in me.

# TABLE OF CONTENTS


Affidavit ........ i

ABSTRACT ........ ii

ACKNOWLEDGEMENTS ........ iii

LIST OF ABBREVIATIONS ........ vii

LIST OF FIGURES ........ x

LIST OF TABLES ........ xiii

1. INTRODUCTION ........ 1

1.1. Motivation and the core objective ........ 2

1.2. Research methodology ........ 5

1.3. Structure of the work ........ 9

2. REAL OPTIONS AS A STRATEGIC DECISION AND PROJECT VALUATION TOOL ........ 12

2.1. Comparison of financial and real options - differences and analogies ........ 13

2.2. Real options taxonomy ........ 18

2.3. ROV vs. DCF (NPV) ........ 23

2.4. Real options implementation issues and limitations ........ 27

3. RISK ASSESMENT IN RES-E PROJECTS WITH FOCUS ON PV AND WIND ........ 30

3.1. RES-E project features ........ 31

***Comparison of RES-E vs. conventional energy projects*** ........ *31*

***Discount rates in RES-E projects*** ........ *32*

***Learning curves*** ........ *33*

***Specific features of PV and wind projects from risk assessment point of view*** ........ *34*

3.2. Technology risks and uncertainties in PV and wind projects ........ 36

***Photovoltaics*** ........ *37*

***Wind*** ........ *40*

***Capacity factor*** ........ *45*

3.3. RES-E support schemes ........ 48

***Background*** ........ *48*

***Different types of support schemes*** ........ *51*

4. CASE STUDY: ROV OF THE RES-E PROJECTS IN SERBIA ........ 54

4.1. Serbia ........ 55

***General overview*** ........ *55*

***Overview of the energy sector in Serbia***.................................................................................... *57*

***RES sector in Serbia with focus on wind and PV*** ......................................................................... *61*

***Risks and opportunities for RES-E investments in Serbia***............................................................ *65*

4.2. Numerical example according to the IRMP framework ............................................... 67

***(1) Risk identification, i.e. qualitative management screening***............................................ *68*

***(2) Risk prediction, i.e. time-series and regression forecasting***............................................ *68*

***(3) Risk modeling of the NPV base case*** ..................................................................................... *68*

***(4) Risk analysis by using MCS***.................................................................................................... *70*

***(5) Risk mitigation – the real options problem framing*** ........................................................... *73*

***(6) Risk hedging through real options modeling and analysis*** ................................................. *76*

***(7) Risk diversification - portfolio optimization***......................................................................... *87*

***(8) Risk management, reporting and permanent update analysis***........................................... *93*

5. CONCLUSION........................................................................................................ 94

References........................................................................................................................ 96

Addendums ..................................................................................................................... 102

Addendum 1: Traditional approaches in project valuation with the focus on DCF................. 104

***DCF***................................................................................................................................... *105*

***Comparison of traditional dynamic KPIs for project valuation*** .............................................. *107*

Addendum 2: Modern approaches to project valuation ........................................................ 111

***Decision Tree Analysis (DTA)*** ................................................................................................. *112*

***Monte Carlo simulation (MCS)***................................................................................................ *114*

Addendum 3: Discount rate vs. risk-free rate....................................................................... 116

***WACC***................................................................................................................................ *117*

***Discount rate as a sum of risk premiums*** ............................................................................... *120*

***Risk-free rate***......................................................................................................................... *123*

Addendum 4: (Financial) Options ......................................................................................... 125

***Payoff charts*** ......................................................................................................................... *127*

***Application of options as non-trading securities*** ................................................................... *128*

Addendum 5: Option pricing models..................................................................................... 130

***Black-Scholes model***............................................................................................................. *130*

***Binomial model*** ..................................................................................................................... *135*

Addendum 6: Real options theory - basics ........................................................................... 141

***Definition***............................................................................................................................. *141*

***Historical background*** ........ *142*

***When managerial flexibility is valuable?*** ........ *143*

***Differences between risk and uncertainty*** ........ *146*

***Volatility as a key value driver in ROV*** ........ *151*

***Real options "In projects" and "On projects"*** ........ *153*

***Portfolio approach in real options*** ........ *155*

Addendum 7: PV Sunpower E20 datasheet ........ 157

Addendum 8: WTG Enercon E101 datasheet ........ 158

Addendum 9: Serbia FiT policy 2013 ........ 159

Addendum 10: List of assumptions for the BASE scenario DCF model for Wind farm and PV power plant project ........ 161

Addendum 11: DCF analysis – Base case ........ 162

Addendum 12: RO Strategy decision tree with datasheet ........ 163

Addendum 13: Underlying asset value binomial tree and cone of uncertainty ........ 164

Addendum 14: Expansion, Repower and Contraction factor calculation ........ 165

Addendum 15: ROV at $T_{op}$=13 binomial tree with sensitivity charts ........ 166

Addendum 16: ROV at $T_{op}$=3 binomial tree with sensitivity charts ........ 167

Addendum 17: ROV at $T_{op}$=-1 ($T_{cf}$ = 1) binomial tree with sensitivity charts ........ 168

Addendum 18: SLS output – proof of the ROV results obtained by the author's MS Excel based software solution ........ 169

Addendum 19: RO model optimization, including the four moments datasheet ........ 170

Addendum 20: RO interactions ........ 171

Addendum 21: RO in the 3D "Tomato garden" model ........ 172

## LIST OF ABBREVIATIONS

**AC** – alternating current
**AERS** – Agencija za energetiku Republike Srbije (Energy Agency of Serbia)
**Ann** – annuity
**ARoR** – accounting rate of return
**BS** – Black & Scholes model (or formula)
**Btoe** – billion tons of oil equivalents
**CAPEX** – capital expenditure
**CAPM** – capital asset pricing model
**CBOE** – Chicago Board Option Exchange
**CCGT** – combined cycle gas turbine
**CCPP** – combined cycle power plant
**CEO** – chief executive officer
**CF** – capacity factor
**CFO** – chief financial officer
**CHP** – combined heat and power
**CRP –** country risk premium
**CSP** – concentrated solar power plant
**DC** – direct current
**DCF** – discounted cash flow
**DDM** – dividend discount model
**DPP** – discounted payback period
**DS** – default spread
**DSCR** – debt-service coverage ratio
**DTA** – decision tree analysis
**EBIT** – earnings before interest and taxes
**EBITDA** – earnings before interest, taxes, depreciation and amortization
**EIA** – Energy Information Administration (US)
**EMS** – Elektromreža Srbije
**EMV** – expected monetary value
**EPS** – Elektroprivreda Srbije
**EU** – European Union
**EXPEX** – exploration expenditure
**FCF** – free cash flow
**FID** – final investment decision
**FiT** – feed-in tariff
**FiP** – feed-in-premium
**FLH** – full load hour
**FV** – future value

**GARCH** – generalized autoregressive conditional heteroskedasticity
**GBM** – geometric Brownian motion
**GDP PPP** – gross domestic product, purchasing power parity
**GWh** – gigawatt hour
**IEA** – International Energy Agency
**IRMP** – Integrated Risk Management Process
**IRR** – internal rate of return
**ISE** – International Securities Exchange
**KPI** – key performance indicator
**ktoe** – kiloton of oil equivalents
**kWh** – kilowatt hour
**LCoE** – levelized cost of electricity
**LIDAR** – light detection and ranging
**LRGC** – long run generation costs
**M&A** – mergers and acquisitions
**M.I.T.** – Massachusetts Institute of Technology, Cambridge, MA, USA
**MAD** – marketed asset disclaimer
**MCS** – Monte Carlo simulation
**MIRR** – modified internal rate of return
**MRP** – mean reversion processes
**MRR** – mean reversion rate
**Mtoe** – million tons of oil equivalents
**MW** – megawatt
**MWp** – megawatt peak
**NPV** – net present value
**NREAP** – national renewable energy action plan (Serbia)
**NREL** – National renewable energy laboratory
**OECD** – Organization for Economic Co-operation and Development
**O&M** – operation and maintenance
**OPEX** – operational expenditure
**OTC** – over-the-counter
**PDE** – partial differential equation
**PI** – profitability index
**PID** – potential induced degradation
**PM** – project management
**PP** – payback period
**PV** – photovoltaic
**PV** – present value
**R&D** – research and development

**RES** – renewable energy sources
**RES-E** – renewable energy sources, electricity generation technologies
**RFR** (also $r_f$) – risk free rate
**RO** – real options
**ROV** – real options valuation
**S&P** – Standard and Poor's
**SDE** – standard deviation in equity
**SDGB** – standard deviation in government bonds
**SHP** – small hydro power plant
**SIEPA** – Serbia Investment and Export Promotion Agency
**SLS** – Super Lattice Solver
**SODAR** – sound detection and ranging
**SPV** – special purpose vehicle
**SRGC** – short run generation costs
**TGC** – tradable green certificate
**toe** – ton of oil equivalent
**TWh** – terawatt hour
**US** – United States
**VaR** – value-at-risk
**VIX** – volatility index S&P 500 (^VIX)
**WACC** – weighted average cost of capital
**WTG** – wind turbine generator

## LIST OF FIGURES

Figure 1-1: Volatility S&P 500 (^VIX) .......... 2

Figure 1-2: Global renewable electricity production and forecast by sources .......... 3

Figure 1-3: World energy use by type, 1970–2050 .......... 4

Figure 1-4: IRMP (Integrated Risk Management Process) steps, by J. Mun .......... 7

Figure 1-5: "Tomato garden" approach .......... 8

Figure 2-1: Basic RO pay-off charts .......... 14

Figure 2-2: Multi-phased nested compound real options .......... 21

Figure 2-3: Basic advantages of ROV over DCF approach .......... 23

Figure 2-4: DCF and RO – risk return comparison .......... 24

Figure 2-5: The option zone concept .......... 25

Figure 3-1: Learning curves for PV technologies .......... 33

Figure 3-2: Intermittency and complementarity of solar and wind technologies .......... 36

Figure 3-3: Sunlight energy spectrum (left) and PV cells efficiency (right) .......... 37

Figure 3-4: Wind mast (left) and SODAR vs. LIDAR comparison (right) .......... 41

Figure 3-5: Real power curves vs. warranted power curve .......... 42

Figure 3-6: Mechanical sub-optimal power curve performance factors .......... 42

Figure 3-7: Environmental power curve performance factors .......... 43

Figure 3-8: Dependence of CF to generation costs .......... 45

Figure 3-9: Sensitivity of CF to $c$ and $k$ .......... 46

Figure 3-10: CF for new large wind projects in non-OECD regions .......... 46

Figure 3-11: CF in respect to axis tracking systems in different regions in the USA .......... 47

Figure 3-12: Global map of countries with renewable policies in place in 2012 .......... 48

Figure 3-13: National overall targets and their achievements in 2010 in EU .......... 49

Figure 3-14: Diversity of RES-E support instruments in the EU-27 .......... 52

Figure 3-15: Grid parity in Europe in 2010 (left) and estimate for 2016 (right) .......... 53

Figure 4-1: Map of Serbia .......... 55

Figure 4-2: Energy intensity – Serbia vs. European indicative countries .......... 57

Figure 4-3: EPS (left) and EMS (right) .......... 58

Figure 4-4: El. prices per consumption categories (left) and average price structure (right) ............ 60

Figure 4-5: Annual RES potential and use in 2011 in Serbia ............ 61

Figure 4-6: Spatial distribution of solar, small hydro and wind potentials in Serbia ..... 62

Figure 4-7: Global irradiation and solar electricity potential for optimally inclined PV modules in Serbia ............ 62

Figure 4-8: Serbia RES 2020 target ............ 63

Figure 4-9: Serbia 2020 targets per RES type ............ 64

Figure 4-10: Freedom from corruption: Serbia vs. Austria vs. World Average ............ 65

Figure 4-11: NPV sensitivity for the Wind project (left) and PV project (right) ........... 70

Figure 4-12: Wind farm business case DCF static vs. P50 (top), trend chart with certainty band (middle) and static NPV probability distribution after MCS (bottom) ... 72

Figure 4-13: Multi-phased sequential compound (nested) mutually exclusive path-dependent real options strategy decision tree ............ 75

Figure 4-14: Underlying asset cone of uncertainty ............ 76

Figure 4-15: Sequential real option set up for the Wind farm project ............ 77

Figure 4-16: Binomial tree for the wind farm project sequential option valuation ........ 78

Figure 4-17: Multi-phased sequential compound mutually exclusive path dependent real options binomial tree ............ 80

Figure 4-18: ROV 3D overlay charts with the optimization results ............ 81

Figure 4-19: The final sensitivity chart ............ 83

Figure 4-20: Preffered RO strategy path per year, which maximizes returns (red fonts) ............ 85

Figure 4-21: Real options interactions results ............ 86

Figure 4-22: The optimal project portfolio selection metrics ............ 89

Figure 4-23: *Efficient frontier* simulation result for the three top ranked portfolios ...... 89

Figure 4-24: Project portfolio risk return ranked according to the Sharpe ratio ............ 91

Figure Ad1-1: DCF shortcomings ............ 106

Figure Ad2-2: DCF vs. new tools for project valuation ............ 111

Figure Ad2-3: How to use four levels of uncertainties ............ 111

Figure Ad2-4: Example of a decision tree for an R&D project ............ 112

Figure Ad2-5: Basic principles of Monte Carlo simulation (MCS) ............................ 114
Figure Ad3-6: Euro area 10-year Government Benchmark bond yield [%]................ 123
Figure Ad4-7: Options payoff charts ........................................................................ 127
Figure Ad4-8: Approximate estimate of insurance payoffs........................................ 129
Figure Ad5-9: Sample paths of geometric Brownian motion (GBM) .......................... 131
Figure Ad5-10: Sample price paths according to GBM (left) and MRP (right) model 133
Figure Ad5-11: Free cash flow certainty band for non-discounted (up) and discounted cash flow (down) of a wind farm project.................................................................. 134
Figure Ad5-12: Sample paths of a Binomial model .................................................... 135
Figure Ad5-13: Example of the underlying asset lattice calculation........................... 136
Figure Ad5-14: Example of the ROV using the binomial tree (lattice)........................ 137
Figure Ad5-15: Trinomial (left) and quadrinomial (right) lattice................................ 139
Figure Ad5-16: Pentanomial lattice as a combination of two binomial lattices........... 140
Figure Ad5-17: Example of non-recombining binomial tree ...................................... 140
Figure Ad6-18: When managerial flexibility is valuable ............................................ 143
Figure Ad6-19: External and internal flexibility in the project .................................. 144
Figure Ad6-20: Risk and opportunity derive from uncertainty in the specific context 146
Figure Ad6-21: Weibull's and Rayleigh's probability distribution of wind speed ...... 147
Figure Ad6-22: Impact–uncertainty matrix ................................................................ 148
Figure Ad6-23: Various log-normal stock prices in case of 20% and 60% volatility .. 151
Figure Ad6-24: 3D implied volatility surface charts of S&P Index 2007 to 2009....... 151
Figure Ad6-25: Real options "on projects" and "in projects" ..................................... 153
Figure Ad7-26: Datasheet of the SunPower E20 PV module...................................... 157
Figure Ad8-27: Enercon E-101 wind turbine generator ............................................. 158
Figure Ad9-28: FiT in Serbia, valid as of Feb 2013 ................................................... 159

# LIST OF TABLES

Table 2-1: Comparison of financial and real options .................................................... 15

Table 2-2: Analogy between financial and real options variables................................. 17

Table 2-3: Real options as Put and Call options........................................................... 21

Table 2-4: Real options traps........................................................................................ 28

Table 3-1: RES-E vs. conventional energy power plant project features....................... 31

Table 3-2: Discount rates for low-carbon and RES-E technologies............................... 32

Table 3-3: Example of WACC calculation in RES-E projects...................................... 32

Table 3-4: Risks in PV and Wind projects ................................................................... 34

Table 3-5: Technical performance and costs by PV technology ................................... 38

Table 3-6: Deviation of real vs. sales power curves...................................................... 43

Table 4-1: Base case static DCF results for the wind and PV projects .......................... 69

Table 4-2: Comparison of static NPV (before MCS) and "dynamic" $NPV_{P50}$ (after MCS), for the wind and PV projects............................................................................ 71

Table 4-3: Inputs for the wind farm project binomial tree ............................................ 76

Table 4-4: RES-E project portfolio - base case ............................................................ 88

Table 4-5: The optimal RES-E project portfolio .......................................................... 88

Table 4-6: Project portfolio prioritization..................................................................... 92

Table Ad1-1: Comparison of traditional project valuation KPIs................................. 107

Table Ad3-2: Example of calculating the discount rate by adding risk premiums....... 120

Table Ad3-3: Convention for long- and short-term ratings......................................... 121

Table Ad6-4: Three levels of uncertainties................................................................. 149

Table Ad6-5: Options-uncertainty matrix.................................................................... 149

Table Ad6-6: Comparison between real options "on" and "in" projects..................... 154

# 1. INTRODUCTION

Since its appearance in the academic community in 1976 at M.I.T.[1], Cambridge, MA, USA, the real options approach has drawn considerable attention of scientists all over the world.

Basic concept of real options is taken over from one of financial derivatives – options. Nowadays, real options valuation (ROV) is an approach available to corporate CEOs and CFOs for tying up corporate strategy and capital budgeting by valuing managerial flexibility under uncertainty.

The ROV, actually, bridges the gap between corporate strategy and finance, by upgrading application of discounted cash flow (DCF) model based on stereotyped net present value (NPV) metric, considering uncertainties built in the analyzed projects by using Monte Carlo simulation (MCS), calculating volatility, making underlying asset present value event tree and decision tree which corresponds to the set of available real options determined through managerial flexibility and finding an optimal path of the capital projects development through the time in order to increase shareholders' wealth.

This chapter gives a brief overview of the motivation and core objective, applied research methodology as well as the structure of this work.

[1] Massachusetts Institute of Technology

## 1.1. Motivation and the core objective

We live in a high-risky world, full of uncertainties. One of the best proofs is the global financial crisis which has begun (suddenly?) in 2008 in US financial and real estate sector and, today in 2013, still continues to ruin economies of most of developed and developing countries as well as keep threatening global stock exchanges, increasing volatility[2] of market returns and makes their recovery very slow, as shown on the **Figure 1-1**, expressed via ^VIX[3].

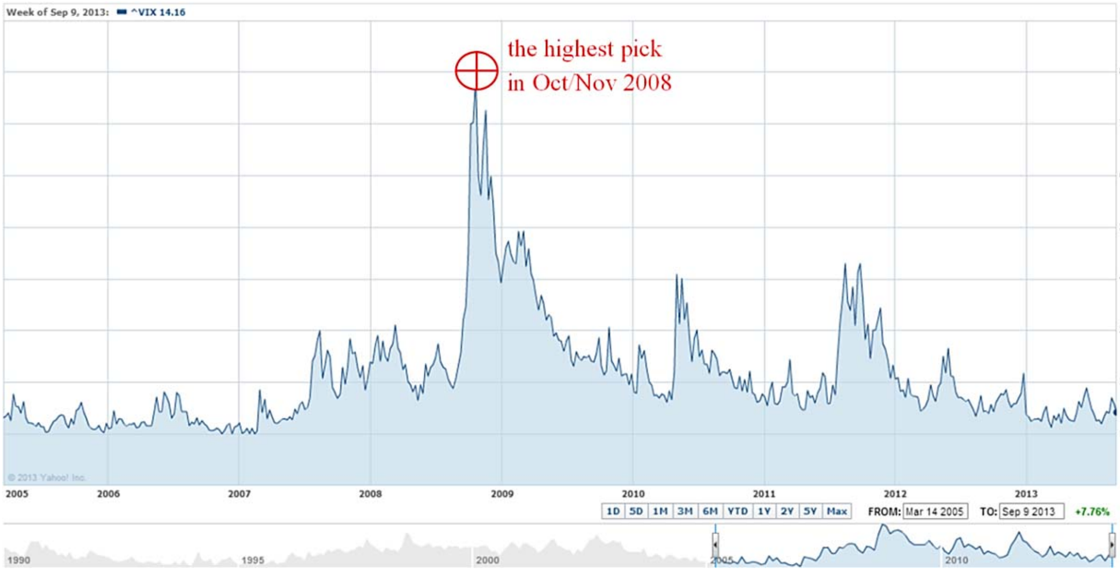



**Figure 1-1: Volatility S&P 500 (^VIX)**
*source: http://finance.yahoo.com*

One of implications of this high-risky business environment to corporate finance and strategic planning of capital investment projects and portfolios, is increased interest in sophisticated strategic valuation tools and techniques, which involves valuation of risk, i.e. uncertainty as well as managerial flexibility in the strategic decision making process during a project life cycle, affecting both – its development and operational phase. As it will be discussed in the **Chapter 2**, there are no many risk valuation based tools and techniques, which are available to a corporate's CEOs and CFOs for bridging the gap between corporate strategy and finance by valuing managerial flexibility under uncertainty.

Real options valuation (ROV), which is the subject of this study, significantly overcomes limitations of discounted cash flow (DCF) approach expressed in NPV (Net

---

[2] **Volatility** is one of the key parameters in both - financial options and real options pricing models (for more, see Addendum 6.5).

[3] **^VIX** (Market Volatility Index) - After the global stock crisis in 1987, NYSE (New York Stock Exchange) introduced switchers in order to protect its investors and to stabilize the stock market. Its investors were allowed to observe dynamic fluctuations of the market. In 1993, the Chicago Board Options Exchange (CBOE) introduced ^VIX in order to measure the fluctuation rate of the market. The VIX is the measure of the market's expectation of stock market volatility over the next 30-day period.

Present Value) as a key profitability indicator - a main case study modeling tool in last 40-50 years in the corporate finance. Additionally, ROV improves decision tree analysis (DTA), which is one of the favorite tools in the corporate strategy and planning.

On the other hand, due to climate change concerns, nuclear dangers (e.g. Fukushima disaster[4]), difficulties in fossil fuel exploitation (e.g. Deepwater Horizon disaster[5]) and high prices of oil, there is increasing interest and support for renewable energy worldwide.

Since **electricity generation from renewable sources (RES-E)**[6] moved from laboratories to the global market in 1990's, it has become one of the fastest growing industries in the world.

In the IEA 2012 report (Houssin, 2012), it was stated that global annual investments in RES-E reached USD 250 billion in 2011. The mid-term forecast to 2017 shows investment volume increase of ca. 40%, mainly driven by hydropower, wind on-shore, bioenergy and solar PV respectively, as illustrated the **Figure 1-2**.

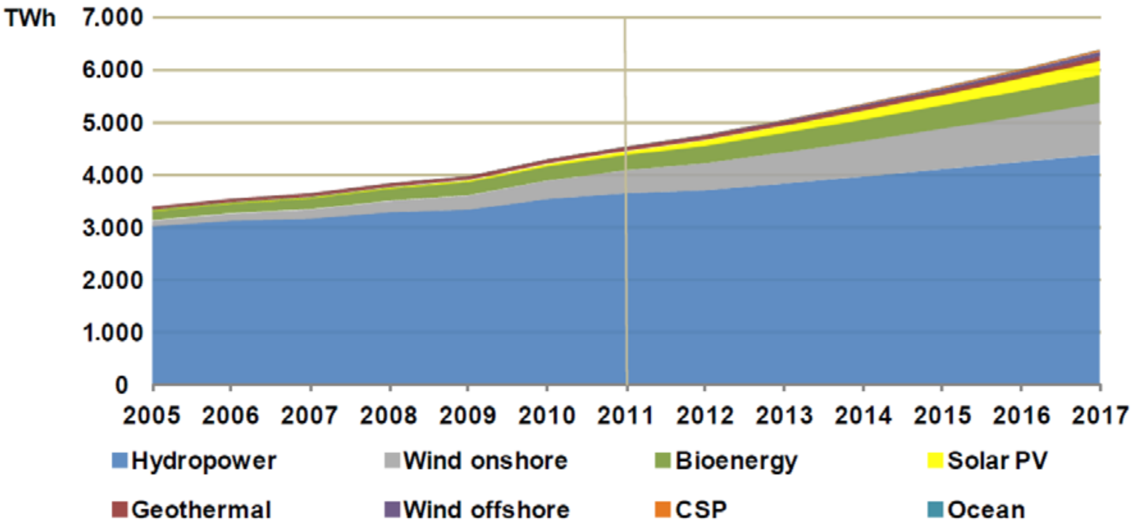



**Figure 1-2: Global renewable electricity production and forecast by sources**

*source:* (Houssin, 2012)

Non-OECD countries (China, Brazil and India) accounts for 2/3 of the overall RES-E growth, followed by OECD Europe, OECD Americas, OECD-Asia-Oceania and the rest of the world countries, respectively.

---

[4] Fukushima Daiichi nuclear disaster was an energy accident on 11.03.2011, at the Fukushima I Nuclear Power Plant in Japan, primarily initiated by the earthquake, followed by 15m high tsunami wave. It was the largest nuclear disaster since the Chernobyl disaster in 1986.

[5] Deepwater Horizon, was an crude oil spill that began on 20.04.2010 in the Gulf of Mexico on the BP-operated Macondo Prospect, considered as the largest accidental marine oil spill in the history of the petroleum industry.

[6] RES–E: Renewable Energy Sources – Electricity generation technologies, such as on-shore and off-shore wind farms, solar PV (Photovoltaic) and CSP (Concentrated Solar Power) plants, small hydro power plants (SHP), marine technologies (wave and tidal), geothermal and biomass power (and CHP – Combined Heat & Power) plants.

According to the global forecast for next forty years (Randers, 2012), it can be expected a tremendous increase in the installed capacity of renewables as shown in the **Figure 1-3**, especially of wind, solar and biomass energy, reaching ca. 40% of total energy consumption by 2050[7].

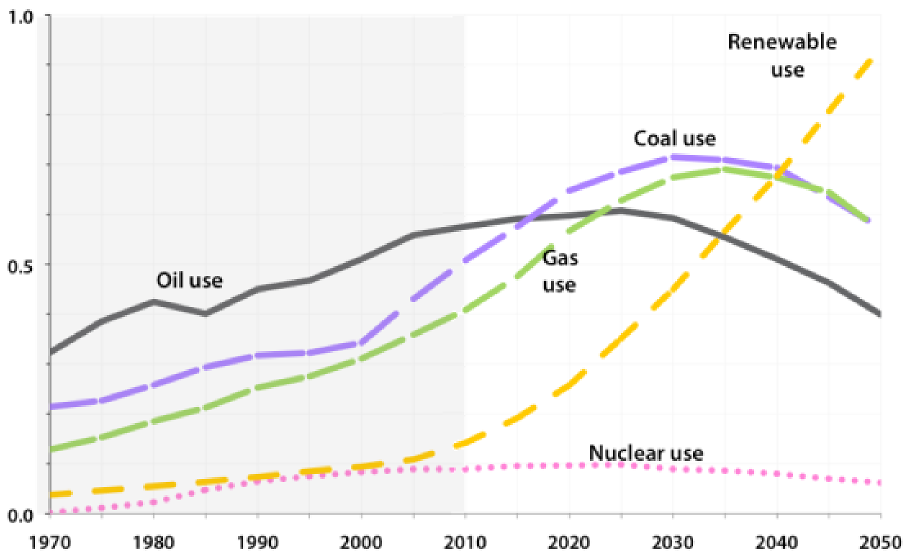



**Figure 1-3: World energy use by type, 1970–2050**
scale: Energy uses (0–7 billion toe8 per year)
*source: www.2052.info*

Consideration of these two topics together – application of real options valuation to renewable energy projects – is the core objective of this master thesis.

In fact, **the core objective** of this work is to examine the applicability of ROV in RES-E investment projects in general, as well as particularly for valuation of compound real options with a focus on wind (on-shore) and solar (photovoltaic) power plant projects in a corporate RES-E strategy.

Apart from the fact that revenues in the RES-E projects are partly hedged against risk by governmental subsidy measures[9], deregulation of the energy markets (mainly gas and electricity) in many countries is another reason that makes applications of the real options in the energy sector, including RES-E, even more important than it was the case in the past.

---

[7] According to J. Randers, by 2050 there will be few nuclear plants in the industrial world. Use of gas will increase, reaching its peak around 2035, because this will be one of the cheapest and most abundant energy sources, especially in the US, where utilities running on shale gas are currently much cheaper than the nuclear alternative, which will accelerate the rapid shift to gas. Although there will be increase of use of coal (mainly because of China) by its peak in 2030, gas will be preferred resource in most of countries, due to its lower carbon footprint (it emits one-third as much $CO_2$ per kilowatt-hour). Gas power plants, due to its fast start-up, also has a beneficial future use as a back-up for intermittent sources like wind (when wind doesn't blow) and solar (during the night and cloudy days), thus having a synergistic effect when coupled with renewables.

[8] tons of oil equivalent

[9] For more about RES subsidies, see the Chapter 3.

## 1.2. Research methodology

**Real options valuation** is a relatively new approach in a corporate finance and strategy planning which applies financial option valuation based techniques to strategic decisions in capital budgeting.

In the available literature, there are several ROV methodologies/frameworks/ approaches, such as:

- **"IRMP - Integrated Risk Management Process"** by Mun (2006) and (Mun, 2010);
- **"The four-steps process"** including MAD (Marketed Asset Disclaimer) approach for option pricing, by Copeland and Antikarov (2003);
- **"Real Options Portfolio Model"** by Brosch (2008);
- **"Tomato garden"** – Strategic portfolio of options framework, by Luehrman (1998);
- **"Stochastic Control Framework"** by Vollert (2003);
- **IEA methodology** for quantification of the impacts of climate change policy uncertainties on power investment (Yang & Blyth, 2007);
- **A ROV framework**, by Bräutigam, Esche and Mehler-Bicher (2003);
- **A step by step framework**, by Arthur D. Little (Real Options for the Future Energy Mix, 2008);
- **The Real Options Approach to Strategic Capital Budgeting and Company Valuation,** by De Maeseneire (2003);
- **"ROV hybrid approach"**, by De Neufville (2001).

First two approaches (Mun's "IRMP" and Copeland's "The four steps") are the most comprehensive ones and similar to each other, while the IRMP goes beyond real options analytics and copes with asset allocation and project portfolio optimization. Besides Mun's IRMP, other two approaches that deal with real options portfolios are Brosch's approach presented in his book "Portfolios of real options" (Brosch, 2008) and Luehrman "Tomato garden" approach, published in Harvard Business Review in 1998, (Luehrman, 1998). Some parts from the other listed approaches have been used in this work mainly from uncertainty and risk analysis point of view.

In the case study in the **Chapter 4**, the author has applied an approach which is the most similar to Mun's IRMP, as this approach integrates projects portfolio optimization which is one of the objectives of this thesis.

At the same time, the IRMP approach has resolved a concern stated by Smith and Nau (1995) that NPV, decision trees and real options modeling have been applied without a clear understanding of strengths and limitations of each model in many fields: *"In the usual MBA curriculum, students learn about decision trees and utility theory in their project management course. In financial management courses, they are taught about how the discounted cash flow and discounted rate are used to model risks. In advanced finance courses, they learn option valuations in the complete market using risk neutral probabilities. The result of all these trainings is the graduates who may understand each method but fail to appreciate the relationships between them and their relative strengths and weaknesses. A similar gap between the decision analysis and finance disciplines exists in the academic literature and professional practice. This gap has become increasingly apparent with the development of option pricing techniques for valuing projects in which managerial flexibility or 'real options' play an important role."*

Although discussions in the academic world on the right approach to real options valuation (mechanism, pricing models, ...) (Borison, 2003)[10] and on the fundamental assumptions (existence of replicating "twin" real asset security, risk neutral measurement in real option pricing in respect to inclusion of non-tradable asset which is not "arbitrage free" - such as R&D and projects of technology innovation – in the complete capital market,...) (Wang & Hallal, 2010) are still present, this master thesis is more oriented to a practical application in the corporate's capital project management and strategy than to something which should resolve doubts of the academic purists.

In the **IRMP approach**, adjustment of the value due to non-marketability of the real options[11] is proposed to be done by computing Bermudan options instead of regular American options or by using higher dividend rate which will reduce real option value. In practice, this adjustment is almost never made, because as long as the approach is comparable among multiple projects, real options analysis results are correct. In most cases, the relative value among evaluated projects is more important than the absolute value of a single project!

The IRMP is an approach which is recognized by the M.I.T.[12] and more than forty other universities all over the world, as well as by numerous large corporations (Airbus, Monitor group, GE, 3M, Seagate, etc.). The IRMP is relatively easily understandable by

[10] Borison analysed application of five different approaches in real options pricing of the same project: Classic, Subjective, MAD-Marketed Asset Disclaimer, Revised Classic and Risk integrated approach. The latter is also called Hybrid approach (by De Neufville) and is recommended by both authors as an optimal approach when there are different uncertainties simultaneously present in the project – public (market) and private (technological, i.e. project) ones.

[11] Unlike financial options that are freely tradable, real options are in most cases not freely tradable (i.e. not freely marketable or transferable).

[12] Massachusetts Institute of Technology, Cambridge, MA, USA.

the managers (decision makers), as well as easy to be implemented in the firms, but it requires comprehensive software support[13], due to complex forecasts and simulations which are consisting part of the ROV process.

The IRMP approach (as shown in the **Figure 1-4**) is a continuous process consisting of the following eight steps, defined in respect to risk: (1) Risk identification, i.e. qualitative management screening, (2) Risk prediction, i.e. time-series and regression forecasting, (3) Risk modeling of the NPV base case, (4) Risk analysis by using MCS, (5) Risk mitigation – framing of Real options problem, (6) Risk hedging through Real Options modeling and analysis, (7) Risk diversification – portfolio and resources optimization and (8) Risk management, reporting and permanent update analysis.

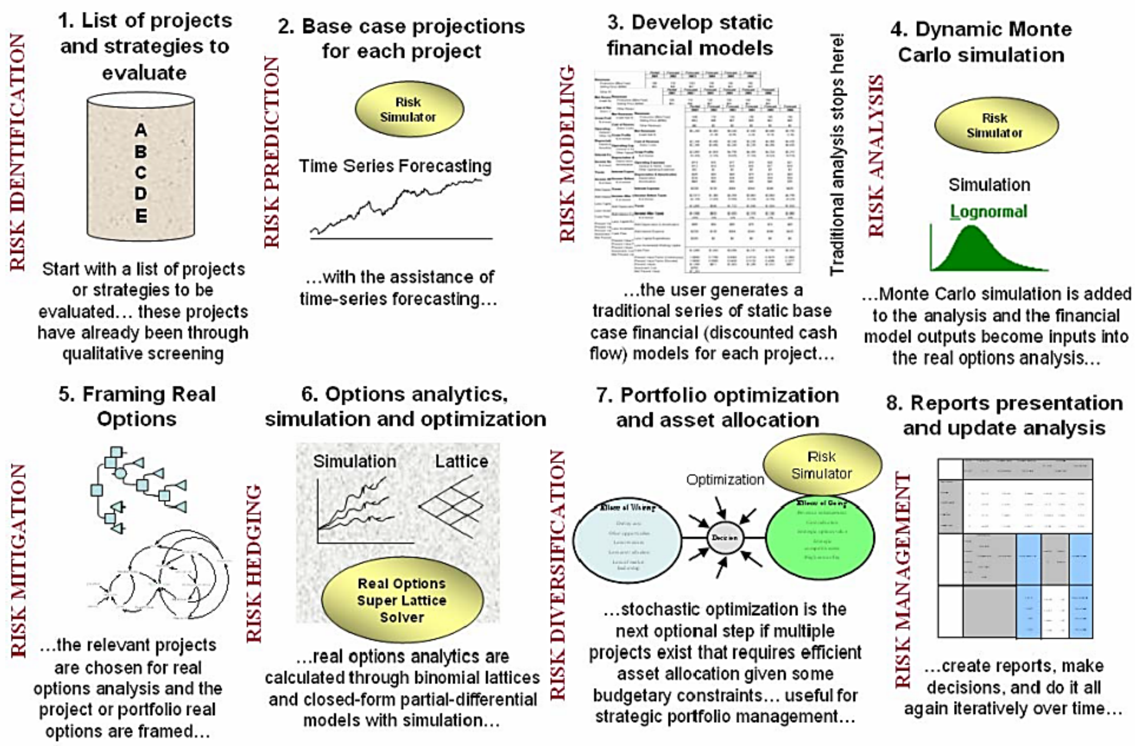



**Figure 1-4: IRMP (Integrated Risk Management Process) steps, by J. Mun**

*source: (Mun, 2010)*

For the purpose of the case study in **Chapter 4**, the author has developed an MS Excel based application for valuation of a sequential compound real options consisting of combination of scale options (expand, contract and repower) and abandon option. The results have been verified by their comparison with Mun's Real options SLS.

[13] "Risk simulator" and "Real options SLS" (Supper Lattice Solver) by Real options valuation Inc., USA (a company owned by J. Mun) *(www.realoptionsvaluation.com)* as well as Oracle's Crystal Ball are some of the software tools the author used in solving real options business case in the Chapter 4.

In addition, Luehrman's "**Tomato garden**" approach (**Figure 1-5**), as a tool for strategic valuation of portfolio of real options, has been applied to the same combination of options in order to proof results of the IRMP approach in the **Chapter 4**.

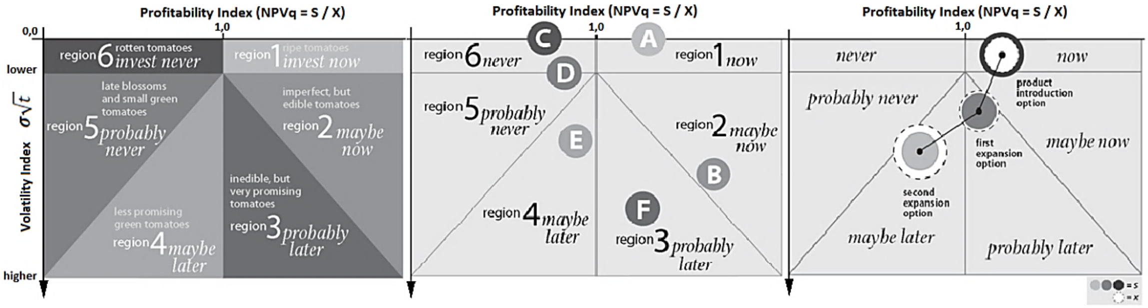



**Figure 1-5: "Tomato garden" approach**

**Tomato garden metaphor (left), locating projects in the garden (middle), project valuations in 3D option space (right)**

*source: (Luehrman, 1998)*

## 1.3. Structure of the work

The work consists of five chapters, including this one (Introduction). In the **Chapter 2**[14], real options as a strategic valuation tool will be discussed on following topics:

- **Comparison of financial and real options** – their differences and analogies,
- **Real options taxonomy** (to defer, to abandon, to expand, to contract, to switch, compound sequential and simultaneous options, etc.),
- **ROV vs. DCF** (NPV) approach, and
- **Real options implementation issues and limitations**.

A greater part of the underlying topics related to this chapter is placed in the **Addendums 1 – 6**, as follows:

- **Addendum 1: Traditional approaches in project valuation with the focus on DCF method** and comparison of most frequently used project profitability metrics which consider time value of money: **NPV** (Net Present Value), **IRR** (Internal Rate of Return), **PI** (Profitability Index), **Ann** (Annuity), **DPP** (Discounted Payback Period) and **EMV** (Estimated Monetary Value);
- **Addendum 2: Modern approaches to project valuation**, with a focus on Decision Tree Analysis (DTA) and Monte Carlo simulation (MCS);
- **Addendum 3: Discount rate** (defined as WACC – Weighted Average Cost of Capital or as a sum of risk premiums) **vs. risk-free rate** which is used in financial and real option valuation;
- **Addendum 4: Financial options** – what are derivatives, option types (American, European, etc.), four types of option payoff charts (short put, short call, long put, long call), options as a non-trading securities;
- **Addendum 5: Option pricing models** such as Black-Scholes model including Brownian motion, assumption of risk-neutral probability and Binomial tree are discussed in details. Also other tree (lattices) models (trinomial, quadrinomial and pentanomial) are explained briefly;
- **Addendums 6** is related to the **detailed definition of the real options**, their historical background, it answers the question "When managerial flexibility is valuable?", and explains differences between risk and uncertainty as well as between real options "in projects" and "on projects". Volatility as a key value driver in ROV and its estimate (Subjective, GARCH, Logarithmic present value returns, etc.) is also explained. At the end of this addendum a theoretical background of the portfolio approach in real options is given, which has been applied in the business case in the **Chapter 4.2**.

[14] Including Addendums 1 – 6, which are related to this Chapter

In the **Chapter 3**[15]**,** more attention is put on application of ROV in renewable projects, with a focus on risk modeling in RES-E projects. Following topics will be discussed:

- **Main features of capital RES-E projects** from project valuation point of view, including identification of key uncertainties with a focus on RES-E wind on-shore and solar PV investment projects (discount rates, capacity factors, electricity price, etc.);
- **Learning and experience curves** as a forecasting tool for the cost risk estimation;
- **Different support schemes** and other hedging instruments against price (revenue) uncertainty in RES-E projects;

In the **Chapter 4**[16], a case study of ROV of on-shore wind and solar PV projects in Serbia will be presented in details. In that regard, the author has developed an MS Excel based application for valuation of **a multi-phased sequential compound mutually exclusive path-dependent real options model**. Following topics will be discussed and analyzed:

- DCF modeling for static NPV calculation;
- establishing a complex book of assumptions (investment horizon, dual risk-adjusted discount rate – during FiT period and after, risk-free discount rate, capacity factors, CAPEX and OPEX, income tax, learning rate, price assumptions in post-FiT period, electricity price escalation, OPEX escalation, etc.);
- modeling of uncertainties and calculation of dynamic NPV and underlying PV by using MCS;
- calculation of project's volatility with lognormal present value returns approach;
- autocorrelation of key assumptions and correlation among assumptions and goals;
- forming the underlying asset value event tree and cone of uncertainty;
- identification of the key events and path dependencies and setting-up the decision tree model;
- application of ROV;
- sensitivity analysis of each step in the ROV;
- real options interactions;
- interpretation of results in 3D space Tomato garden (Luehrman, 1998);
- project portfolio optimization by using the *efficient frontier* method as well as portfolio ranking according to the *Sharpe ratio*;

[15] Including Addendums 7 – 8, which are related to this Chapter

[16] Including Addendums 9 – 21, which are related to this Chapter

- overall interpretation of the results after the portfolio optimization
- due to the complexity of the valuation calculation, a greater part of the ROV is attached to **Addendums 9-21**.

Overall conclusion is provided in the **Chapter 5**, while a comprehensive list of references (books, articles, web sites, etc.) is listed in the chapter **References**.

# 2. REAL OPTIONS AS A STRATEGIC DECISION AND PROJECT VALUATION TOOL

Since the ancient times, when its ultimate objective was to enable an army "to crush the enemies, see them driven before the winner, and to hear the lamentation of their women"[17], the strategy passed a long way to enter corporate life in the second half of 20th century in the form of sophisticated strategic tools for investment valuation.

Real options valuation (ROV) is a relatively new branch of corporate finance and strategy which applies financial option valuation techniques to strategic decision in capital budgeting process[18]. ROV gradually improves traditional DCF project valuation methodology by transforming higher risk and lower returns in DCF model to lower risk and higher returns in RO model. It incorporates Monte Carlo simulation (MCS) as well as improves Decision Tree Analysis (DTA)[19] by using binomial tree (lattice)[20] – both for decision analysis and for valuation of the real options.

Application of real options valuation in capital projects is recognized by numerous leading global consulting companies (McKinsey & Co., Roland Berger, ROG, IPA, etc.), investment and national banks (Credit Suisse, NBB, etc.), corporates (Boeing, Airbus, Shell, BP, Conoco, Halliburton, Schlumberger, Intel, Seagate, Pfizer, Merck, GE, Motorola, Unilever, 3M, Syngenta, etc.), universities (M.I.T., University of Pennsylvania, University of Maryland, ...), military (US Navy, US Army, US Air-Force, US Marines) and international organizations (IEA, IFC, etc.).

The discussion on real options valuation cannot start without clarification what are the options at all. In the following sections similarities and differences between financial and real options will be explained, followed by real options taxonomy and comparison of ROV vs. DCF. The chapter ends with an overview of the real options implementation issues and limitations.

---

[17] Words of Conan (played by Arnold Schwarzenegger) in the "Conan the Barbarian", a 1982 American adventure film, directed and co-written by John Milius.

[18] The term "real option" was invented by Stewart C. Myers, professor of finance at the MIT Sloan School of Management in 1976. See Addendum 4 on financial options and Addendum 6 on real options historical background.

[19] For more about MCS and DTA see Addendum 2: Modern approaches to project valuation.

[20] For more about binomial tree approach see Addendum 5: Option pricing models.

## 2.1. Comparison of financial and real options - differences and analogies

Real options are not derivative instruments such as financial options, but actual options (in the meaning of "choices") that a company may execute during realization of a particular investment project. There is a whole arsenal of real options available to the company in that regard, such as option to upsize (expand) or downsize (contract) the business, to switch among different products or resources, to abandon the project, to defer investment decision until the moment when some of uncertainties are resolved, etc.

Considering existing literature, the **real option** itself can be formulated as the right - but not the obligation - to undertake certain business decisions, such as deferring, abandoning, switching, expanding (upsizing) or contracting (shrinking, downsizing) a capital investment project which can be, in simple case, executed either as a financial “call” or a “put" option or, in more complex case, as a compound option consisting of combination of different “call” and “put” options. Moreover, real options present not only a valuation tool but a framework to incorporate knowledge from various parts of the organization into the investment decision-making process.

In some basic cases, real options are similar to financial options. A good way to compare financial and real options is via payoff charts. As presented in the **Addendum 4.2**, there are four basic types of pay-off charts: long put, long call, short put and short call.

Typical pay-off charts for the long put and long call option, adjusted for real options (unlike financial options, in real options the underlying asset value can be negative!) are illustrated in the **Figure 2-1**. On the both charts, the vertical axes represent the value of the strategic option and the horizontal axes represent the value of the underlying asset (i.e. project’s PV). The sloped bold line represents the payoff function of the option at termination, i.e. the project’s NPV, because at termination, maturity effectively becomes zero and the option value reverts to the NPV (project’s PV less implementation costs). The dotted curved line represents the payoff function of the option prior to termination, where there is still time before maturity and hence uncertainty still exists and option value is positive. This curved line is the expanded NPV (eNPV), which includes static NPV and strategic option value. Both lines effectively have a horizontal floor value, which is effectively the premium on the option. In order to reach better understanding, two situations are illustrated in the chart: A and B. NPV is negative in A (it decreases eNPV) and positive in B (it increases eNPV).

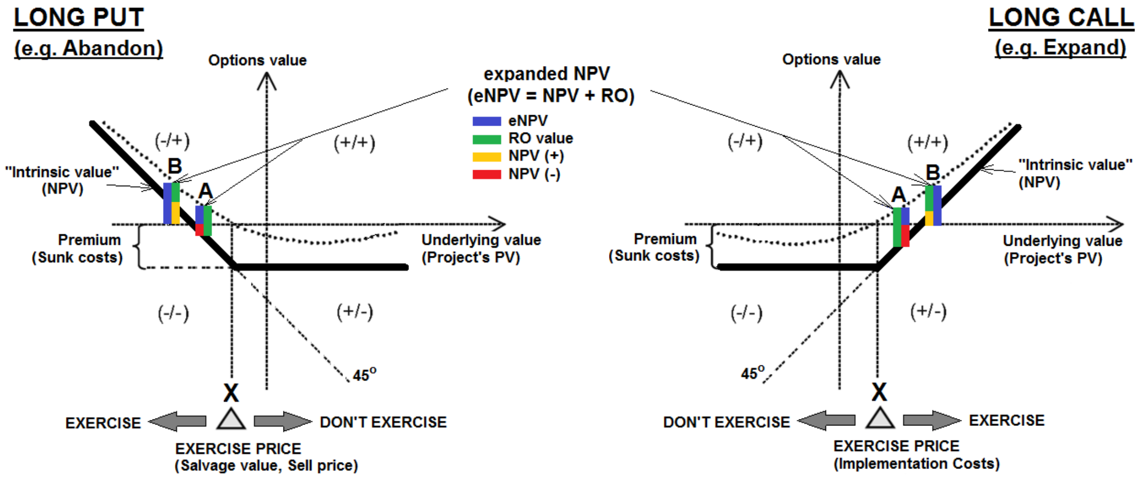



**Figure 2-1: Basic RO pay-off charts**

*source: the author, modified from (Mun, 2006)*

The position of a **"Long Call"** is similar to an "**Expand"** real option. In opposite, the **"Long Put"** is similar to **"Abandon"** real option. This is because both - an expansion or an abandonment real option usually costs something to set them up → option's premium or purchase price. If the underlying asset does not increase in value over time, the maximum losses incurred by the holder of this expansion option will be the cost of setting up this option (e.g. geotechnical research for foundation of the Wind farm in case of Expand option, or market research for finding a buyer of the Wind farm we want to sell), which have to be treated as sunk costs.

In case of expand option - when the value of the underlying asset increases enough above the strike price (X), the value of this expansion option increases. There is unlimited upside to this option, but the downside is limited to the premium paid for the option. The break-even point is where the bold line crosses the horizontal axis, which is equivalent to the strike price plus the premium paid.

In case of abandon option - when the value of the underlying asset decreases sufficiently below the strike price (X), the value of this abandonment option increases. The option holder will find it more profitable to abandon the project currently in existence. There is unlimited upside to this option but the downside is limited to the premium paid for the option. The break-even point is where the bold line crosses the horizontal axis, which is equivalent to the strike price less the premium paid.

In order to make a clear distinction, a comparison between financial and real options is given in the **Table 2-1** summarized from (Brach, 2003), (Haahtela, 2012), (Copeland & Antikarov, Real options – A practitioner's guide, 2003) and (Mun, 2006).

**Table 2-1: Comparison of financial and real options**

*sources: (Brach, 2003), (Haahtela, 2012), (Copeland & Antikarov, Real options – A practitioner's guide, 2003) and (Mun, 2006)*

| Financial options | Real options |
|---|---|
| Have been traded for more than three decades. | A recent development in corporate finance and strategy, within the last decade. |
| Expiration time is defined in the options contract. | Expiration time is clearly known only in some cases (e.g. duration of FiT period). |
| Exercise time (for European options) or time period (for American option) known in the beginning, usually in months | Exercise time, especially optimal one, not necessarily known due to complexity of the real options, usually in years |
| Mostly European by nature. | Mostly American by nature. |
| Underlying variable driving its value is equity price or price of a financial asset. | Underlying variables are free cash flows, which in turn are driven by competition, demand, management. |
| Price paid to acquire the option, which is fixed by financial markets. | Price paid to acquire or create the option, keep it alive, and clear the uncertainty. The price is not fixed. |
| Exercise price is paid to buy/sell the underlying stock. It's a fixed value defined in the option contract. | Exercise price is cost of buying/selling the underlying real asset. |
| Values are usually small. | Capital projects in million and billion euro decisions. |
| Option's holder cannot control option value over the option's life. | Adequate management decision can increase option value, while limiting downside potential. For instance, option holder can expand power plant capacity in case of positive outcomes in previous operating period and promising market future trends, or to decide to reduce (contract) capacity or to totally shutdown the plant (abandon) in opposite case. |
| Option value increases in case of longer life of the option. | In general, option value increases in case of longer life of the option, but it can decrease in case of entry of new competitors in the market. |
| Option value increases in case of underlying asset volatility increases. | Option value increases in case of underlying asset volatility increases. |
| Competitive or market effects are irrelevant to its value and pricing. | Competition and market drive the value of a strategic option. |
| Usually solved using closed-form partial differential equations and simulation / variance reduction techniques for exotic options. | Usually solved using closed-form equations and binomial lattices with simulation of the underlying variables, not on the option analysis. |
| Marketable and traded security with comparables and pricing info. | Not traded and proprietary in nature, with no market comparables. |
| Uncertainties are resolved automatically with time; the option holder has to do nothing to resolve them. | In some cases, uncertainties are resolved through time, but in most cases, the option holder has to act in order to resolve uncertainty, for instance through market research or pilot project testing, etc. |
| Options are liquid and tradable in financial markets. | Most often neither liquid nor tradable. |
| Exercise decision is clear and rational – affected by the price difference between underlying asset (e.g. stock) value and the exercise price. | Exercise decision may have political or emotional background. |
| Volatility increases always beneficial. | Volatility increase after committed investments may have negative effect. |
| Volatility sufficiently stable. | Time-varying, usually diminishing, volatility. |
| Follows better GBM. | Rather mean reverting in the long run. |

| | |
|---|---|
| Underlying variable is equity or asset price. | Underlying variables are free cash flows driven by competition, demand and management. |
| Management assumptions have no effect on valuation. | Management assumptions and actions drive the value of the real option. |
| Numerical accuracy more important. | Framing the option case more important. |
| Often single options. | Often rainbow and 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 (not on the option analysis). |
| Depends only on risk-free interest rate. | Dependent on both risk-free interest rate and risk-adjusted premium or equilibrium rate in dynamic programming context. |
| Option value known at exercise | Expected value may be known, but it may still have fluctuations in the future |
| Ordinary payoff functions. | Different and sometimes complex payoff functions. |
| Timing of option payoff known (immediate). | Timing of option payoff delayed, not precisely known, and may spread over a period of time. |
| Option has certain price to acquire. | May not have price for acquiring the option or the price is unknown. |
| Strike price often known. | Strike price may also be stochastic. |
| Proprietary possibilities. | Shared and proprietary nature. |
| Usually no information asymmetries. | May have information asymmetries with arbitrage possibilities. |
| Precise parameterization. | May have fuzziness or ambiguity in parameter values. |
| Owned by one party. | Owned, created and exercised by the cooperative activity of more than one company. |
| May not have negative values. | Underlying asset may have negative values. |
| Continuous information flow. | Discrete information flow with occasional managerial reactions. |
| Computational efficiency important. | Computational efficiency less important. |
| Can be diversified. | Cannot be diversified. |
| Valuation parameters mostly primary and observable variables. | Valuation parameters are often secondary, derived and estimated from the primary parameters of the cash flow simulation. |
| Sensitivity analysis based on the 'Greeks'. | More complex sensitivity analysis. |
| All options are known in the beginning. | Some options may be acquired during the project. |
| Can be hedged. | Not necessarily ability to hedge. |

There is a set of six variables which affect a value of the financial and real options. An analogy between them is shown in the **Table 2-2.**

.

**Table 2-2: Analogy between financial and real options variables**

*source: the author*

| Var. | Financial options | Call | Put | Real options | Call | Put |
|---|---|---|---|---|---|---|
| ***S*** (or ***V***) | Value of the underlying asset, i.e. current stock price | ↑ | ↓ | (Gross) Present value (PV) of project's cash flows | ↑ | ↓ |
| ***X*** (or ***K***) | Exercise (strike) price | ↓ | ↑ | Implementation cost (CAPEX), i.e. amount of money to be invested or received in launching (exercising) the action (option) | ↓ | ↑ |
| ***σ*** | Standard deviation (volatility) of the underlying asset, i.e. stock price value | ↑ | ↑ | Uncertainty about the future project value (probability distribution) | ↑↓ | ↑↓ |
| ***T*** (or ***t***) | Time until the option expires (maturity time) | ↑ | ↑ | Time until the decision must be made, i.e. until the investment opportunity expires | ↑↓ | ↑↓ |
| ***r*** (or $r_f$) | Risk-free rate of interest | ↑ | ↓ | Risk-free discount rate | ↑ | ↓ |
| ***d*** (or ***D***) | Dividends paid out by the underlying asset | ↓ | ↑ | Dividends like cash outflows or inflows of project over its life-cycle, i.e. value lost over duration of the option | ↓ | ↑ |

For financial options, the relationship between the various input parameters and option value is well defined. In general, increases in volatility and maturity time always raise the option value (↑) no matter is it a call or put. Increase of other four variables has different effect on call and put options, as illustrated in the **Table 2-2**[21]. However, for real options, those relationships are much more complex. In some cases volatility increase after committed investments in the real options may have negative effect (Brach, 2003) (Brosch, 2008). In fact, real options do not value uncertainty, but only value flexibility in response to uncertainty. RO value increases in case of longer life of the option, but it can decrease in case of entry of new competitors in the market.

Furthermore, according to de Maeseneire (2003), when *volatility* is used to determine the upside and downside of the project a constant volatility during the time to maturity is assumed. Especially for long term projects the risk profile may change and when the risk profile changes volatility changes too. According to Mun (Mun, 2010), this is not a must, because the risk can be modelled with two or more uncertainties which can change over time.

Again, according to de Maeseneire (2003), the *risk-free rate (*$r_f$*)* is typically assumed constant over time, but in reality there is no such thing as risk free rate. Assumptions of long term government bond rates are used, but even these bonds change over time.

---

[21] The up (↑) and down (↓) arrows related to the real options is valid only for simple real options (call and put). In case of compound real options consisting of a portfolio of puts (e.g. abandon, contract) and calls (e.g. defer, expand), variables affect the real option value in different ways, depending on the portfolio.

## 2.2. Real options taxonomy

At the beginning, a distinction between ***"simple***" and ***"compound"*** (***"complex"***) real options (RO) shall be made. Simple RO are consisted of solely one real option taken along in a project (e.g. only abandon or only expand). In contrast, compound RO are created by a combination of different types of options (Trigeorgis, 2005). ROV of a simple real option is more straightforward, as there is only one valuation assessment to be carried out. When a combination of (different types of) RO are taken along in a project, each with its own characteristics, the value of the options may **interact** with each other (Trigeorgis, 1993), which may affect the final real option value. This makes the assessment of the (individual) options value more difficult. Interaction effects prohibit calculating the sum of the options assessed as simple options. Brosch (2008) has developed a methodology to analytically assess **real option portfolios** in order to acquire the appropriate value while not ignoring their interaction effects.

***Simple real options***

There is a division to seven categories of simple RO which the author extracted from (Amram & Kulatilaka, 1999), (Trigeorgis, 2002), (Brach, 2003), (de Maeseneire, 2003), (Copeland & Antikarov, 2003), (Mun, 2006), (Brosch, 2008):

**1. Option to defer (wait and see, wait and learn, delay):** Postponing an investment to allow learning can increase the value of a project. More uncertainty about the project outcomes can be resolved. The investor can be given better insight about future financial flows and allow a better decision for commitment to the investment. This is the most common discussed real option throughout academic literature. The lost profit due to later start of cash flow is expressed in the options valuation through dividends. This option is particularly valuable for the projects with high uncertainties and long investment horizons (real estate development, oil, gas, gold mines, etc.).

**2. Business Scope options (alter scale: up → expand and down → contract):** A company can have the choice of expanding or contracting its business activities at sites, depending on the market situation. An example is to build in initial over-capacity to expand activities in case market demand increases, or to (temporarily) shut down certain plants in case of an economic crisis causing significant drops in demand or even more to permanently reduce size of the plant in case of modular, i.e. scalable technologies, such as wind generators and PV modules. In the case study in the **Chapter 4**, contract and repower options are integrated in the model immediately after expiration of the FiT period for wind and PV. In the RES-E projects, a **repower** real option is a special type of the expand option, which is executed by replacement of existing equipment after certain period of technology maturity and thus gaining higher returns due to increased efficiency of the new technology. The repower option is closely related to learning curves concept, which will be discussed in the **Chapter 3**.

CAPEX and OPEX cost mix should be considered when applying the option to contract because it may be preferable to build a power plant with lower initial CAPEX and higher OPEX in order to have the flexibility to contract operations by cutting down OPEX if market conditions become unfavorable.

**3. Staging options (sequential and simultaneous):** If a project remains uncertain, the project can be broken into several "sub-projects". This allows intermediate abandonment of the project in case results are not as expected, while maintaining the options to continue development of the project. According to Mun (2006), the staging options can be divided into simple and complex sequential and simultaneous compound options.

**4. Sourcing options: (switch, vary input/output):** A company can choose to invest into more flexible inputs, where can be changed in case demand favors a switch between possible inputs (process flexibility) or possible outputs (product flexibility). An example of the process flexibility is the choice for a power plant with a flexible burner to switch from oil to coal and vice versa during operation stages. In RES-E, this option can be used for switching between fossil and biomass based fuels in co-firing CHP and/or biomass power plants. Process flexibility can be achieved not only through technology, but also through a sound procurement strategy by maintaining relationships with a numerous suppliers, changing the feedstock mix as their relative rates change. Process flexibility is valuable in feedstock-dependent facilities, such as oil and minerals, electric power, chemicals, refineries, etc. Product flexibility, that enables switching among alternative outputs/products, is more valuable in industries such as pharmaceuticals, consumer electronics, automobiles, toys, or where product diversification is important and/or product demand is volatile.

**5. Learning options:** A company may invest in a project or a pilot plant, which will intentionally result in losses, but can improve the technology and performance. In case of favorable market conditions such technology can be brought promptly to the market, thus providing competitive advantage to its initiator.

**6. Growth options:** This is a similar option to the previous one. A company also may invest in a business which will intentionally result in losses, thus opening the door for multiple follow-up investments in order to turn the assets into a profitable investment, in case of favorable market conditions. This option is valuable for the investments where the micro location of the project is important, e.g. for logistic centres, shopping malls, airports, highways, real estate developments, etc.

**7. Exit options (staged abandon, decommission, temporarily shut down & restart).** Staged abandon is one of the most frequently used real options in sequential (phased) investments. The actual staging of capital investment as a series of costs over time creates valuable options to abandon at any given stage (e.g., in the wind farm development project after unfavorable wind speed result in the start-up phase, or if land availability for PV project is not enough). Thus, each stage (e.g., plant construction) can be treated as an option on the value of subsequent stages by spending the costs required to proceed to the next stage, and can be valued similar to compound options (Trigeorgis, 2002). This option is valuable in long development capital-intensive projects, such as power plants, in pharmaceutical and other R&D intensive industries, in highly uncertain or large scale construction, high-tech start-ups, etc.

A project can be abandoned if the market conditions severely change in comparison to expected. A project or assets can be sold against salvage value or (if possible) used for other purposes. One of recommended ways how to enable exercising abandon option in a project is to integrate it in the contract with other parties involved in the project. Additionally, contracts with suppliers may be concluded on a short term rather than on a long term basis, employees may be hired on a temporary basis rather than permanently, the equipment used for a project may be leased on a short term basis rather than bought. Finally, it is possible that abandoning a project may create costs instead to earn a salvage value in return, e.g. a manufacturing firm may have to pay severance to its workers, for instance. In such cases, it would not make sense to abandon, but to find another exit strategy.

Staged abandon during the project development as well as abandon for salvage value real options have been applied in the case study (**Chapter 4**).

Temporarily shut down and restart real option is one of common cases in power plant industry, e.g. it might be better to shut down the plant temporarily if electricity prices are not sufficient to cover variable operation costs (e.g. maintenance), especially if the costs of switching between the operating and idle modes are relatively small. If electricity prices rise sufficiently, operations can start again. Due to different support schemes available in RES-E projects, option to temporarily shut down is not of high importance, but it can be applicable in hybrid power plants, e.g. CCPP[22] & Wind farm, or CCPP & CSP[23], etc.

[22] CCPP (Combined Cycle Power Plant) or CCGT (Combine Cycle Gas Turbines) is a technology which uses combination of gas and steam turbines for electricity and heat generation. A hybrid system consisting of CCPP, Wind and/or CSP technologies has high flexibility, because former system uses natural gas as a fuel and latter two systems use renewable sources (wind, solar). When the ratio between gas and electricity price is unfavorable, CCPP can be temporarily shut down, so wind and/or CSP will continue electricity generation. The latest generation of CCPP plants have short start-up and shut-down period, which is importance for valuation of this real option.

[23] CSP (Concentrated Solar Power) systems use lenses or mirrors to concentrate a large amount of solar thermal energy, onto a small area. Electrical power is generated when the concentrated light is converted to heat, which drives a steam engine or a steam turbine, connected to an electrical power generator.

The real options can be also categorized as a put or call type of option, as shown in the **Table 2-3**.

**Table 2-3: Real options as Put and Call options**

| Option | Real option |
|---|---|
| Call | Option to wait<br>Option to alter scale (expand)<br>Option to vary (switch)<br>Option to grow |
| Put | Option to abandon<br>Option to alter scale (contract)<br>Option to vary (switch) |

The option to vary can be a call or a put option depending on whether the variation is used to minimize losses (put option) or to increase benefits (call). The same holds for the option to alter scale.

***Compound real options***

If the company wants to have a flexible strategy by using real options, it is most likely they will incorporate more options in form of compound options into a single project. It can make valuation more difficult, and requires more focus on the RO implementation and monitoring processes.

The most frequent case of compound options are multi-phased sequential options with nesting (e.g. expand, contract and abandon, which are mutually exclusive (see **Figure 2-2**) and simultaneous compound options when the value of the project depends on the success of two or more investment decisions executed in parallel in time.

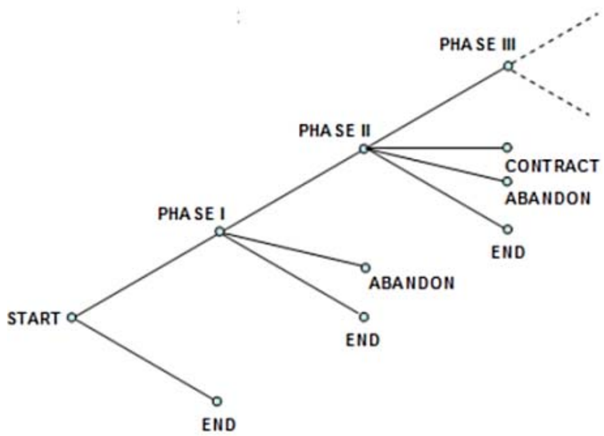



**Figure 2-2: Multi-phased nested compound real options**
*source: (Mun, 2006)*

Besides sequential option, the most applicable real options in RES-E projects are: to defer, to alter scale (expand and contract) and to abandon, as well as their combinations, as it will be presented in the case study in the **Chapter 4**.

According to Trigeorgis (1993), interactions among options can be small or large, negative or positive. They depend on the type (call/put, American/European, etc.), separation (which options at which time), moneyness (in, out, at the money) and the order of the options involved. In the case study (**Chapter 4**) we have examined valuation of multi-phased sequential compound (nested) mutually exclusive path-dependent real options and their interactions.

Some authors, e.g. Brosch (2008), call these combination of options – portfolio. He also made distinction between combination of real options within a project (portfolio of options) and combination of different projects within a project portfolio. Besides examination of portfolio of real options, at the very end of case study in the **Chapter 4**, it will be also demonstrated an optimization of the project portfolio (consisting of six wind and six PV projects), by valuing returns at risk and their ranking according to the *efficient frontier* method and the *Sharpe ratio*.

## 2.3. ROV vs. DCF (NPV)

One of main shortcomings of DCF is that it doesn't consider uncertainty and variability of the future outcomes, which are mainly risky and stochastic in their nature. The discounted rate (r) which is a constant value, completely justifies all risks in the DCF model, although, in reality, project risks may vary during the project life cycle.

In fact, due to ignoring of uncertainties which may arise during the project life, DCF method implicitly ignores an arsenal of various strategic real options available to the management as a response to such uncertainties, which can be quantified through volatility of the cash flow during the project life cycle. Some of the commonly used real options are options to defer, to expand, to switch, to contract and to abandon, as well as their combinations in the form of compound options. These options may increase the project value, by adding value of the option to the static NPV obtained through traditional DCF approach[24]. Namely, in situations when DCF undervalues the project, management can decide to expand the project in order to maximize returns, and in contrast – when DCF overvalues the project, management can decide to abandon the project, and minimize the loss, as illustrated in the **Figure 2-3**.

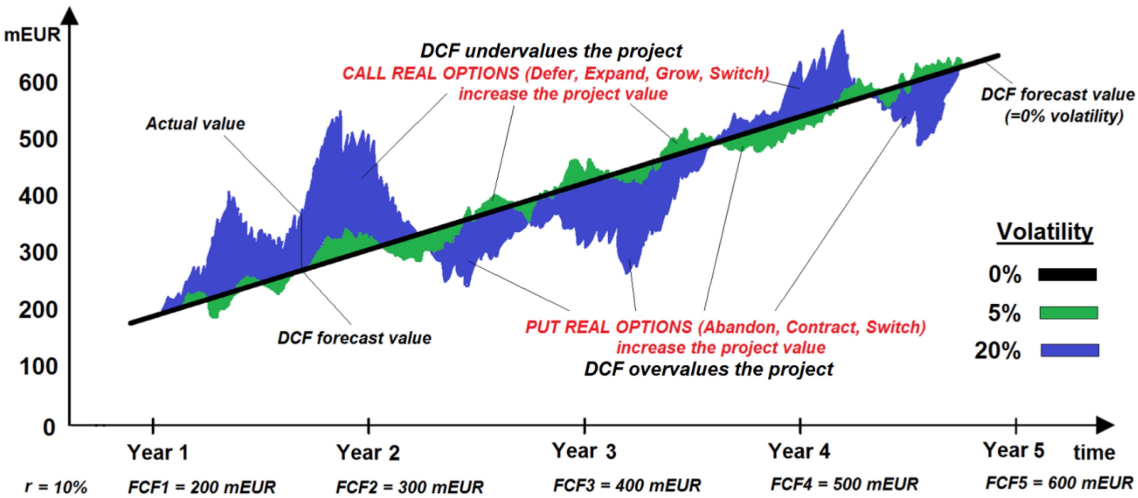



**Figure 2-3: Basic advantages of ROV over DCF approach**

*source: the author, adapted from (Mun, 2006)*

As shown in the **Addendum 1**, where traditional project valuation methods are discussed, DCF expressed via NPV recognizes two variables in respect to the options model: benefits (present value of the project, i.e. underlying asset value) and costs (implementation costs, or strike price X). The other four variables which are used in the financial and real options theory ($t$ - time to maturity, $\sigma$ – volatility, $r_f$ - risk free rate and $d$ – dividends) are not recignized by NPV.

[24] For details see Addendum 1: Traditional approaches in project valuation with the focus on DCF.

NPV and RO value are identical when decision can no longer be deferred, because when $t$=0, $\sigma$ and $r_f$ do not affect call option value, as only $S$ and $X$ matter. At the expiration, call option value is either $S$-$X$ or 0, whichever is greater, therefore:

$$NPV = \text{Present Value of the project } (S) - \text{Implementation costs required } (X)$$

In other words, this means that DCF method implicitly neglects strategic opportunities which may arise as a management response to project uncertainties and which may increase the project value. Due to that, management must rely on their intuition in investment decision making process. However, by assigning quantifiable values to uncertainties, ROV enables decision makers to measure risk and react accordingly over time in order to downsize it (or to upsize it in case of opportunities), which implies that the ROV recognizes the value of learning. Therefore, RO model captures the basic (static) NPV originated from the DCF model, plus managerial flexibility value over the option's life by considering $t$, $\sigma$ and $r_f$ (and alternatively $d$) in the ROV, thus providing strategic or **expanded NPV (eNPV)** of the project:

$$eNPV = NPV + RO\ value$$

Project value obtained in that way reduces need to rely on intuition in the investement decision making process. Actually, a key advantage of ROV is that it is a gradual improvement, inherently incorporating DCF (Copeland & Antikarov, 2003). That improvement is reflected in transformance of higher risk and lower returns in DCF model to lower risk and higher return in RO model, as illustrated in the **Figure 2-4**:

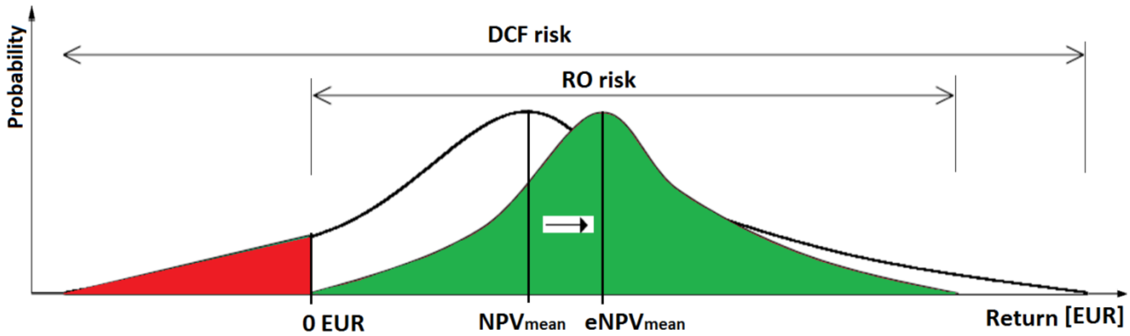



**Figure 2-4: DCF and RO – risk return comparison**
*source: modified from (Mun, 2006)*

The rationale behind is that all downside risks (red filed) in DCF model are reduced in RO model, because the project would not be executed in that case, but only in the case when the upside risks (opportunities) are expanded i.e. maximized in a way that the returns are increased.

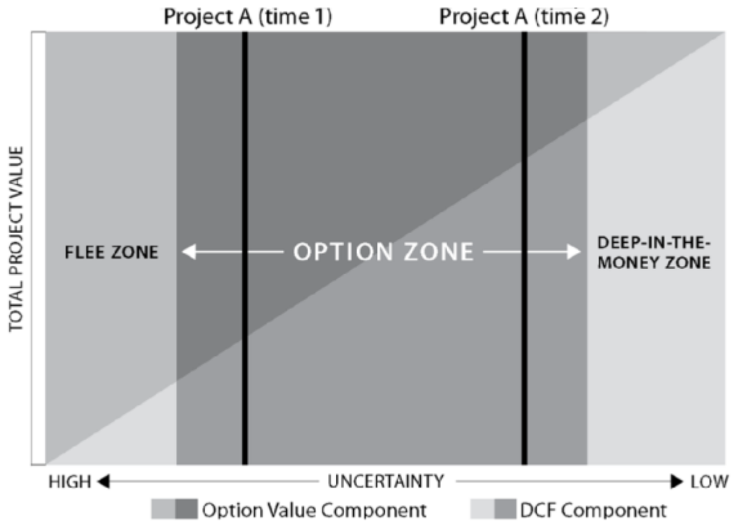
Furthermore, instead of **eNPV**, Van Putten and MacMillan (2004), introduced a new term - **Total Project Value (TPV)**, as a sum of static NPV, adjusted option value (AOV) and abandonment value (ABV), depicted as:

$$TPV = NPV + AOV + ABV$$

If cost volatility exceeds revenue volatility, then the AOV should be calculated with *adjusted volatility*[25], as follows:

***adjusted volatility = project volatility x (revenue volatility / cost volatility)***, otherwise ***adjusted volatility = project volatility***.

According to them, ABV is always present in the real options valuation as a generic option put (i.e. abandon) option, because managers can always exercise it as a hedge against drops in the price of the underlying asset. Abandonment value can arise in a number of ways, e.g. early investment that have to be abandoned can be valuable to another business unit within the same company.




.

**Figure 2-5: The option zone concept**
*source: (Van Putten & MacMillan, 2004)*

To make TPV value more depictive, they created so called ***option zone*** chart. Depending on the project's uncertainty, the TPV can be placed in one of three zones: ***flee zone***, ***option zone*** and ***deep-in-the-money zone*** (**Figure 2-5**). The greater the uncertainty, the larger the option component and the smaller the DCF component. In fact, when the TPV is consisting of almost entirely of option value and the NPV is highly negative, the project falls in the *flee zone* — the zone filled with projects far too risky to consider. Conversely, when uncertainty is very low, a project's TPV will be located in the *deep-in-the-money* zone and made up almost entirely of DCF value – which means that ROV isn't necessary, if the project has positive NPV. Between these two zones there is the *option zone*, from where we extract values option values. It is here that traditional DCF clashes with management intuition, so it becomes important to compute both the NPV and the AOV of a project. In this example, ***Project A*** (depicted by the solid vertical lines) is in the *option zone*. As ***Project A*** progresses, uncertainty

[25] This was considered in the case study (Chapter 4).

should be reduced, so the vertical line should move to the right, which implies increase of the DCF component and decrease of the RO value component.

Nevertheless, the option value cannot be generated without managerial flexibility as response to the project's uncertainty. **Addendum 6** explains in detail when managerial flexibility is relevant to ROV.

## 2.4. Real options implementation issues and limitations

ROV is a very dynamic valuation method. According to Brach (2003), it works best if used consistently throughout the organizations that encourage brainstorming discussions and risk management culture, and if integrated well with other, complementary financial and strategic tools. Real options have a natural life-cycle which has to be closely followed and observed, as defined by Mun in the IRMP approach (Mun, 2006) and (Mun, 2010). Some of the companies that had little success with the real option method implementation in their organizational structure and abandoned it in frustration did so because either wrong risk modeling (due to too few data or misunderstanding of the modelling process) or due to wrong organizational setup (e.g. inconsistent application of the framework).

In most of cases, CEOs intuitively understand value of flexibility embedded in RO – but there is a misunderstanding by CFOs that get precedence to static DCF analyses.

CEOs are aware that the company will miss opportunities if they ignore option value:

- in screening investment opportunities, low risk projects have priority over higher flexibility projects with increased risk
- in tender competition - a bidder needs to know full value of investment opportunity (e.g. in bidding for getting exploitation permits for new oil fields).

From the author's point of view, the key factor of successful implementation of real option valuation in a corporation which invest in capital projects lays in a proactive cooperation between CEO and CFO, i.e. between departments responsible for corporate strategy, finance and capital project management. Much useful information which can be used in real options valuation remains unused in corporate cabinets and hard drives. That's why a proactive data collection and data warehouse system is of high importance to capture benchmarks on historic and on-going projects which can be used in risk modeling for ROV. Another issue for successful implementation of real options within organization is to encourage decision makers to think flexibly in response to uncertainties which are incorporated in the project from the beginning, but also might pop-up during the project execution and operation. Nevertheless, in order to implement the real options methodology within an organization, the one should be aware of its limitations especially in case of sequential compound real options.

According to their empirical research on the use of real options in organizations, Adner and Levinthal (Adner & Levinthal, 2004), identified "real options traps" that hinder the abandonment of opportunities, as shown in the **Table 2-4**.

**Table 2-4: Real options traps**
*source: (Adner & Levinthal, 2004)*

| | **Target market fixed** | **Target market flexible** |
|---|---|---|
| **Technical agenda fixed** | Option trap: In the absence of expiration, the firm can maintain the option indefinitely until conditions improve. Maxim: "Things will get better". | Option trap: negative market signals may lead to a search for new potential markets or market interventions rather than abandonment. Maxim: "We can try it somewhere else". |
| **Technical agenda flexible** | Option trap: further development efforts always hold the potential for overcoming any negative market signal. Maxim: "We can try harder". | Option trap: too many degrees of freedom for ruling out success. Maxim: "We can make this work". |

Furthermore, Copeland and Tufano (2004), recognizes two critical situations in RO implementations, opposite to each other by their nature:

- "Falling asleep" i.e. when managers (option holders) are asleep and don't exercise RO at the right time, which affects the RO value destruction, and
- "Itchy finger trigger", i.e. when managers exercise RO too quickly, i.e. on the first positive market signal.

Option theory implies that the higher the volatility the higher the loss will be in both cases - for exercising too slowly or too quickly.

There are two sources of RO limitations – theoretical, i.e. academic and practical, i.e. organizational (corporative).Academic limitations refer to the transferability of financial options features (such as non–tradable underlying assets, incomplete markets, asset twin security) to real options theory. Detailed discussions on these issues can be found, in (Wang & Hallal, 2010), (Mun, 2006), (Smit & Trigeorgis, 2004), (Borison, 2003), (Trigeorgis, 1996), (Smith & Nau, 1995).

On the corporate level, main opponents of RO are CFOs, as pointed out by Van Putten and MacMillan (2004): "For all their theoretical attractiveness as a way to value growth projects, real options have had a difficult time catching on with managers. CFOs tell us that real options overestimate the value of uncertain projects, encouraging companies to over-invest in them. In the worst case, they grant excessively ambitious managers a license to gamble with shareholder's money."

On the other side, as stated by Alexander J. Triantis[26]: "It took decades for NPV to become widely accepted in practice. The real options is an even more sophisticated tool. It's going to take few decades in order to be well integrated in corporations".

[26] Quotation from "Will Real Options Take Root?", CFO.com, July 1, 2003.

That is the reason why a proactive cooperation between CEO and CFO as well as easy understandable frameworks proven in practise (such as IRMP) and availability of advanced software tools (such as Crystal Ball, Risk simulator, SLS) that cope with ROV, are of the key meaning for successful real option adoption and implementation in corporate capital budgeting and strategy.

# 3. RISK ASSESEMENT IN RES-E PROJECTS WITH FOCUS ON PV AND WIND

As it was mentioned in the **Chapter 1**, in the last decade RES-E became one of the fastest growing industrial sectors in the world, with a total annual investment volume of USD 250 billion in 2011.

RES-E investment projects have certain features which makes their valuation a bit different than valuation of conventional energy projects.

As the subject of this work is closely related to the risk and uncertainties, in this chapter we will discuss on RES-E projects features from the risk assessment point of view, with a focus on PV and wind power plant projects.

Risk mitigation and risk transferability measures in RES-E projects such as use of variety of insurance policies, financial derivatives (options, swaps, futures), SPV[27], etc., are out of the scope of this work. For more on these topics, the author recommends "Managing the risk in renewable energy" (The Economist Intelligence Unit, 2011) and "Risk quantification and risk management in renewable energy projects" (Altran & Arthur D. Little, 2011).

The risk mitigation in terms of real options will be demonstrated through the strategic real options implementation in the business case in the **Chapter 4.2**, which follows the IRMP framework.

---

[27] SPV – special purpose vehicle

## 3.1. RES-E project features

***Comparison of RES-E vs. conventional energy projects***

RES-E projects have relatively short track record in comparison to mature conventional energy projects based on fossil resources (coil, oil, gas).

**Table 3-1** shows comparison of key project features of RES-E and conventional energy power plant projects. Non-quantifiable criteria are ranked as high/medium/low.

**Table 3-1: RES-E vs. conventional energy power plant project features**

*source: the author*

| **Feature** | **RES-E** | **Conventional** |
|---|---|---|
| Source of energy | renewables | fossil |
| Local availability of energy sources | high | low |
| Impact to environmental pollution | low (manufact.) | high |
| Project development time | ≤ 3 years | ≥ 5 years |
| Operational life (average) | 25 – 30 years | 10 – 30+ years |
| Plant efficiency (electricity) | low | high |
| CAPEX volume range (EUR) | 100k – 100m | > 100m – 10b |
| O&M costs | low | high |
| Cost dependence on learning curve | high | low |
| Dependence on government subsidies | high | low |
| Modularity and scalability of technology | high | low |
| Sensitivity to project technical uncertainties | high | medium |
| Sensitivity to market (public) uncertainties | high | high |
| Sensitivity to oil/gas/coil prices variation | medium | high |
| Sensitivity to electricity prices variation | high | medium |
| Sensitivity to delay in completion | high | medium |
| Sensitivity to weather changes during oper. | high | low |
| Sensitivity to feedstock i.e. fuel reserves | low (biotech.) | high |
| Level of technical standards development | medium | high |
| Level of abandonment and sunk costs | low | medium |

***Discount rates in RES-E projects***

As already mentioned in the **Chapter 2** (incl. **Addendum 3**), discount rate is one of the best indicators of the level of risk in investment projects. In RES-E projects finance, different type of projects bear different risks, which is reflected in different discount rates. In the report prepared for the Committee on climate change (Oxera, 2011), it is shown how the discount rates can develop in period 2011-2040, depending on level of risk (low / high) of the particular project per each of RES technologies. Due to better understanding, low carbon technologies (CCGT and Nuclear) also shown in **Table 3-2**.

**Table 3-2: Discount rates[28] for low-carbon and RES-E technologies**

*source: (Oxera, 2011)*

| Technology | Risk perception | 2011 | | 2020 | | 2040 | |
|---|---|---|---|---|---|---|---|
| | | Low | High | Low | High | Low | High |
| **Hydro** | low | 6 | 9 | 6 | 9 | 5 | 8 |
| **Solar** | low | 6 | 9 | 6 | 9 | 5 | 8 |
| **Wind on-shore** | low | 7 | 10 | 6 | 8 | 5 | 8 |
| **Wind off-shore** | medium | 10 | 14 | 7 | 14 | 6 | 13 |
| **Biomass** | medium | 9 | 13 | 6 | 11 | 6 | 8 |
| **Wave** | high | 10 | 14 | 7 | 14 | 6 | 13 |
| **Tidal** | high | 12 | 17 | 9 | 17 | 7 | 16 |
| **CCGT** | low | 6 | 9 | 6 | 9 | 5 | 8 |
| **Nuclear (new build)** | medium | 9 | 13 | 8 | 11 | 6 | 9 |

Currently, more mature RES-E technologies (hydro, solar, wind on-shore) have lower discount rates than technologies under development (wind-off-shore, wave and tidal), but this discrepancy will be reduced in coming years, due to technological learning.

The share between equity and debt in RES-E projects is most commonly 70% (debt) : 30% (equity), regardless the level of the risk assessment (high / low). Although the expected market rate of return is higher for more risky projects, the risk premiums are also higher, which reflects the higher discount rates in total, as shown in the study (Ecofys, Fraunhofer ISI, TU Vienna EEG, Ernst&Young, 2011).

**Table 3-3: Example of WACC calculation in RES-E projects**

*source: (Ecofys, Fraunhofer ISI, TU Vienna EEG, Ernst&Young, 2011)*

| WACC methodology | Abbreviation / Calculation | High risk assessment | | Low risk assessment (proactive risk mitigation) | |
|---|---|---|---|---|---|
| | | Debt (d) | Equity (e) | Debt (d) | Equity (e) |
| Share equity / debt | g | 70.0% | 30.0% | 70.0% | 30.0% |
| Nominal risk free rate | $r_n$ | 4.0% | 4.0% | 4.0% | 4.0% |
| Inflation rate | $i$ | 2.0% | 2.0% | 2.0% | 2.0% |
| Real risk free rate | $r_f = r_n - i$ | 2.0% | 2.0% | 2.0% | 2.0% |
| Expected market rate of return | $r_m$ | 4.3% | 8.4% | 3.9% | 7.7% |
| Risk premium | $r_p = r_m - r_f$ | 2.3% | 6.4% | 1.9% | 5.7% |
| Equity beta | $b$ | | 1.6 | | 1.6 |
| Tax rate (corporation tax) | $r_t$ | | 30.0% | | 30.0% |
| Post-tax cost | $r_{pt}$ | 3.0% | 12.2% | 2.7% | 11.1% |
| Pre-tax cost | $r = r_{pt} / (1-r_t)$ | 4.3% | 17.5% | 3.9% | 15.9% |
| **Weighted average cost of capital** (pre-tax) | ***WACC*** | **8.3%** | | **7.5%** | |

[28] real, pre-tax, in %

***Learning curves***

When we discuss on main features of RES-E technologies as well as setting of their subsidy prices, it is inevitable to discuss **learning and experience curves.**

In 1936, Theodore Wright presented observations of regularity in cost reduction as planes were manufactured at Boeing (Heutte, 2012). Further studies in industrial manufacturing found similar "learning effects" and became known as the "learning curve," usually expressed as a constant cost reduction per doubling in cumulative production. The effect is usually expressed as the "learning rate" (LR) or percentage reduction per doubling in cumulative production, or the "progress ratio" (PR), which is reduction relative to the previous period. These are identities; a 20% LR is the same as 80% PR. Both LR and PR parameters continue to be used in the literature.

In the 1960s, especially with influential studies by the Boston Consulting Group (BCG), the learning curve concept was expanded from assessment of single-firm product learning curves to industry wide assessments, and the term "experience curves" came into use. While the terms have still been used somewhat interchangeably, because we are looking at global product categories it is more appropriate to use the term "experience curve" in this context. One of most depictive examples of learning curves in RES-E technologies is for PV technologies (**Figure 3-1**).

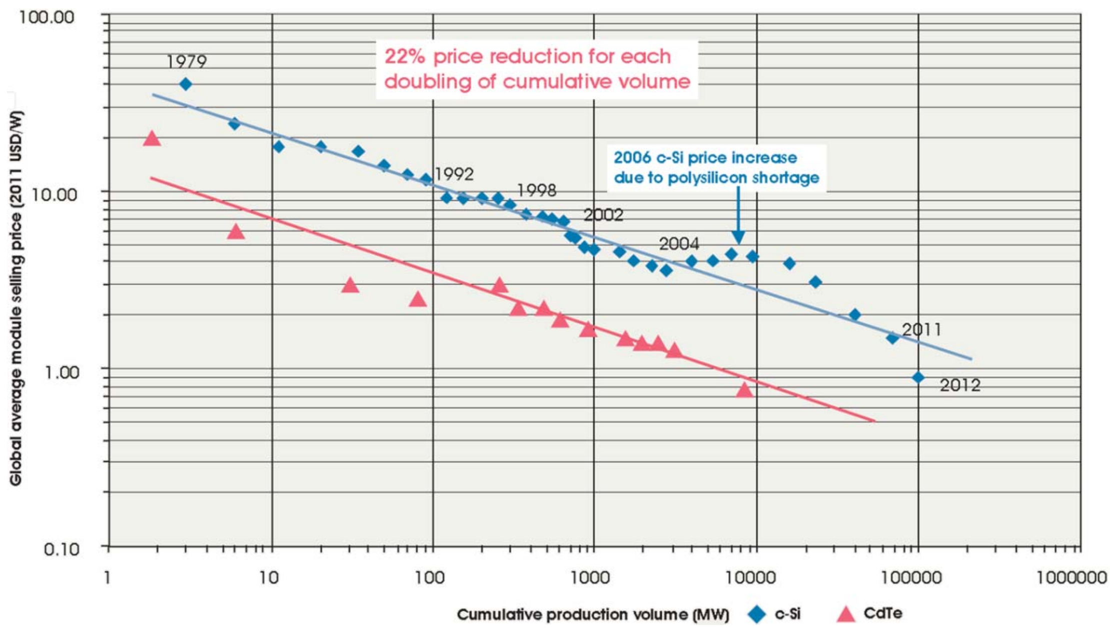



**Figure 3-1: Learning curves for PV technologies**
*source:* (IRENA, 2013)

Nevertheless, unlike their popularity of application in RES-E cost estimation, there are important conceptual and practical limitations in the learning curves use for technology policy analysis, since the future development of RES-E technologies is likely to be different from their progress in the past.

*Specific features of PV and wind projects from risk assessment point of view*

Specific risks associated with wind farm and PV projects can be summarized as follows:

**Table 3-4: Risks in PV and Wind projects**

| Risks | Wind | PV |
|---|---|---|
| **(1) Political and long-term investment security risks,** due to: government instability, frequent elections, changes in legislation, changes of macroeconomic factors such as x-rate, interest rates, inflation, terms of trade, corruption index, etc. | **high** | **high** |
| **(2) Support scheme risks,** due to: reduction of benefits which come from subsidized measures such as FiT, TGC, investment subsidies, tax incentives, tender schemes, and/or reduction of subsidized period or even introduction of moratorium on further supports, etc. | **medium (on-shore)** **high (off-shore)** | **high** |
| **(3) Financial risks,** due to: difficulties in access to capital, keeping a stable DSCR[29] during the debt period, etc. | **high** | **high** |
| **(4) Market risks,** due to: increase in number of competitors, increase in commodity prices such as steel for WTG and silicon wafers for PV, decrease of electricity prices if the plant is not covered by support schemes, etc. | **medium (on-shore)** **high (off-shore)** | **medium** |
| **(5) Weather-related volume risk,** due to: lack of wind or solar irradiance during operation in comparison to projected values, etc. (depends on quality of the wind measurement at site) (reliable data available for Europe, e.g. PVGIS) | **high** | **low** |
| **(6) Environmental risks,** due to: liability for environmental consequences such as increased noise, increased mortality rate of birds, bats and game animals, shadowing, ice-throw and ice-fall (wind farms), land availability due to arable land (PV plants), landscaping issues, and restricted zones such as archeological sites, national parks (both wind farms and PV plants), etc. | **high (on-shore)** **medium (off-shore)** | **low** |
| **(7) Construction and grid integration risks,** due to: absence (or use of an invalid) procurement and contracting strategy, use of obsolete wind and PV technologies, site accessibility (e.g. on-shore WTG blades), difficulties in foundation and cabling (e.g. | **medium (on-shore)** **high (off-shore)** | **low** |

[29] DSCR – debt-service coverage ratio

| | | |
|---|---|---|
| in off-shore wind farms), natural hazards, etc. | | |
| **(8) Operational risks,** due to: use of unproven technologies, temporarily or permanent shut down of the plant due to high intermittency or resource unavailability or the plant component failure, etc. | **medium (on-shore)**<br>**high (off-shore)** | **medium** |

Weather-related volume risks and operational risks can be additionally named as technology performance risks. They refer to the revenue/cost risks which are outcome of the uncertainties in the electricity generation, due to intermittency of the energy sources as well as overall efficiency of the specific technology.

Support scheme risks refer to the revenue/cost risks which are outcome of the uncertainties in the development of different support schemes by respective country government.

Assessment of political, environmental, financial, market and other external risks is out of the scope of this work. In further text, we will make a detailed analysis of technology performance risks and support scheme risks in RES-E projects, with the focus on PV and wind technologies.

## 3.2. Technology risks and uncertainties in PV and wind projects

Impact of the technological risks in PV and wind projects valuation depends on numerous uncertainties, which can be divided into two categories: resource (wind, solar) uncertainties and power production uncertainties.

As already mentioned in the **Table 3-4**, weather data reliability for the wind projects is one the key risks for the overall electricity generation. Unlike the solar irradiance data which is one of the key inputs in solar yield calculation in the PV projects, and which is mainly available for the whole Europe on a high level of accuracy (e.g. PVGIS and national databases), situation with the wind measurement data is quite different – due to lack of centralized registry of the wind speed data in many of European countries. Accuracy of wind speed at the site coupled with the WTG manufacturer's power curve are main uncertainties for the wind energy yield estimation, and thus for the revenue risk.

Intermittent nature of its resources in comparison to other RES-E projects, ranks wind and PV projects into risky projects from generation efficiency i.e. revenue point of view. This is illustrated in the **Figure 3-2** from the Fraunhofer Institute report for electricity production from solar and wind in Germany in 2012 (Fraunhofer: Burger, Bruno, 2013). The sum of PV and wind power in Germany up to now was always smaller than the installed power of the single sources. It is also clear that PV and wind technologies complement one another in a high degree – wind blows during day and night equally, but more during colder months (Jan, Feb, Mar, Oct, Nov, Dec), while PV doesn't generate electricity during night and it has much higher production during sunny months (Apr, May, Jun, Jul, Aug, Sep).

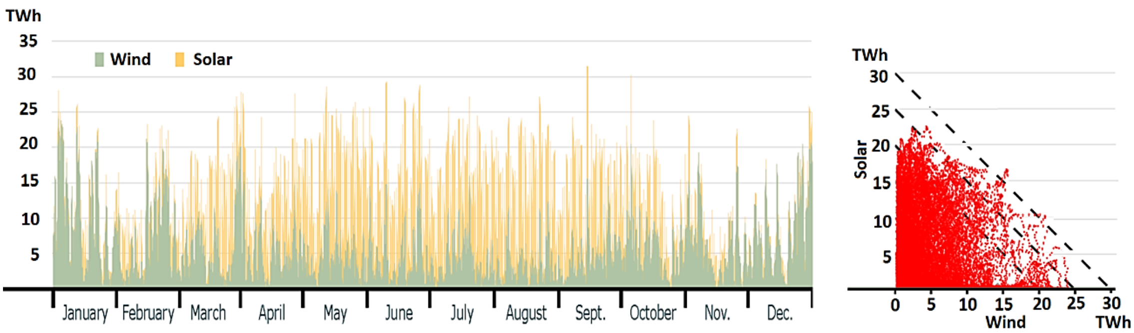



**Figure 3-2: Intermittency and complementarity of solar and wind technologies**
*source: (Fraunhofer: Burger, Bruno, 2013)*

The author finds interesting to note that one of the latest trend in weather-related volume risks hedging is use of derivatives. In that regard, Celsius Pro AG, a Zurich-based originator of the OTC weather derivatives, offers Low Wind Day and Low Wind Season certificates. Similar options are provided by Swiss Re Corporate Solutions (Raizada, 2013).

## *Photovoltaics*

**Photovoltaics (PV)** is a technology where the sunlight is directly converted to DC, thankfully to the photoelectric effect[30]. The energy of the photon of light is determined by its wave length in nanometers, where shorter wavelengths have higher energy and vice versa. In the **Figure 3-3 left**, the “green area” denotes waveleengths (280 – 1.100 nm) and spectral irradiance (0 – 1 W/m$^2$/nm) for silicion based PV cells which can be used for PV electricity generation. The largest portion of the area belongs to infrared spectrum, smaler portion is in visible spectrum, while a very small portion is in UV (ultraviolet) spectrum. Theoretical maximum efficiency of a single PV cell is 31%, but, according to NREL, has been increased in the laboratory to max 44% by producing PV cell made up of multiple layers, tuned to different wavelengths, thus harnessing whole “green area” spectrum. Currently, at the market there are available 22% efficiency PV cells, which implies efficiency of a PV module of ca. 20% due to internal losses, which further implies efficiency of ca. 18% of a PV plant built with these modules. The efficiency is lower due to system losses – inverter losses during DC to AC transformation, cable losses, temperature losses, grid connection losses, etc. Efficiency of each of four available types of PV cells today (monocrystaline, polycrystaline, thin film[31] and organic[32]) is shown in the **Figure 3-3, right**.

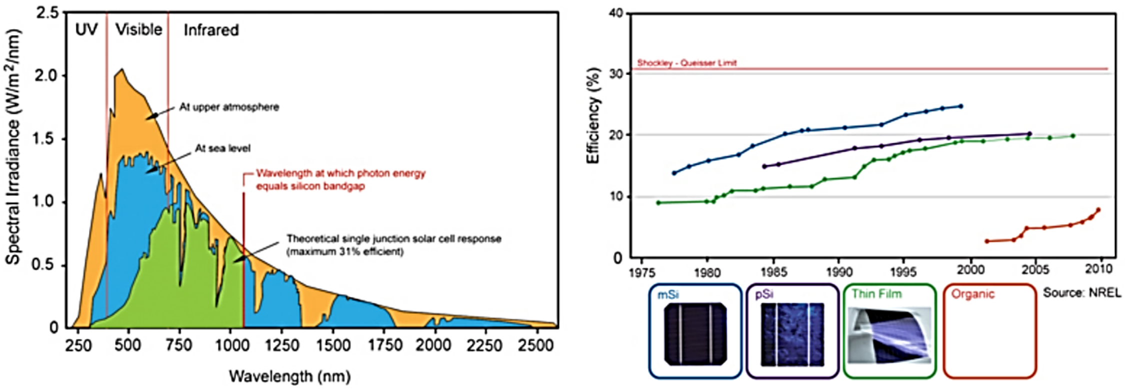



**Figure 3-3: Sunlight energy spectrum (left) and PV cells efficiency (right)**
*source: NREL*

Besides these four technologies, there is a concentrated PV (CPV) technology under development, which is expected to have cell efficiency of ca. 40%.

Due to better overview, the latest figures on technical performance and costs by PV technologies are shown in the **Table 3-5**.

---

[30] In the photoelectric effect, electrons are emitted from solids, liquids or gases when they absorb energy from light. Electrons emitted in this manner may be called photoelectrons.

[31] Thin film technologies are: (1) a-Si (amorphous silicon) and μ-Si (micromorph silicon multi-junctions), (2) CdTe (Cadmium Telluride), (3) CIS or CIGS (Copper Indium Gallium Selenide).

[32] Organic technologies are: (1) hybrid dye-sensitized solar cell (hDSC) and (2) polymer based cells.

**Table 3-5: Technical performance and costs by PV technology**
*source: (IEA-ETSAP & IRENA, 2013)*

| Technical performance | Typical current international values and ranges | | | | | |
|---|---|---|---|---|---|---|
| Energy input/output | Sunlight/ Electricity | | | | | |
| **Current PV technologies** | **Crystalline Si** | | **Thin Film** | | | **CPV** |
| | **sc-Si** | **mc-Si** | **a-Si/m-Si (m-SiGe)** | **CdTe** | **CI(G)S** | |
| Max. (record) cell efficiency, % | 22 (24.7) | 18 (20.3) | 10 (13.2) | 11.2 (16.5) | 12.1(20.3) | (>40) |
| Max. module efficiency, % | 19-20 | 15-16 | 9 | na | na | na |
| Commercial modules effic., % | 13-19 | 11-15 | 7-9 | 10-11 | 7-12 | 20-25 |
| Land use, $m^2$/kW | 6-8 | 7-9 | 11-15 | 9-10 | 9-15 | na |
| Lifetime, yr | 25 (30) | | 25 | | | na |
| Energy payback time, yr | 1-2 | | 1-1.5 | | | na |
| Material use, g/W | 5-7 | | na | | | na |
| Wafer thickness, µm | <180-200 | | na | | | na |
| Market share, % | ~85 | | ~15 | | | na |
| Typical size (capacity), kW | Residential < 10 kWp; Commercial < 100 kWp; Industry 100Kwp -1MWp; Utility > 1MWp | | | | | |
| Total cumulative capacity | 1.4 GW (2001), 23 GW (2009), 40 GW (2010), 70 GW (2011) | | | | | |
| Annual installed capacity | 2.8 GW (2007), 5.9 GW (2008), 7.2 GW (2009); 15 GW (2010); 30 GW (2011) | | | | | |
| Capacity factor, % | From 9-16% (in most favourable locations), based on annual electricity production | | | | | |
| CO2 emissions, $gCO_{2eq}$/kWh | Occurring during manufacturing only - between 12-25 $gCO_{2eq}$/kWh | | | | | |
| Avoided $CO_2$ emissions | ~ 600 $gCO_{2eq}$/kWh (based on electricity mix in developed countries); up to 900 $gCO_{2eq}$/kWh in countries with coal-based power generation. | | | | | |

| Costs By technology | Typical current international values and ranges (2012 USD, 1EUR = 1.3 USD) | | | | |
|---|---|---|---|---|---|
| | **Crystalline Si** | **Thin Film** | | | **CPV** |
| | **c-Si** | **a-Si/µ-Si; (µ-SiGe)** | **CdTe** | **CI(G)S** | |
| Module cost, \$/kW (2012)[1] | 880-1140 | 650-750 | 770-1000 (1500) | 770-1000(1500) | 3100-4400 |
| BoS cost, \$/kW (2012) | 820-1660 (best practice to global average) | | | | |
| O&M cost | Estimated at 1% of the investment cost per year | | | | |
| Typical cost breakdown | PV module 50-60% (TF-c-Si); Inverter 10-11%; BoS & Installation 32-23%; E&P 7% | | | | |
| By applications | Residential systems | | Commercial systems | Utility systems | |
| System cost, \$/kW | 2200 – 4500 | | 1900 - 2500 | 1700 – 2100 | |
| Electricity cost[2], \$/MWh | 190-200[3] | | 130-160[4] | 100 -150[5] | |
| Cost projections 2016 | Residential systems | | Commercial systems | Utility systems | |
| Module cost, \$/kW | 920 (c-Si) -950 (TF) | | | | |
| BoS cost, \$/kW | 1200-1600 (global average) | | | | |
| Electricity cost, \$/MWh | 150 | | 110-130 | 80-140 | |
| Market share projection | 2030 | | | 2050 | |
| Global electricity share, % | 2-3.3% (IEA,2012); 4.9-5.7% to 7.8-9.1% (EPIA,2012) | | | 17-21% (EPIA,2012) | |

1 Sources: www. Sologico.com – 2012; Photon Consulting 2012; (overall TF module cost)
2 25-year lifetime, 10% interest rate, 1%/yr O&M cost
3 With reference to the US and Japan markets,
4 With reference to Italian and German market
5 With reference to Chinese and US markets

More serious source of uncertainty in PV technologies is efficiency loss due to potential induced degradation (PID). It is a phenomenon where leakage of electrical current from the solar cell to the panel frame drives ion migration, which modifies the electrical characteristics of the solar cell and degrades the panel's power output during its life time. Temperature, humidity and voltage all accelerate this process.

In the **Addendum 7**, a datasheet of one the most efficient mono-crystalline PV modules available in the market (Sunpower E20, models SPR-333 and SPR-327) is shown. The E-20 modul has the PID of 5% only, which is much better than global average of 20% for standard PV modules.

PV cell efficiency of the SPR-333 model is 22,8%, the module (panel) efficiency is 20,4%, and the nominal power is 333 W/module, with the output range (error) of +5% / - 0%, which is not critical source of uncertainty in this case, as the risk for underproduction is 0%.

### *Wind*

Wind is air in motion. Kinetic energy from the wind can be converted to different forms of useful energy by using different technologies, such as wind turbine generators (WTG) for electricity generation, windmills for mechanical energy, sails to propel ships or wind pumps for water pumping and/or drainage.

The key driver of the wind power generation is wind speed. The formula for kinetic energy is $\boldsymbol{E = \frac{1}{2} * m * v^2}$

Mass of the wind $\boldsymbol{m}$, with a density $\boldsymbol{\rho}$ flowing through an imaginary circle area ***A (= d*π)*** during the time $\boldsymbol{t}$, can be denoted as:

$\boldsymbol{m = \rho * d * \pi * v * t}$ ,

which implies the total wind energy produced by a WTG with total efficiency $\boldsymbol{c_p}$ (also known as power factor), as:

$$\boldsymbol{E = \frac{1}{2} * \rho * d * \pi * v * t * v^2 * c_p = \frac{1}{2} * \rho * d * \pi * t * v^3 * c_p,}$$

and out of that, the wind power can be denoted as:

$$\boldsymbol{P = \frac{E}{t} = \frac{\frac{1}{2} * \rho * d * \pi * t * v^3 * Ce}{t} = \frac{1}{2} * \rho * d * \pi * v^3 * c_p}$$

Therefore, wind energy generation is proportional to the 3rd power of the wind speed, which means that available power increases eight times when the wind speed doubles.

In general, wind speed depends of four factors: temperature, roughness, obstacles, and orography. Wind power is very consistent from year to year but it has significant variation over shorter time scales – i.e. wind shows its intermittent nature on a daily basis. Wind speed is commonly measured together with the wind direction, by installing wind monitoring equipment (anemometers, data loggers, etc.) on the mast at the planned location of installation of the WTGs, as shown in the **Figure 3-4, left**.

According to Lackner, Rogers & Manwell (2010), sophisticated wind measurement devices – wind profilers, such as SODAR[33] and LIDAR[34] can reduce wind resource assessment uncertainty for 25%, by eliminating errors due to shear model uncertainty and tower/boom effects. This is possible thankfully to advanced measurement trigonometry, which uses radial velocity for calculation of 3D meteorological velocity components (u, v and w), wind speed and wind directions. In the **Figure 3-4**, **right**, SODAR vs. LIDAR comparison is given.

---

[33] SODAR comes from sound detection and ranging. It is a technology which wind profiler to measures the scattering of sound waves by atmospheric turbulence, in order to provide wind speed at various heights above the ground, and the thermodynamic structure of the lower layer of the atmosphere.

[34] LIDAR comes from light detection and ranging. It is a remote sensing technology that measures distance by illuminating a target with a laser and analysing the reflected light.

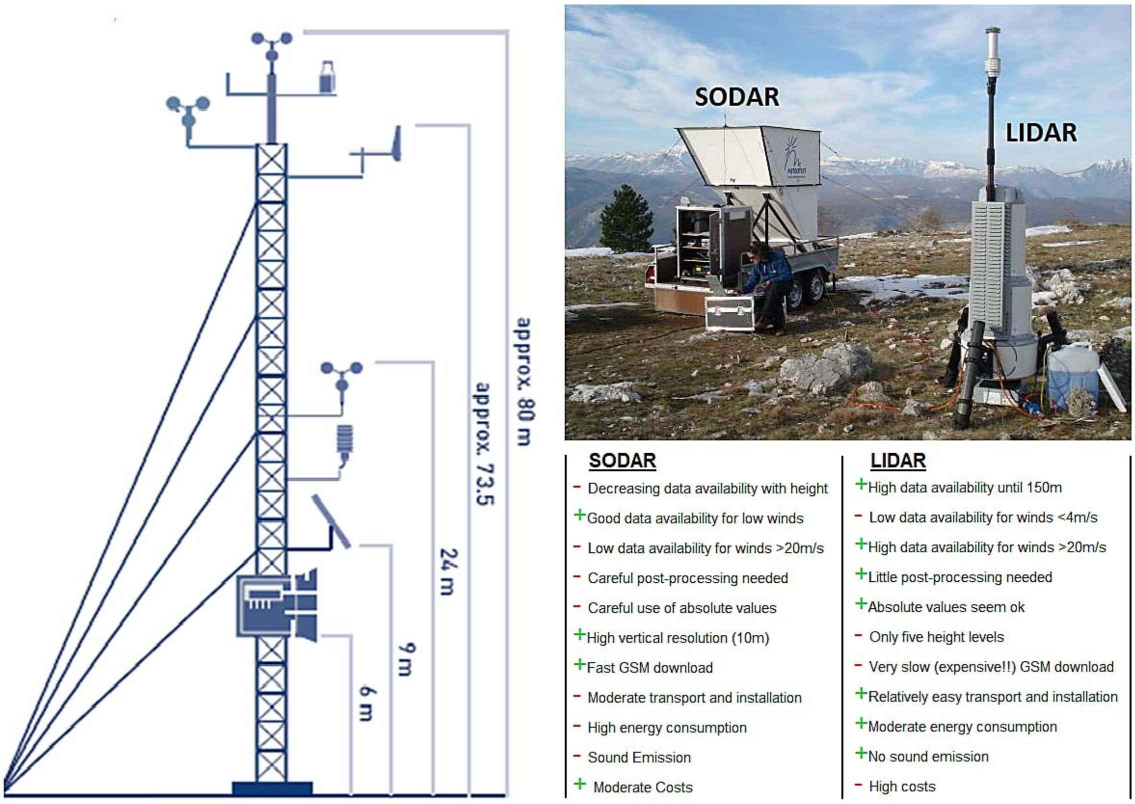



**Figure 3-4: Wind mast (left) and SODAR vs. LIDAR comparison (right)**
*source: (Neubauer, 2011)*

Wind speed probability ***p(U)*** can be quite well approximated with the Weibull's distribution, denoted as:

$$p(U) = (k/c)(U/c)^{k-1} \exp(-(U/c)^k)$$

***U*** – wind speed [m/s]; for most of the WTGs, cut-in wind speed when WTG starts to rotate and generate electricity is 3 – 4 m/s, rate output speed when WTG reaches its maximum production is 12 – 17 m/s, while the wind cut-out speed, when WTG stops production, is ca. 25 m/s at the hub height – this is shown in the power curve in the **Figure Ad8-27** in the **Addendum 8**.

***k*** – shape factor [-]; the range goes from 1 (steady winds) to 3 (very variable winds). A special type of the Weibull's distribution is the Rayleigh's distribution, where k = 2. This distribution is often assumed when only the mean wind speed is known.

***c*** – scale factor [-], also denoted as "***A***" by some authors; it is nearly proportional to the mean wind speed, and it is logical to assume that the percentage uncertainty in the mean wind speed is equal to the percentage uncertainty in ***c***.

Weibull's wind speed probability distributions for different values of ***c*** and ***k*** is illustrated in the **Addendum 6.4**.

Once the wind resource at a site has been determined, it is combined with a selected power curve and the energy loss factors to yield an estimate of the energy production of the wind turbine or wind farm. The power curve as well as power factor of Enercon E-101 WTG are depicted in the **Addendum 8**, together with for basic technical features.

However, real power curves rarely lie on the manufacturer's (sales) power curve due to several factors, which can be summarized in four categories: (1) Generic power curve performance, (2) Mechanical sub-optimal performance, (3) Environmental impacts, and (4) Wind conditions.

Generic power curve performance is a WTG model specific factor. In the **Figure 3-5**, there is a result of comparison of power curves of the sixteen WTG from an on-shore wind farm in operation against the power curve warranted by the manufacturer.

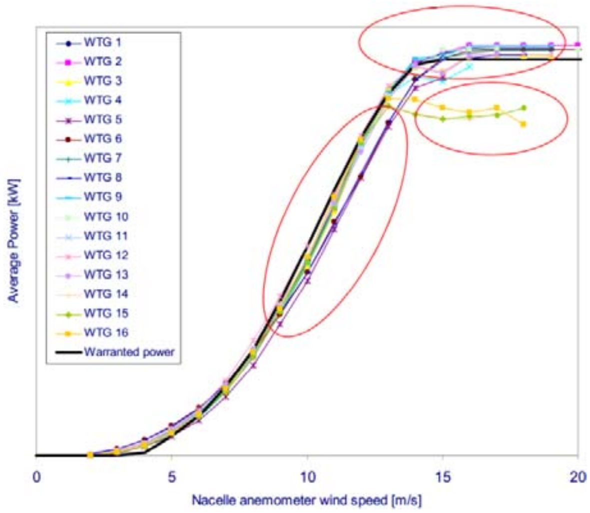



**Figure 3-5: Real power curves vs. warranted power curve**
*source: (Wind Farm Loss Factor Assumptions: Experience From Operational Data, 2013)*

Mechanical sub-optimal performance factors, such as de-rating, non-optimal controller settings or sensor errors, are all together wind farm operator specific factors. Some examples of are shown in **Figure 3-6**:

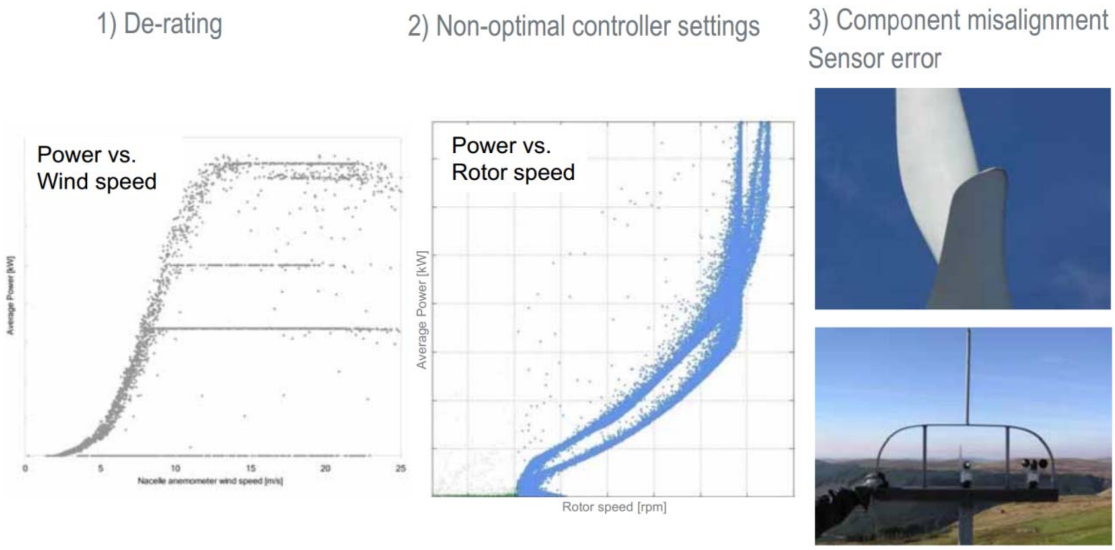



**Figure 3-6: Mechanical sub-optimal power curve performance factors**
*source: (Wind Farm Loss Factor Assumptions: Experience From Operational Data, 2013)*

Environmental factors are always regional specific. Some examples of the environmental impact to the WTG power curve due to icing, bugs and dirty blades are shown in the **Figure 3-7**.

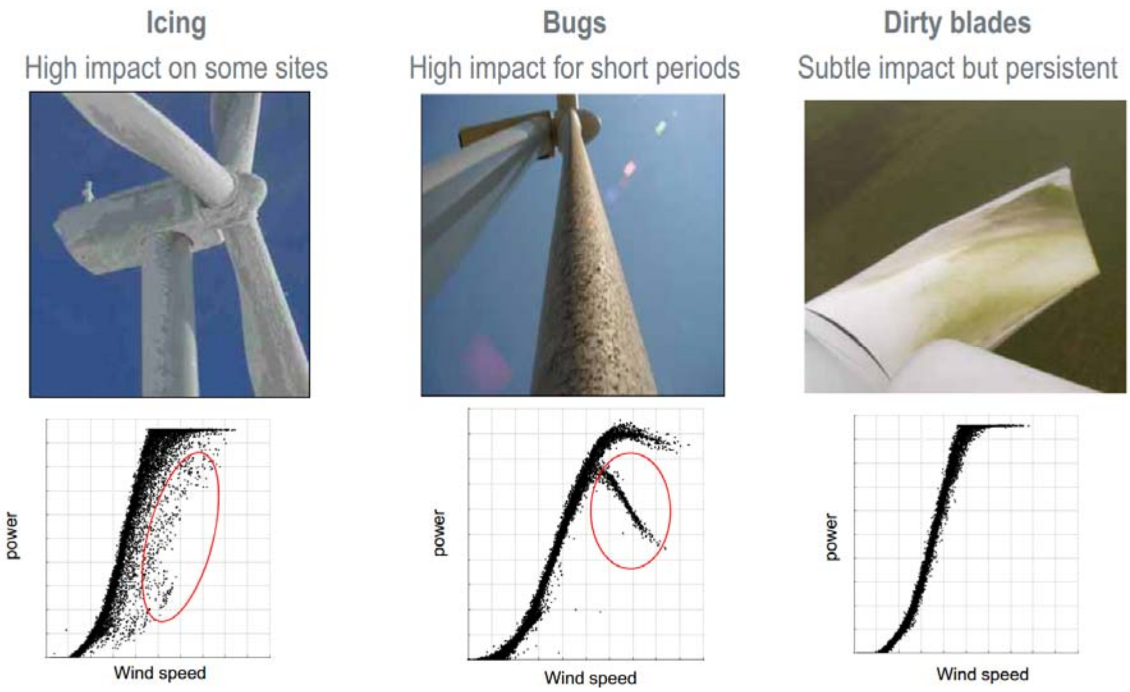



**Figure 3-7: Environmental power curve performance factors**
*source: (Wind Farm Loss Factor Assumptions: Experience From Operational Data, 2013)*

Wind conditions, such as turbulence intensity, shear and flow inclination, are site specific factors which also affect the power curve performance.

In most of cases, the real electricity generation is below expected due to the impact of above mentioned factors, while sometimes it goes over expected. In the **Table 3-6**, a summary of four affecting categories is given, where we can see the magnitude of total losses of a WTG performance.

**Table 3-6: Deviation of real vs. sales power curves**
*source: (Wind Farm Loss Factor Assumptions: Experience From Operational Data, 2013)*

| | **Category** | **Typical range loss (-) or gain (+) of nominal energy (%)** | **Median (of nominal energy %)** |
|---|---|---|---|
| **1** | Genereic power curve performance | -5% to +3% | -1% (model specicfic) |
| **2** | Mechanical sub-optimal performance | -5% to +0% | -1% (operator specicfic) |
| **3** | Environmental impacts (ice, bugs, dirty blades) | -3% to -0.2% | -0.5% (region specific) |
| **4** | Wind conditions (turbulence intensity, shear and flow inclination) | -5% to +1% | -1% (site specific) |

Besides these losses, there are other losses which might occur in the wind power generation, such as shadowing losses (due to suboptimal micro-location of the WTGs in the farm), electricity transmission losses, etc.

As we could see in this and in the previous section, there are numerous sources of uncertainties in the PV and Wind electricity generation. In the next section we will discuss on the capacity factor – a dimensionless unit which sublimes all gains and losses during electricity generation process in one figure.

***Capacity factor***

The uncertainty in the RES-E sources (wind speed, solar irradiance, etc.), the power production, and the energy loss factors contribute to an overall uncertainty in the energy production. Often, it is more convenient to use the **capacity factor (CF)** as a measure of energy production. Furthermore, CF is used for simplified comparison among power outputs of different RES-E technologies.

CF equals to the total power output (electricity generation) divided by the rated power[35]. It is an indicator how much energy particular power plant (e.g. wind, PV, etc.) produces at a particular site compared to its maximum output. For example, if one WTG with a capacity of 3 MW produced 7.000 MWh for a period of one year, then its CF is:

$$\boldsymbol{CF} = \frac{\frac{7.000\ MWh}{365*24\ h}}{3\ MW} = \boldsymbol{0{,}2664 \sim 0{,}27\ \ (27\%)}$$

In fact, the CF in wind technologies is a function of the estimate of the long-term hub height Weibull's parameters (c and k), together with a wind turbine power curve ($P_W$), and the overall energy loss factor (ELF), which is denoted as

$$\boldsymbol{CF = CF\ (c, k, Pw, ELF)}$$

Sensitivity of wind CF to generation cost of electricity is illustrated in the **Figure 3-8**, in comparison with the gas technologies. It is clear that, due to no fuel consumption costs, wind farms with high CF (> 28%), have generation cost lower than CCGT - the most efficient gas power plant technology nowadays.

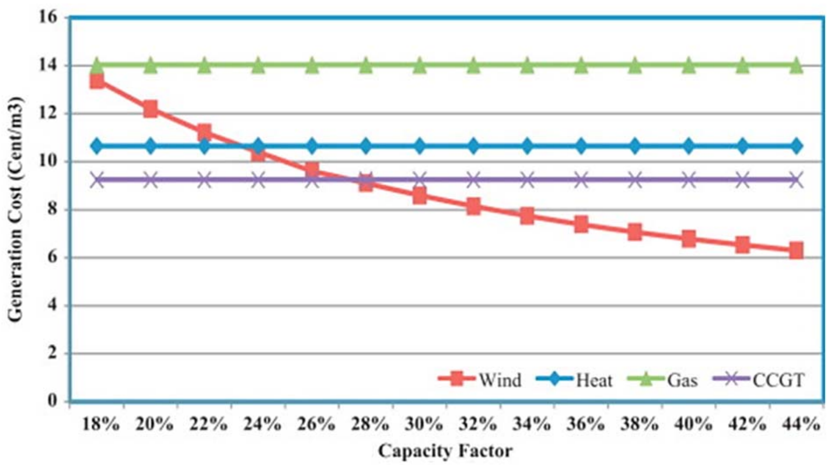



**Figure 3-8: Dependence of CF to generation costs**

*source: (Mousavia, Ghanbarabadia, & Moghadamb, 2012)*

Nowadays, with the current level of technology, CF for WTG are in range of 0,22 to 0,32, while in laboratory it goes over 0,40.

---

[35] Rated power may is also known as "nameplate capacity" or "peak capacity." This may be further distinguished as the "net capacity" of the plant after plant parasitic loads have been considered, which are subtracted from the "gross capacity."

There is a theoretical limit on the amount of power that can be extracted by a wind turbine from an airstream. It is called the Betz[36] limit and it amounts to $\eta$ =16/27 ≈ 59%. Efficiency $\eta$ in the wind projects is often referred to as the power coefficient $c_p$, and it is defined as the actual power delivered divided by the available power of the WTG.

In the study (Lackner, Rogers, & Manwell, 2010), dependence of ***CF*** to simultaneous change of ***c*** and ***k i***n laboratory conditions was examined. The results showed that CF is more sensitive to ***c*** than to ***k***, as illustrated in the **Figure 3-9**.

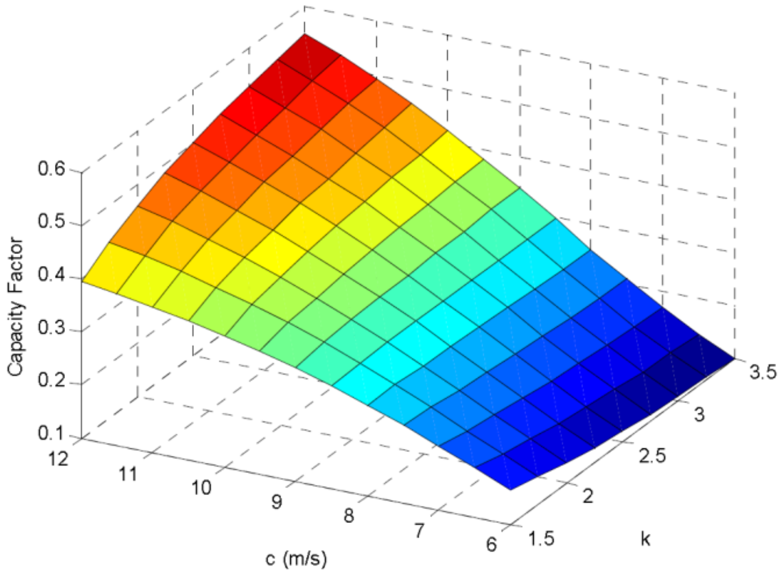



**Figure 3-9: Sensitivity of CF to *c* and *k***
*source: (Lackner, Rogers, & Manwell, 2010)*

According to IRENA statistics (IRENA, 2013), average weighted CF in new wind projects (> 5 MW), varies by region between ca. 25% for China and 42% for Latin America (**Figure 3-10**).

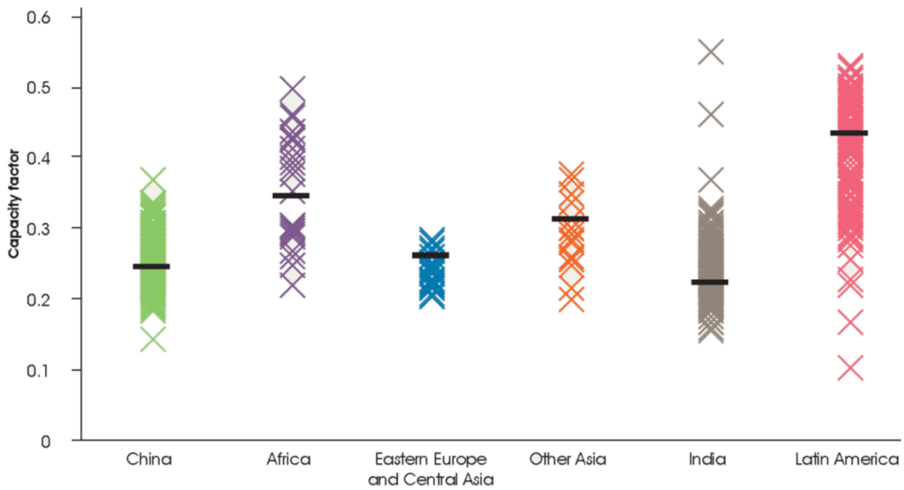



**Figure 3-10: CF for new large wind projects in non-OECD regions**
*source: (IRENA, 2013)*

[36] After Albert Betz, German scientist, who published this result in 1920.

In PV projects, CF is highly sensitive to PV plant location (latitude), PV module orientation (azimuth), vertical angle (tilt), PV cell and module efficiency, as well as to shadowing effect and system losses (inverter, cables, DC to AC conversion, temperature, etc.). Additionally, CF can be improved with single-axis or double-axis tracking system. The **Figure 3-11** shows variance in CF in respect to axis tracking systems in different regions in the USA.


**Figure 3-11: CF in respect to axis tracking systems in different regions in the USA**
*source: (IRENA, 2013)*

Due to its simplicity of calculation and comparability among different RES-E technologies, CF has been used as a key input for modeling the energy outputs of the wind and PV power plants in the numerical example of the business case in the **Chapter 4.2**.

## 3.3. RES-E support schemes

***Background***

In order to eliminate the finance gap between them and conventional energy sources, RES-E projects needs external support. The main reason why conventional energy sources (coil, oil, gas, nuclear) are still more competitive than renewable energy sources, is that the environmental impact of using "dirty" energy technologies is not reflected in the energy price, which then does not reflect the total costs of generating electricity. In last years this situation has changed and some countries accounted for these costs through taxes or emissions trading schemes.

In the context of reductions of carbon emissions due to global warming considering climate change as a greatest example of market failure, economists try to correct it by mean of direct policy, such as imposing price on carbon emissions (e.g. EU Emissions Trading Scheme), but in the absence of direct measures to reduce emissions, support for renewable energy can be seen as a second-best policy.

Out of the **Figure 3-12** it is obvious that renewables are globally supported. According to the REN21 (Renewable Energy Policy Network for the 21st Century), the number of countries with renewable targets is more than doubled between 2005 and 2012. However, a large number of cities and local governments are also promoting renewable energy.

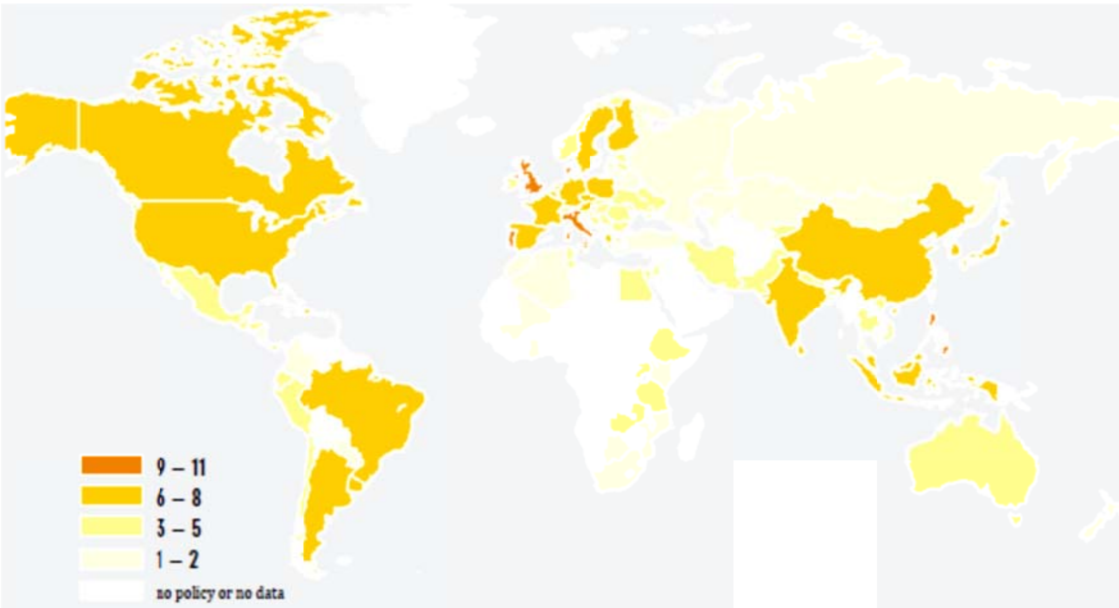



**Figure 3-12: Global map of countries with renewable policies in place in 2012**
*source: (REN 21, 2012)*

First incentives to RES-E sector in EU started in 2001, by introduction of the following two directives:

- Directive 2001/77/EC for the promotion of electricity from renewable energy sources (known as the RES-E Directive), which sets the legal framework applicable in all EU member states for the promotion of electricity generated from RES establishing an ambitious target of doubling the contribution of RES to the gross domestic consumption by 2010 in the EU, and
- Directive 2003/53/EC concerning common rules for the internal market in electricity which establishes common rules for the generation, transmission, distribution and supply of electricity. It lays down the rules relating to the organization and functioning of the electricity sector, access to the market and the operation of the systems among others.

To make use of renewable energy more challenging to its member countries, EU introduced **Directive 2009/28/EC** (EU Directive 2009/28/EC, 2009) which is in line with EU visionary 20/20/20(/10) targets[37]. It extends the scope of preceding legislation, by amending and recalling Directives 2001/77/EC and 2003/30/EC on the promotion of the use of biofuels and other renewable energy sources in transport. As shown in the **Figure 3-13**, cumulative achievement in 2010 was 12,4% (out of 20%), but some of the countries are already very close to reach the targets (Estonia, Romania, Sweden).

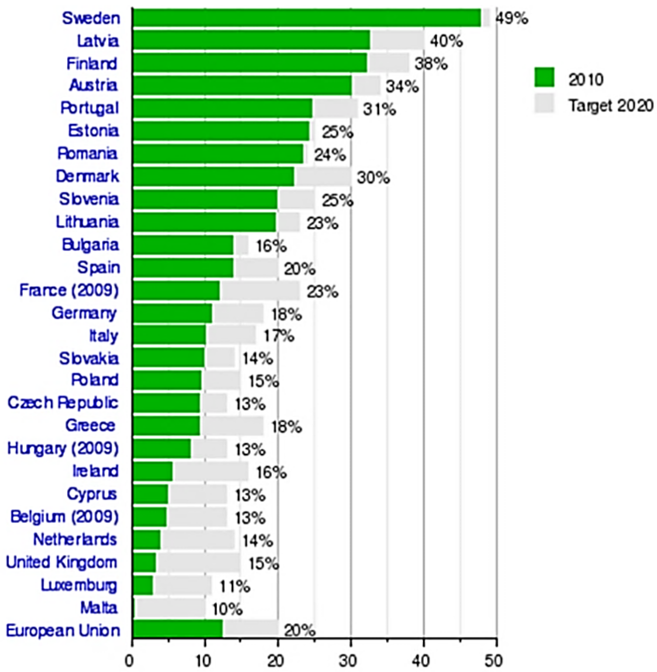



**Figure 3-13: National overall targets and their achievements in 2010 in EU**
*source: Eurostat*

[37] **20%** reduction in EU's Greenhouse Gas (GHGs) emissions (or 30% as part of an international agreement), base year is 1990, **20%** increase in energy efficiency and **20%** share of energy from renewable sources in gross final consumption of energy (and 10% of share of renewable sources in transport), base year is 2005. These targets are to be achieved by the year 2020. The ultimate goal of the plan is to limit the average global temperature rise to 2°C.

Some countries which are outside of EU or have the EU candidate status (e.g. Serbia), are also committed to reach certain renewable targets through Energy community membership. In the **Chapter 4** renewable energy situation in Serbia will be discussed in details.

*Different types of support schemes*

There are several types of RES-E support schemes in use worldwide:

- **Feed-in Tariffs (FiT)** are specific unit prices per electricity generation (e.g. €c/kWh) from renewable sources that must be paid by electricity companies, usually distributors, to domestic producers of RES-E during predefined long–term period (most commonly it is ten or more years). Alternatively, the government can set a fixed-premium paid above the normal or spot (market) electricity price, to RES-E producers. The fixed price or fixed premium may be revised by the government to reflect falling costs of the technology (see the **Chapter 3.1.3** on learning curves). The FiT scheme is one of the safest support schemes for investing in RES-E projects, as the cash inflow is secured, but the political risk is always present (e.g. new government can decide on moratorium for further RES-E support or even worse to terminate contracts in-place due to insufficient funds in the national budget for subsidies like this one).
- **Quota Obligation Systems and Green Certificates.** Quota obligations impose a minimum consumption or production of electricity from RES. The government sets the plan within which the electricity market has to produce, sell or distribute a certain amount of electricity from renewable sources. The quota can usually be traded directly between companies in order to avoid market turbulences. A Tradable Green Certificate (TGC) is a tool for this trading – the producers sell electricity in the open market, but at the same time receive a "green certificate" per MWh produced, which is traded separately from the physical commodity. The value of the TGC comes as the result of the obligation, placed on all consumers to purchase a certain amount of green certificates from RES-E producers according to the quota, i.e. a fixed percentage of their total electricity consumption/production. Intention of consumers to buy green certificates as cheaply as possible implies creation of a secondary TGC market, where RES-E producers compete with each other to sale as much green certificates as possible.
- **Investment Subsidies** in % of the total CAPEX. It bridges the funding gap of a high initial investment and it is often used to stimulate investments in less profitable RES-E projects, but it can be also applied for small installations for households (e.g. building integrated PV modules).
- **Fiscal measures** have different forms, from discounts on general energy taxes, discounts on special emission taxes, proposals for lower VAT rates, tax exemption for green funds to fiscal attractive depreciation schemes, etc.
- **Tendering schemes and bidding systems** is combined either with FiTs or TGCs. It works in a way that prospective RES-E producers submit competitive bids for fixed-price contracts offered by authorities. The criteria for the evaluation of the bids are

set before each bidding round. The government decides on the desired level of RES-E mix, their growth rate over time and the level of long–term price security offered to producers over time, while electricity providers are obliged to purchase a certain amount of electricity from RES at a premium price. The difference between the premium and market price is reimbursed to the electricity consumption. In each bidding round the most cost-effective offers will be selected to receive the subsidy.

The latest situation with application of specific support schemes in EU member states is shown in the **Figure 3-14**:

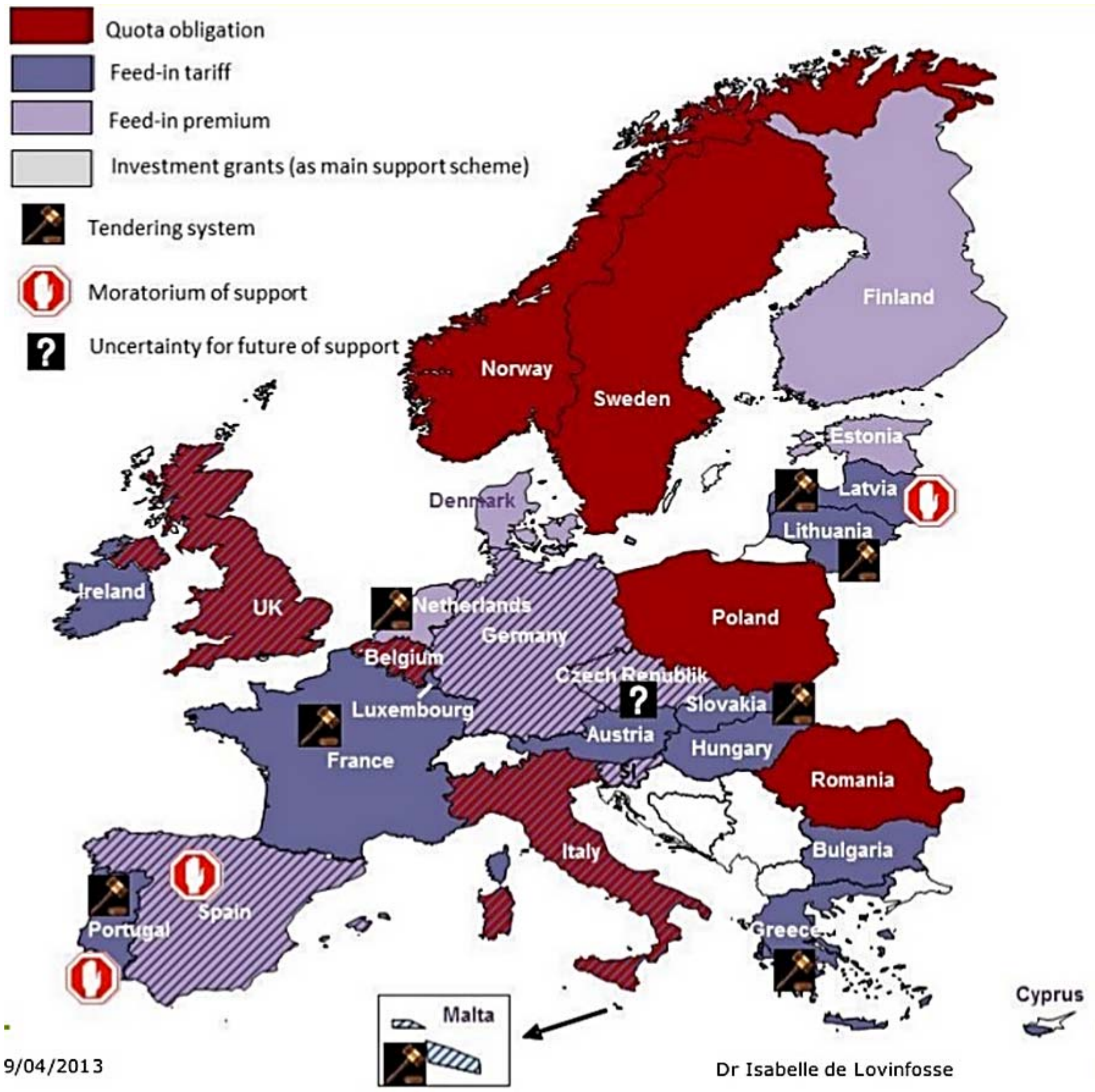



**Figure 3-14: Diversity of RES-E support instruments in the EU-27**
*source: (de Lovinfosse, 2013)*

As a result of support schemes implementation in EU in the last decade, total new RES-E investments (except hydropower) increased fivefold. Nevertheless, some countries have recently announced their intentions to cancel further support to RES (Latvia, Spain, Portugal), while the grid parity for some technologies has been already reached in some countries in residential (household) sector (e.g. in Denmark, Cyprus, Spain, Portugal, Germany, etc.) and will be reached soon in commercial (industrial) sector (e.g. in Cyprus, Spain, Portugal, Italy, Turkey, etc. – see **Figure 3-15**), thus eliminating the need for support schemes.

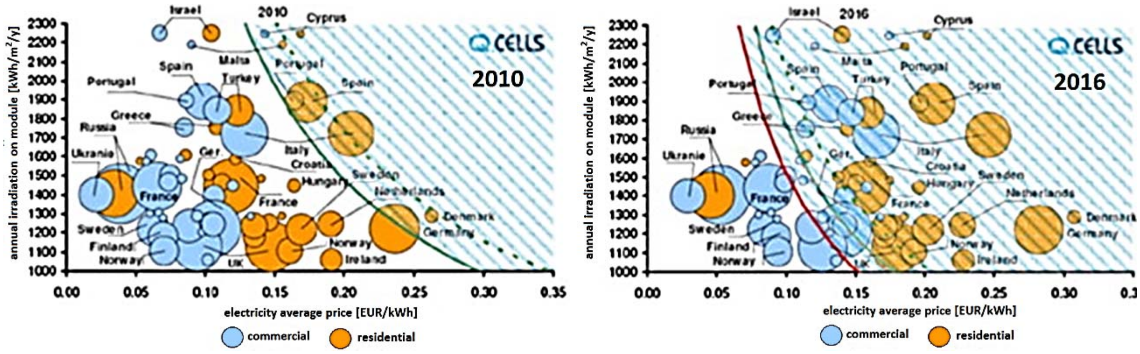



**Figure 3-15: Grid parity in Europe in 2010 (left) and estimate for 2016 (right)**
*source: (Ruiz-Romero, Colmenar-Santos, Gil-Ortego, & Molina-Bonilla, 2013)*

All these aspects (willingness of the government to continue further implementation of RES-E support schemes as well as reaching the grid parity), must be properly considered in the risk identification phase during the project valuation, in order to prepare adequate risk mitigation measures.

# 4. CASE STUDY: ROV OF THE RES-E PROJECTS IN SERBIA

The author has selected Serbia for this case study, as it is his home country as well as considering overall market situation - lack of competitors, market liberalization (as of 2014 for industrial consumers and as of 2015 for households) and increased electricity demand in forthcoming period.

This chapter has two sections:

- in the first section, the author briefly explains general overview of Serbia, its economic indicators as well as energy situation with the focus on the latest changes in the RES-E sector.
- the second section demonstrates numerical example of the wind and PV projects real options valuation in Serbia by applying combinations of sequential, expand, contract and abandon real options. After completion of the ROV, a portfolio consisting of six wind and six PV projects, has been examined including portfolio optimization through the *efficient frontier* approach as well as ranking of the first three best portfolios according to the *Sharpe ratio*. The whole procedure demonstrated in this section follows the IRMP framework recommendations.

## 4.1. Serbia

***General overview***

Serbia is a landlocked country in central and southeast Europe, surrounded by eight countries (Hungary, Romania, Bulgaria, Macedonia, Albania, Montenegro, Bosnia and Herzegovina and Croatia). Via pan-European multimodal Corridor X and Danube Corridor VII, Serbia bridges Europe and Asia, as illustrated in the **Figure 4-1**. Total area is c a. 88 million km2, population ca. 7,2 million, capital is Belgrade (ca. 1,7 million).


**Figure 4-1: Map of Serbia**
*(source: www.siepa.gov.rs)*

Since 2002, when the law on foreign investments was adopted, equalizing all rights of domestic and foreign investors, there have been increasing trend of foreign investments in different business sectors, such as: food, tobacco, automotive, telecommunication, electronic, oil, petrochemicals, metallurgy (steel, copper, aluminum), clothing, etc. (source: SIEPA). The largest energy company is NIS, majorly owned by Russian Gazprom Neft since 2008, with EBITDA of ca. 600 million EUR (2012).

Serbia has one of the most attractive tax systems in Europe (salary tax 12%, corporate income tax 15%, VAT 20%). GDP PPP per capita in 2012 was ca. 10.000 USD, growth rate in 2013 is 1,5% (estimation) and forecast for 2014 is 2,0 % (source: IMF, 2013).

Serbia has been tremendously impacted by global economic crisis since end of 2008. The largest threats to Serbian prosperity are high unemployment rate (ca. 25%), high inflation rate (ca. 12%), high public debt (ca. 65% of GDP) as well as minor GDP growth rate.

Serbia is member of the United Nations, Council of Europe, Organization for Security and Co-operation in Europe (OSCE), Partnership for Peace, Organization of the Black Sea Economic Cooperation (BSEC), and Central European Free Trade Agreement (CEFTA).

Since 2005, Serbia has become a member of the **Energy community** (also referred European Energy Community - EEC), which is established between the European Union (EU) and a number of non-EU countries (Macedonia, Albania, Montenegro, Bosnia and Herzegovina, Serbia, Ukraine and Moldova), in order to extend the EU internal energy market to Southeast Europe and beyond. The Contracting Parties committed themselves to implement the relevant EU legislation (*Acquis Communautaire*), to develop an adequate regulatory framework and to liberalize their energy markets.

Serbia has EU candidate status since March 2012. Negotiations to entering EU are supposed to start in Jan 2014.

Construction of nuclear power plants in Serbia is forbidden by Law.

*Overview of the energy sector in Serbia*

According to the EIA 2012 report, Serbia is the second worse ranked country in Europe according to energy intensity[38], which is one of the key indicators of country energy efficiency. In 2010 in Serbia it was 3,705 kWh/2005 USD GDP PPP (i.e. 0,32 toe/2005 USD GDP PPP) and only Iceland had worse energy intensity than Serbia in the whole Europe.

**Figure 4-2** shows comparison among Serbia versus European worst ranked country (Iceland), European best ranked country (Ireland) and EU 27 average, for period 2006-2010. Main reasons of poor energy intensity in Serbia are final energy use inefficiency, high energy losses in transformation, transmission and distribution, as well as irrelevant use of renewable energy sources so far.

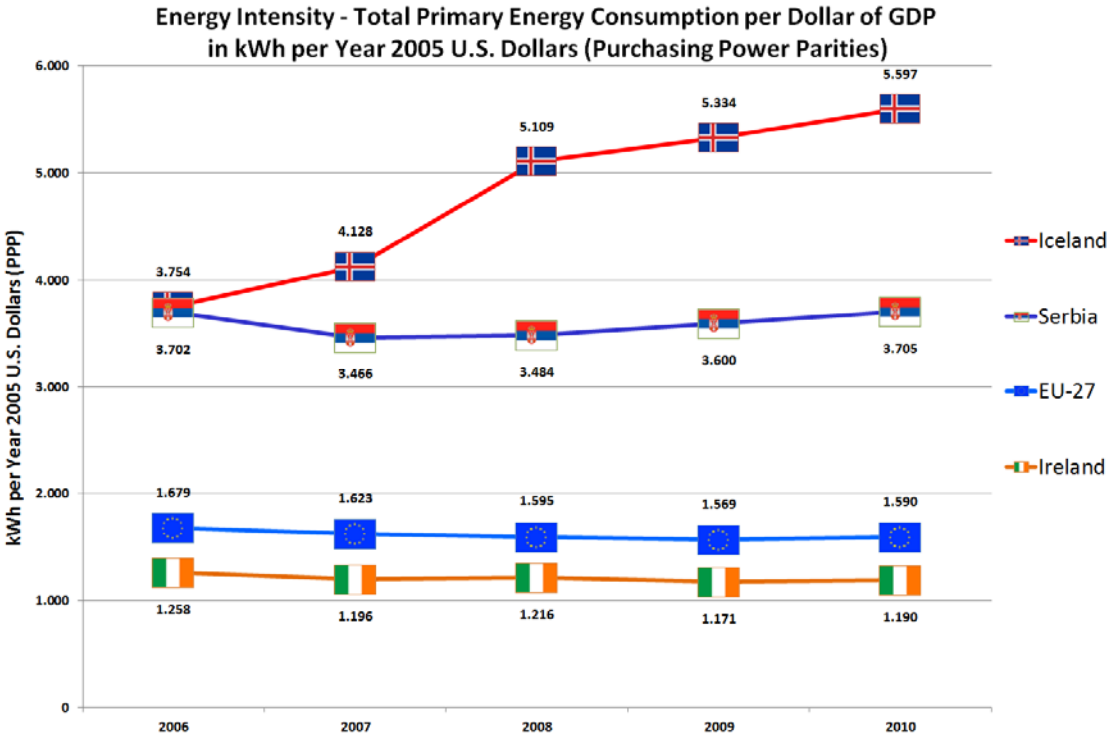



**Figure 4-2: Energy intensity – Serbia vs. European indicative countries**
*source: www.eia.gov*

Other key energy indicators for Serbia are: total annual primary energy consumption – ca. 16.000 kWh/capita and total annual electricity consumption – ca. 5.000 kWh/capita in 2010 (*www.indexmundi.com*).

Main players in the Serbian power sector (besides Ministry of Energy) are AERS, EPS and EMS. In the following text the competences of each of them will be briefly explained.

[38] **Energy intensity** is a measure of the energy efficiency of a country's economy. It is computed as units of energy per unit of GDP. High energy intensities shows a high price or cost of converting energy into GDP, and opposite – low energy intensity shows a lower price or cost of converting energy into GDP.

**AERS** ("Agencija za energetiku Republike Srbije", *www.aers.rs*) – Energy agency of Serbia, is national energy regulatory body for oil and oil derivatives, gas and electricity (power) market, including RES-E. Its main activities and responsibilities are the following: (1) Price regulation, (2) Licensing of Energy Entities for Conducting Energy Activities, (3) Deciding appeals, (4) Energy Market Supervision and (5) International Activities and Implementation of International Agreements;

**EPS** ("Elektroprivreda Srbije", *www.eps.rs*) – is the state owned electric power industry company of Serbia and holds licenses for the following business portfolio: coal production, electricity generation, electricity trade, electricity supply, distribution of electricity. According to the capital valuation and with a staff of 33.851 employees, as of 31 December 2011, EPS is the largest enterprise in Serbia. EPS is a holding company consisting of 11 subsidiaries: six generation companies (one produces coal and electricity, one is purely thermal electricity generation, one is CHP generation and two are hydro generation companies), five distribution/supply companies (covering the low and medium voltage network, parts of the 110kV high voltage network, telecommunication and information systems and other infrastructural assets, as well as supply). The power plants and mines, as well as each distribution company area is shown in the **Figure 4-3, left**. EPS is monopolist in distribution and supply of electricity. According to Energy Law, electricity market will be demonopolized in 2014 for industrial customers and in 2015 for households.

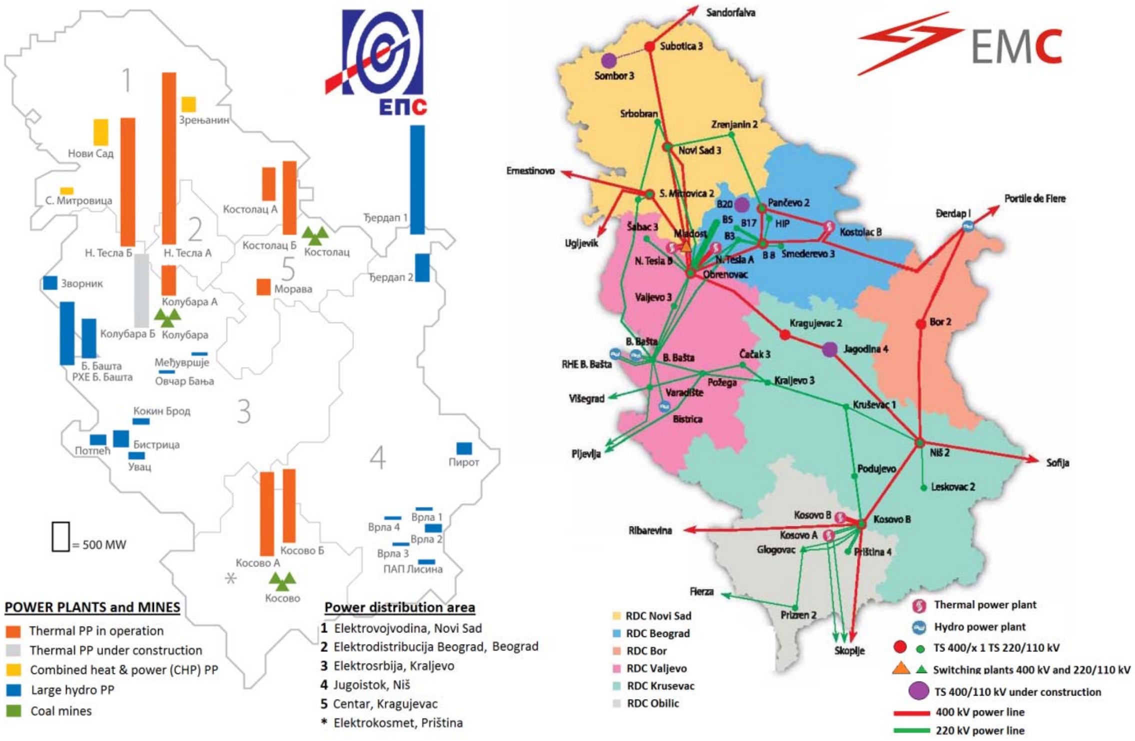



**Figure 4-3: EPS (left) and EMS (right)**

*source: www.eps.rs, www.ems.rs*

In July 2013, EPS formed new business unit – "EPS Snabdevanje" (EPS Supply), due to separation of power distribution and power supply business, which was a necessary step for the market opening to the new suppliers as of Jan 2014. In Serbia there are no generation units independent from EPS connected to the transmission network, except some irrelevant small plants.

**EMS** ("Elektromreža Srbije", *www.ems.rs*) is the state owned TSO (Transmission System Operator), responsible for power transmission, transmission system control and organization of the power market in Serbia. EMS owns and operates ca. 9.000 km of 400 kV and 220 kV high voltage transmission grids (natural monopoly), and it is consisting of 6 subsidiaries which covers area as shown in the **Figure 4-3, right**. In 2012, EMS reported power import of ca. 6,0 TWh and export of ca. 5,4 TWh, therefore – the power deficit of ca. 600 GWh.

The main primary energy sources for electricity generation in Serbia are water and domestic lignite coal. A minor share of the generation capacities is powered with fuel oil and gas. Among the thermal power plants, pure electricity generation clearly dominates over combined heat and power generation. The average ratio of electricity generation between thermal and hydro power plants in Serbia is 70%:30%, respectively, with minor annual deviations subject to the hydrological conditions.

The installed generation capacity in Serbia is 7,144 MW, where 3,936 MW (56%) are electricity only TPPs, 353 MW (5%) are CHPs and 2,831 MW (39%) are HPPs. Also, there are 13 mini hydro power plants with a total installed capacity of 24 MW. In 2009, EPS's power plants generated 36,112 GWh of electricity, where 24,880 GWh were from electricity-only TPPs, 139 GWh from CHPs and 11,093 GWh from both large and small HPPs. Total electricity demand in 2012 was 35,150 TWh, and according to EPS forecast, demand will rise ca. 0,9% p.a. by 2015, and ca. 1,7% p.a in period 2015 – 2020, thus reaching ca. 40.000 TWh in 2020 (KEMA Consulting GmbH, 2011).

The most important energy resource in Serbia is medium quality lignite with its total exploitation reserves of ca. 13.350 Mt. Nevertheless, since its high dependence of energy import (33,6% in 2010) and low reserves of oil and gas (less than 1% of the total energy reserves of Serbia), the most important task for Serbia in the future will be to reduce the energy import dependence by providing reliable supply of energy generated by environmentally friendly technologies which will be used in an efficient way. In that regard, the main goals of Serbian energy policy are increase of energy efficiency and increased use of renewable energy sources.

**Electricity price in Serbia** have risen over the past 10 years, but without any logical and reasonable pricing algorithm, such as GBM or MRP, behind their actual value. It is perceived as one of main drivers of inflation increase and is a significant social factor, and thus subject to political manipulation. The development of electricity prices for different categories of consumers during the period 2000 – 2009 (in €c/kWh), as well as average price structure, are illustrated in the **Figure 4-4**.

| Consumption category | YEAR | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 2000 | 2001 | 2002 | 2003 | 2004 | 2005 | 2006 | 2007 | 2008 | 2009 |
| 110 KV | 0.55 | 1.00 | 1.75 | 2.13 | 2.31 | 2.37 | 3.08 | 3.59 | 3.87 | 3.55 |
| 35 KV | 0.57 | 1.20 | 2.05 | 2.56 | 2.58 | 2.55 | 3.10 | 3.68 | 4.49 | 4.13 |
| 10 KV | 0.86 | 1.45 | 2.41 | 2.92 | 2.96 | 2.86 | 3.36 | 4.05 | 4.92 | 4.62 |
| High Voltage | 0.74 | 1.30 | 2.19 | 2.66 | 2.72 | 2.67 | 3.24 | 3.87 | 4.54 | 4.25 |
| 0,4 KV I step | 0.99 | 1.94 | 3.28 | 3.79 | 3.88 | 3.94 | 4.74 | 5.78 | 7.09 | 6.68 |
| 0,4 KV II step | 1.25 | 3.03 | 5.60 | 5.66 | 5.26 | 4.85 | 5.22 | 6.08 | 6.90 | 6.37 |
| Households | 1.00 | 1.83 | 3.08 | 3.44 | 3.53 | 3.47 | 3.88 | 4.59 | 5.06 | 4.67 |
| Public lighting | 0.98 | 1.45 | 2.55 | 3.18 | 3.26 | 3.13 | 3.66 | 4.40 | 5.12 | 4.73 |
| Low Voltage | 1.03 | 1.97 | 3.36 | 3.71 | 3.74 | 3.66 | 4.13 | 4.91 | 5.57 | 5.15 |
| Average price | 0.95 | 1.79 | 3.04 | 3.44 | 3.46 | 3.39 | 3.88 | 4.62 | 5.28 | 4.91 |

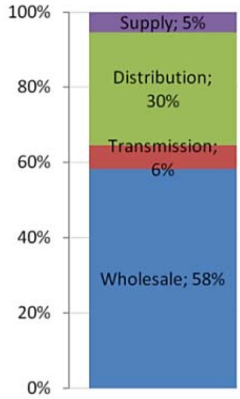



**Figure 4-4: El. prices per consumption categories (left) and average price structure (right)**

*source: (AERS)*

*RES sector in Serbia with focus on wind and PV*

Serbian Energy Law (Republic of Serbia, 2011/2012) defines energy from renewable energy sources as "the energy produced from non-fossil renewable sources like: waterflows, biomass, wind, sun, biogas, landfill gas, gas from the sewage water treatment plants and geothermal energy sources". (Rakic & Stosic Mihajlovic, 2010)

Renewable energy sources with an estimated technically usable annual potential of ca. 6 Mtoe, can considerably contribute to a reduction of fossil fuels use and GHG emissions, as well as achievement of defined targets regarding the share of renewable sources in the final energy consumption. The biomass potential amounts to ca. 3.300 ktoe per year, 1.700 ktoe is hydro-potential, 200 ktoe is geothermal energy potential, 200 ktoe is wind energy potential and 600 ktoe is solar energy potential. Out of the total available technical RES potential, Serbia already uses 33% (900 ktoe of hydro-potential and 1.060 ktoe of biomass potential). This is illustrated in the **Figure 4-5**.

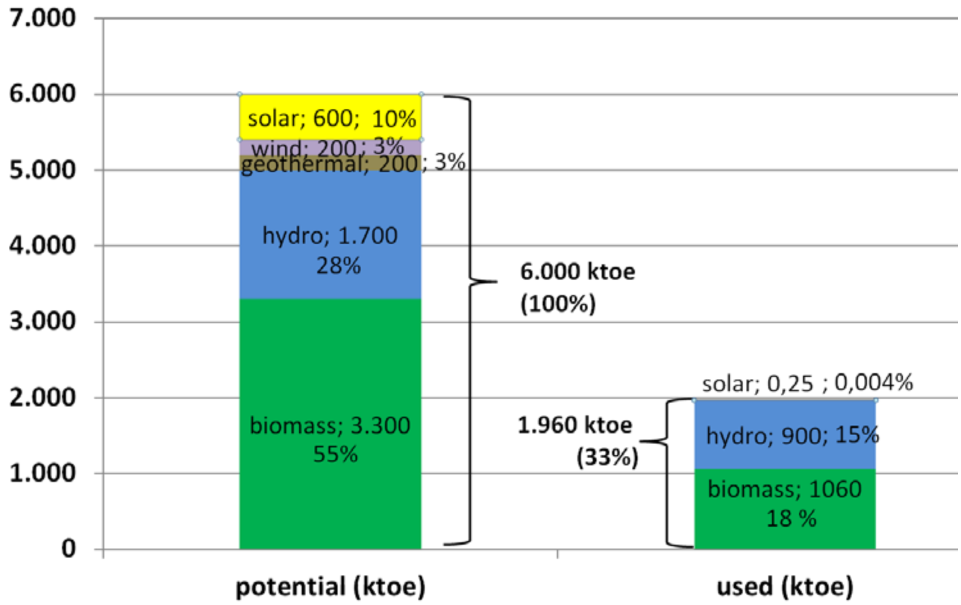
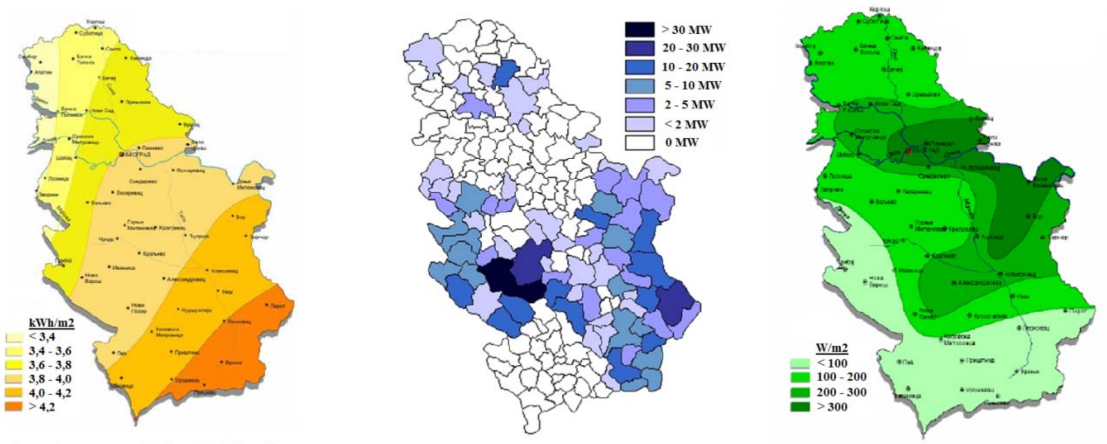



**Figure 4-5: Annual RES potential and use in 2011 in Serbia**

*source: (NREAP, 2013)*

Currently (Sep 2013), there are no wind farms in operation, but there are wind projects under development in Vojvodina (Kula, Plandiste, Indjija, Alibunar, Pancevo, Vrsac, Kovin) and in Eastern Serbia (Kladovo, Negotin). So far, there is only one ground-mounted PV plant in operation (ca. 2 MWp), in Merdare, Southern Serbia. In 2011, there was an announcement of construction of the largest global PV plant in Southern Serbia in capacity of 1 GWp, but the project is currently on-hold. Small Hydro is most developed RES-E sector in Serbia – there are 31 SHP plants in operation, 26 plants under development by EPS, and Ministry of Energy recently finished public tender for 317 SHP plants. The maps in the **Figure 4-6** show spatial distribution of potentials for solar, small hydro and wind energy investments in Serbia, respectively.




Annual average of daily global irradiance on horizontal plane

Total estimated power of small hydropower plants (SHP) by municipalities

Average wind power at 100m altitude

**Figure 4-6: Spatial distribution of solar, small hydro and wind potentials in Serbia**

*source: Spatial plan of Serbia 2010*

According to the latest PVGIS solar map update (Huld, Müller, & Gambardella, 2012), yearly sum of global irradiation and solar electricity potential for optimally inclined PV modules in Serbia is shown in the **Figure 4-7**.

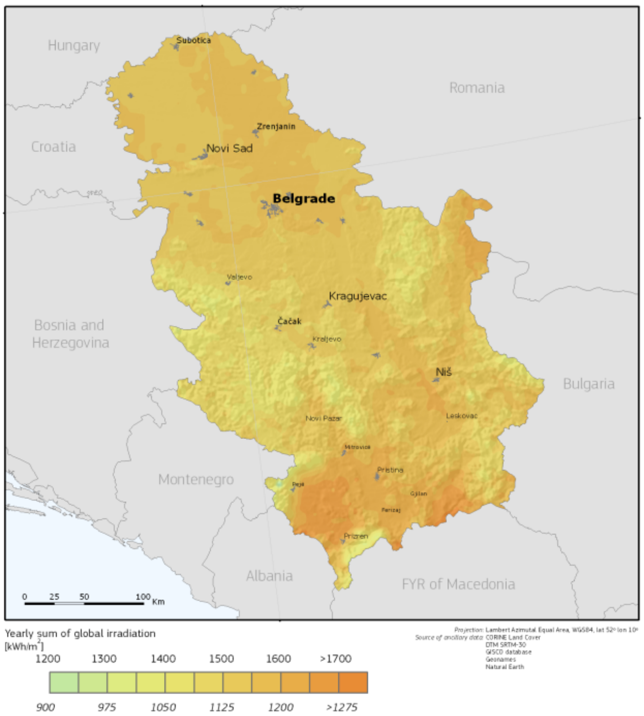



**Figure 4-7: Global irradiation and solar electricity potential for optimally inclined PV modules in Serbia**

*source: (Huld, Müller, & Gambardella, 2012)*

However, there are no available reliable detailed wind maps for Serbia, which implies a high importance of the wind measurement at preferred site, as one of the first steps in the wind farm project valuation.

**NREAP – National Renewable Energy Action Plan (2013)**, a strategic document for RES development by 2020 in Serbia, has been adopted in accordance with the directive 2008/29/EC, which imposes that each member of the European Community shall prepare a national action plan for renewable energy sources in compliance with the adopted template for the preparation of this document (Decision 2009/548/EC). NREAP sets national targets regarding the share of energy from renewable energy sources until 2020 in the electricity, heating and cooling and transport sector, considering the effects of energy efficiency improvement measures on the final energy consumption. NREAP's strategic goal is to encourage and increase the share of green energy field investments in the total energy mix in Serbia.

According to NREAP, there are two scenarios for reaching 2020 targets: one conservative called "REFSC – reference (base) scenario" which doesn't consider energy efficiency measures, and another one called "EESC - energy efficiency scenario" with applied energy efficiency measures. Modeling of the scenarios was done by Ecofys. In both scenarios, RES share in the gross final energy consumption (GFEC) should raise from 21,2% in 2009 (base year) to 27% in 2020, as shown in the **Figure 4-8.**

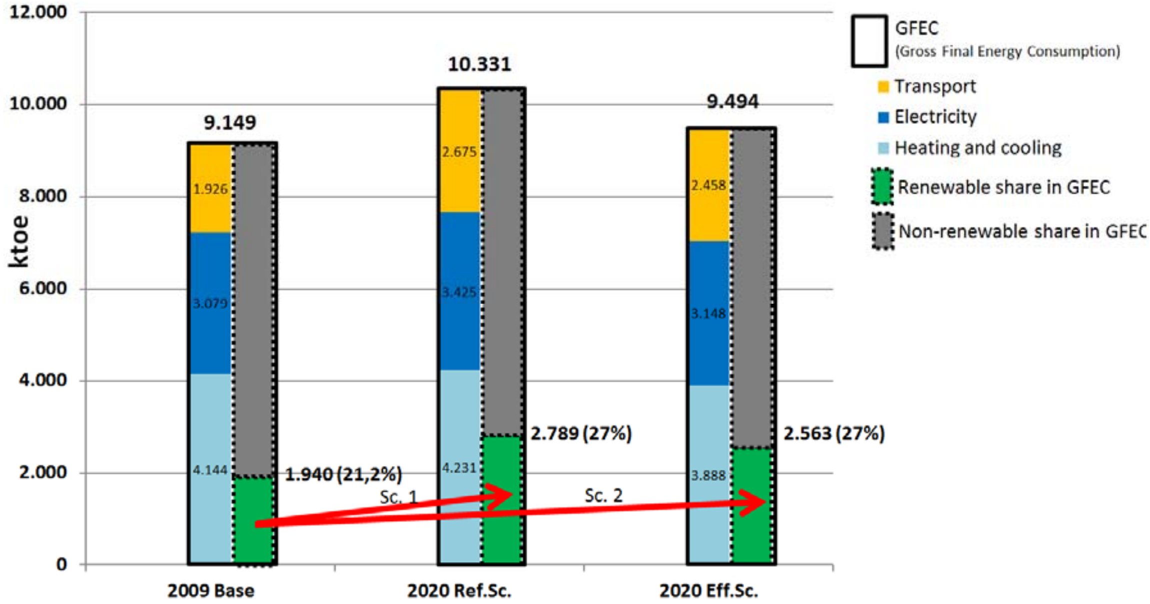



**Figure 4-8: Serbia RES 2020 target**
*source: the author, based on (NREAP, 2013)*

Furthermore, RES targets are set by each source separately by capacity. In compliance with the REFSC scenario in the electricity sector, it will be necessary to increase share of RES for 43,3% (1.267 ktoe) in comparison to the baseline 2009 (884 ktoe). This affect GFEC increase from 9,7 % in 2009 to 12,2 % in 2020 in the electricity sector.

To achieve its 2020 targets in the power sector, Serbia shall install additional 1092 MW until 2020, diversified in RES-E power plant capacities, as shown in the **Figure 4-9**:

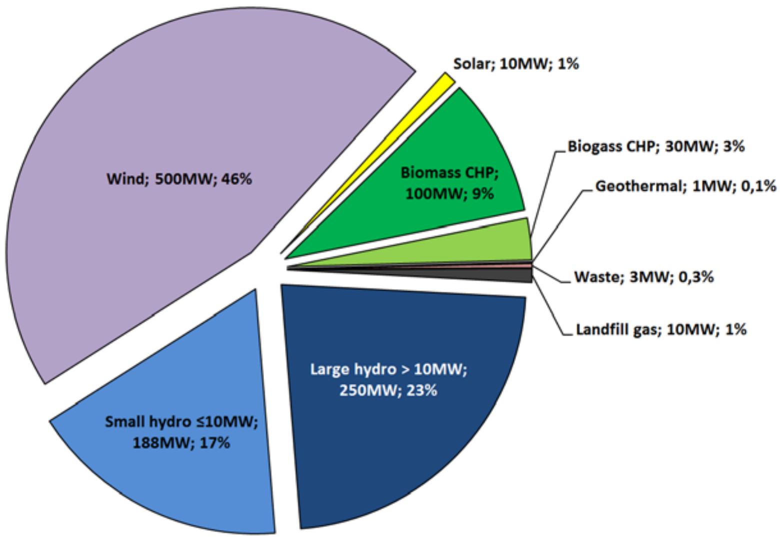



**Figure 4-9: Serbia 2020 targets per RES type**
*source: the author, based on (NREAP, 2013)*

Serbian RES-E Feed-In-Tariff (FiT) policy came in force in February 2013, through the *Decree on Incentive Measures for Privileged Energy Producers (2013)*. It replaced the first Serbian FiT policy adopted in 2009, which didn't achieve significant results, as was expected by the Government. Validity of the Decree is by 31.12.2015. A summary of the latest Serbian FiT policy is given in the **Addendum 9.**

Although most of the FiTs in this Decree are lower than in the previous Decree from 2009 (mainly due to technological learning and lowering of investment costs in last three years), an **annual adjustment of the agreed FiT with the inflation rate in the Euro-zone** is foreseen. This measure, certainly, makes the FiT more attractive to investors.

*Risks and opportunities for RES-E investments in Serbia*

One of the major risks for doing business in Serbia is a high level of corruption. In the **Figure 4-10** it is shown that, according to the "freedom from corruption" index, Serbia belongs to repressed countries – its index is below the world average and far below Austrian one.

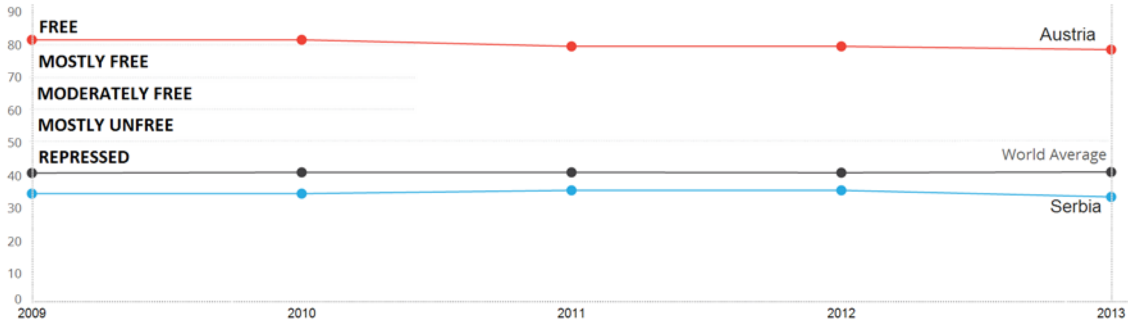



**Figure 4-10: Freedom from corruption: Serbia vs. Austria vs. World Average**
*source: 2013 Index of economic freedom, www.heritage.org/index/*

Overall, the RES market in Serbia is a market in an early stage of development, with the associated opportunities and risks.

Some of key opportunities are:

- RES strategy in place (NREAP),
- attractive FiT system (12 years, Eurozone inflation rate adjustment, ...),
- lack of medium and large competitors in RES-E market, especially in wind and PV,
- a good RES potential,
- ambitious government RE targets defined in NREAP (1092 MW until 2020),
- a well developed and managed E-grid.

Some of key risks are:

- short run substantial risks regarding implementation of relatively new procedures, due to immaturity of the RES sector,
- too complex and time consuming permitting procedure,
- land ownership and cadastral issues,
- FiTs are not yet cost-reflective, especially not for PV ground installations, as it will be explained in the case study in the next section,
- separation of distribution and supply in the electricity sector recently done but not proven in practice,
- E-grid access rules still to be proven in practice,

- Serbia has brand new legislative framework on energy efficiency in place, with unclear implementation plan,
- low caps on some RES-E until 2020 (e.g. only 10 MW for PV as stated in NREAP),
- last but not least – according to EU regulation, Serbia is not allowed to export renewable power to EU, until it has already achieved its own RES 2020 target approved by the EU.

## 4.2. Numerical example according to the IRMP framework

**The idea** behind this business case is briefly explained in the following text. Considering that Serbia:

- has established an attractive FiT system,
- has committed itself to RES development through NREAP,
- has planned installation of RES-E power plants in total capacity of 1092 MW until 2020,
- has lack of medium and large size competitors in the RES-E market,
- became EU member candidate in 2012 (and negotiations to entering EU are supposed to start in Jan 2014),
- will liberalize its electricity market as of 2014 for industrial (commercial) and as of 2015 for residential (household) sector,

a corporate from the EU has decided to enter Serbian RES-E market by developing and operating portfolio of wind and PV power plant projects of different sizes (small, medium and large) within limited budget of EUR 400 million[39]. In its prefeasibility study, the corporate has a list of 12 short listed projects with a total CAPEX of EUR 500 million. By using the ROV and the portfolio optimization approach, the corporate shall identify the best portfolio of wind and PV projects which will fit to the budget constraints, by hedging risks and quantifying uncertainties which might appear during the projects development and operation. Due to complexity of calculation, the ROV is applied to one wind and one PV power plant project, while the portfolio optimization at the end of this section is carried out over a mix of twelve projects (six wind and six PV), in the form of a basic demonstration of the portfolio approach to real options.

As already mentioned in the **Chapter 1.2** (Research methodology), the numerical example in this business case follow the IRMP framework recommendations consisting of eight steps. The main focus has been put on the steps: (3) Risk modeling of the NPV base case, (4) Risk analysis by using MCS, (5) Risk mitigation – the real options problem framing, (6) Risk hedging through real options modeling and analysis (which is the most comprehensive steps) and (7) Risk diversification - portfolio optimization[40]. The steps (1) Risk identification, i.e. qualitative management screening and (2) Risk prediction, i.e. time-series and regression forecasting, have been explained in terms of their general application, while the step (8) Risk management, reporting and permanent update analysis is illustrated in various tables and charts in the **Addendums 10-21**.

---

[39] Entering strategy itself is not a subject of this work, but application of the ROV in the RES-E portfolio strategy of the corporate which already decided to enter Serbian electricity market.

[40] Due to simplification, the projects used in this step are arbitrary and have no continuity with the projects applied in the previous steps.

**(1) Risk identification, i.e. qualitative management screening**

This is the first step in any ROV, as management has to decide which projects, ideas or strategies are subject to valuation (quick penetration to new market due to competitive advantage, new product development, etc.). In this step various risk and uncertainties are identified during framing the problem by management and by multidisciplinary team if required, but on macro level.

**(2) Risk prediction, i.e. time-series and regression forecasting**

In this step, the business analysts are focused on estimating probabilities on future events using available historical time-series or comparable data. If such data doesn't exist, other qualitative forecasting methods can be used, such as Delphi method[41], subjective guesses, expert opinions, growth trend assumptions, check lists, HAZID[42], cause-effect diagrams. Brainstorming sessions and workshops are also recommended in this step. Mun proposes using the Risk simulator software tool. Besides this software, the author recommends the Crystal Ball, which has been successfully used in this business case calculation.

**(3) Risk modeling of the NPV base case**

In this step a DCF model for the base case scenario is created for each project which has passed previous two steps.

For the purpose of this business case and due to simplification of very complex ROV calculation, it will be assumed that one 30 MW wind farm project and one 5 MW PV project have successfully passed screening and forecasting steps.

The base case scenario refers to electricity generation over the period of 25 years, where the first twelve years are covered by FiT, next six years are modelled to be covered with FiT premiums[43] and the remaining period of seven years is market related. Electricity price escalation is set to 2% pa., which is very conservative considering currently very low electricity price in Serbia which is expected to rise after market liberalization in 2014 and 2015 (see the **Chapter 4.1.2**).

The discount rate is set to 12%. It is consisting of country specific risks, i.e. risk premium for Serbia of 6% (see **Addendum 3**), while the rest of 6% is the weighted sum of risk-free rate and project specific risks. Due to the fact that revenue risks are hedged

---

[41] Delphi method is a way to gain the experts' agreement or disagreement about the problem. The Delphi facilitator should aggregate the opinion received by al experts, and send them back to the experts as an anonymous feedback. The experts might revise their opinions and/or create new ideas or keep the previous ones. The process is repeated 4-5 times, and areas of agreement/disagreement documented. The main advantage of Delphi method is avoidance of direct mutual influence on opinions and judgments among experts.

[42] HAZard IDentification, is an early stage (Conceptual, Front-End) hazard analysis tool in the plant life cycle, which identifies scenarios with consequence affecting beyond plant boundary.

[43] this is just an assumption, it is not defined in the current Serbian FiT policy.

by the FiTs guaranteed by the Government, and that the FiTs are adjusted every year according to the inflation rate in Eurozone[44], it has been decided to use lower discount rate of 8% during the FiT period[45]. At the same time, discount rate of 8% has been also proposed by Serbian Ministry of Energy to be used in the RES-E project feasibility analyses. Therefore, there are two risk adjusted discount rates applied in the DCF model: $r_1$=8% during the FiT period (first 12 years of the plant operation, i.e. $T_{op}$ = 1–12year) and $r_2$=12% after the FiT period, until the end of the investment horizon, i.e. from $T_{op}$= 13–25year. Currently, the FiT for wind is 9,2 c€/kWh and 16,25 c€/kWh for ground mounted PV plants.

The risk-free rate ***rfr*** =4%, is used for discounting of implementation costs in the Base case, as well as for discounting of the implementation costs in additional DCF modeling for calculation of expansion and contraction factors which will be used as inputs for proposed real options (invest, expand, repower and contract). The same ***rfr*** is used later for calculation of the risk-neutral probability (***p***) value in the binomial tree model during the ROV. The ***rfr*** of 4% is based on the Eurozone 10-year government benchmark bond yield, according to Damodaran's recommendation (see **Addendum 3**).

All costs assumptions used in the model are based on the data from (IRENA, 2013) and (Ecofys, Fraunhofer ISI, TU Vienna EEG, Ernst&Young, 2011). Corporate tax in Serbia is 15%.

In the base case model there are 37 assumptions in total, as illustrated in the **Addendum 10**. DCF chart with static and median P50 values is shown in the **Figure 4-12, top**, while the DCF calculation datasheet itself is shown in the **Addendum 11**. The results of base case static DCF calculation of both projects are shown in the **Table 4-1**. It is clear that, the wind farm project shows better results than the PV plant, which NPV indicates it is deeply out-of-the-money. No matter to that, the ROV will proceed for the both projects in the next step, in order to check if the MCS applied to the PV project can give us some indications on the possible profitability of this project.

**Table 4-1: Base case static DCF results for the wind and PV projects**

*source: the author*

| | WIND | PV |
|---|---|---|
| **NPV** | **3.554.478 EUR** | **-1.164.387 EUR** |
| **Annuity** | 1.724.927 EUR | 173.612 EUR |
| **IRR** | 11,415% | 8,244% |
| **PI** | 0,06924 | -0,11973 |
| | | |
| **LRGC** | 76,25 EUR/MWh | 159,43 EUR/MWh |
| **SRGC** | 18,77 EUR/MWh | 23,93 EUR/MWh |

[44] assumed 2,0% according to the ECB mid-term forecast (*source: http://www.ecb.europa.eu/stats/prices/indic/forecast/html/table_3_2013q3.en.html*)

[45] but the possible OPEX escalation is only partly hedged in this way.

**(4) Risk analysis by using MCS**

As the results from the previous step are static ones, i.e. based on single inputs, they are of little confidence, considering that future cash flows are highly uncertain. In order to get more reliable value of the project, Monte Carlo simulation shall be applied. Before running MCS, appropriate probability distributions should be set for each of uncertainties in the DCF model. There are 15 uncertainties identified in the model: two risk-adjusted discount rates ***r1*** and ***r2*** [%], risk-free rate ***rfr*** [%], capacity factor [%], "market"[46] electricity price in T=0 [EUR/MWh], annual market electricity price escalation [%], inflation rate in the Euro-zone [%], specific investment costs [EUR/MW], specific O&M costs [EUR/MW/y], other costs [%], annual OPEX escalation [%], corporate income tax [%], annual CAPEX reduction due to experience and learning rate [% of specific investment costs], FiT premium after the FiT period [EUR/MWh], duration of the FiT premium guarantee period [years]. Probability distributions for each of them have been chosen as illustrated in the **Addendum 10**.

After 50.000 trials have been conducted on the DCF model, NPV sensitivity results (**Figure 4-11, left**) show that the Wind farm project is dominantly sensitive (ca. 66%) to the capacity factor variations. The second ranked uncertainty is discount rate ***r1*** (ca. 14%), the third ranked is electricity price escalation (ca. 5%), while all other uncertainties contribute with less than 15% in total. On the other hand, the NPV of the PV project (**Figure 4-11**, **right**) is highly sensitive to specific investment costs (ca. 60%), followed by capacity factor (17%) and discount rate ***r1*** (ca. 14%), while all other uncertainties contribute with less than 10% in the total sensitivity.


**Figure 4-11: NPV sensitivity for the Wind project (left) and PV project (right)**

*source: the author*

The median NPV (P50) value for the Wind farm project after the simulation is 213.965 EUR, i.e. slightly above zero, which is tremendously different result in comparison to

[46] There is still no open electricity market established in Serbia.

the static NPV value obtained in previous step (comparison of static and P50 DCF is shown in the **Figure 4-12, top** and the trend chart with certainty band in the **middle)**. The $NPV_{P50}$ for the PV project is even worse, as shown in the **Table 4-2**.

**Table 4-2: Comparison of static NPV (before MCS) and "dynamic" $NPV_{P50}$ (after MCS), for the wind and PV projects**

| | WIND | PV |
|---|---|---|
| NPV | 3.554.478 EUR | -1.164.387 EUR |
| $NPV_{P50}$ | 213.965 EUR | -3.218.122 EUR |

At the same time, certainty (cumulative probability) that the Wind farm NPV will be > 0 is only 51,9%, as depicted in the **Figure 4-12, bottom,** while the certainty for positive NPV of the PV project is 0%, i.e. there is 100% probability that the PV project will fail under given assumptions! No matter to that, it has been decided to proceed valuation of the both projects in the next step, in order to check if the real options applied to the PV project can make it profitable, as well as how much the real options can increase the total project value of both projects.

Another application of the MCS in the ROV is for the **volatility estimate**. As explained in the **Addendum 6.5**, the *logarithmic present value returns* approach will be used in this business case. It is based on the standard deviation of the variable X:

$$X = \ln\left(\frac{\sum_{i=1}^{n} PVCF_i}{\sum_{i=0}^{n} PVCF_i}\right) = \ln\left(\frac{\frac{CF_1}{(1+D)^0} + \frac{CF_2}{(1+D)^1} + \frac{CF_3}{(1+D)^2} + \ldots + \frac{CF_N}{(1+D)^{N-1}}}{\frac{CF_0}{(1+D)^0} + \frac{CF_1}{(1+D)^1} + \frac{CF_2}{(1+D)^2} + \ldots + \frac{CF_N}{(1+D)^N}}\right)$$

The cash flow for the $PV_0$ has been frozen during simulation, as recommended by Mun (2010). Discount rates for the cash flow stream for the variable X calculation have been temporarily set to the risk-free rate (4%), and after that real discount rates have been reset to their original value. It is important that the nominator remains unchanged, while only the numerator is simulated. Volatility is a standard deviation ($\sigma$) of the variable X. The result is 12,70%. In addition, volatility has been calculated also with unfrozen risk-free discount rate, and the result is 13,45%. The final value of the volatility for the **Wind project** is rounded to **13,00%** (see **Addendum 11, last row**). Volatility for the **PV project** has been computed in the same way and the result is **8,50%**.

Furthermore, according to the recommendations given by Van Putten and MacMillan (2004) mentioned in the **Chapter 2.3**, revenue volatility and cost volatility have been calculated separately in order to examine if there is a need for the volatility adjustment. After running MCS over cash flow streams separately for revenue and costs, it appears that revenue volatility (11%) is greater than cost volatility (7%), which means there is no need for the volatility adjustment.

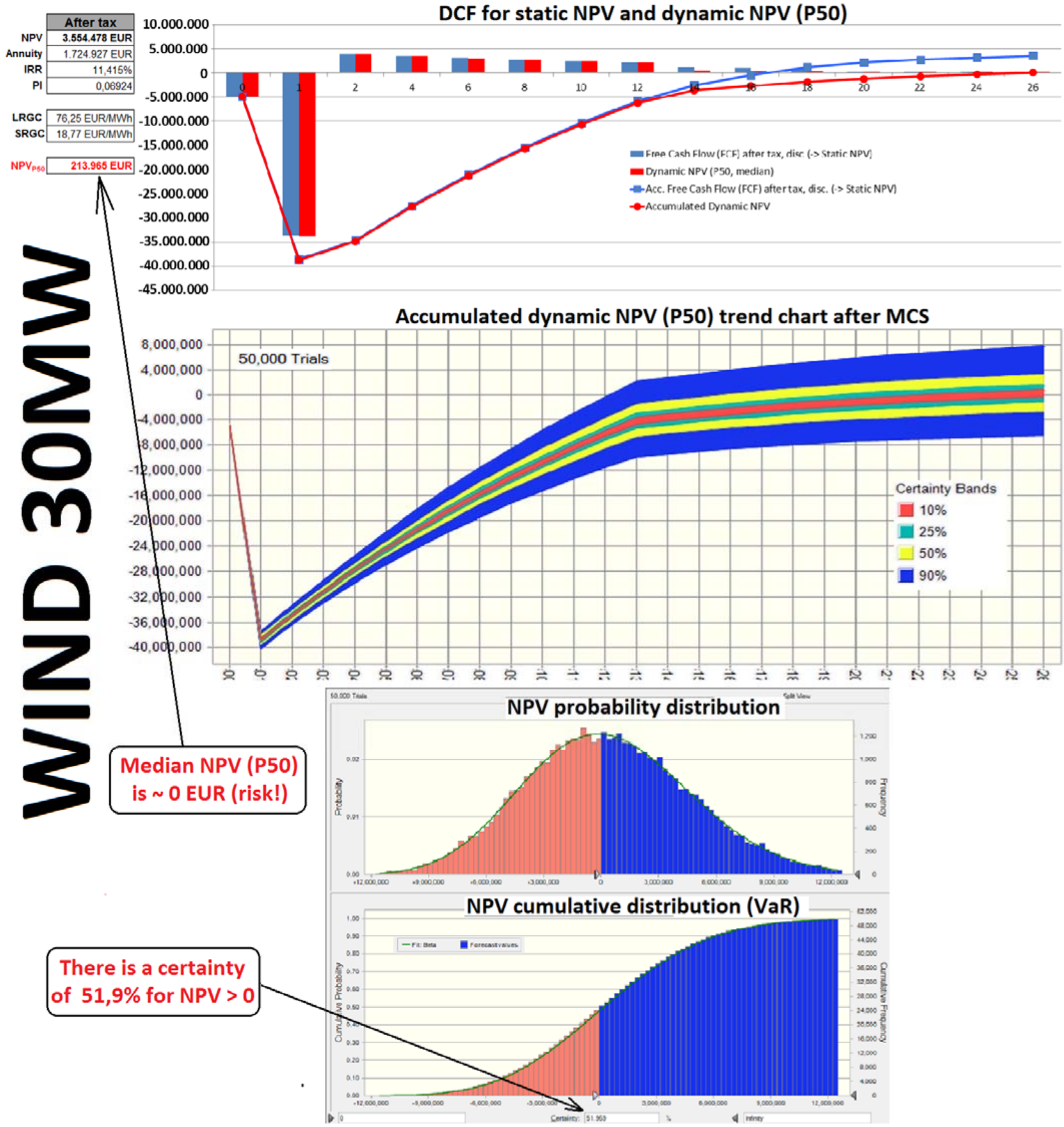



**Figure 4-12: Wind farm business case DCF static vs. P50 (top), trend chart with certainty band (middle) and static NPV probability distribution[47] after MCS (bottom)**

*source: the author*

[47] best fit = Beta distribution

**(5) Risk mitigation – the real options problem framing**

In this step it will be identified which type of the real options (sequential, expand, abandon, contract, etc.) can be applied, in which way (American, European) and when (maturity), in order to hedge downside risks as well as to take advantage of the upside opportunities.

Corporate RES-E projects are capital investment projects with a CAPEX volume commonly in millions of EUR, which means they are subject to certain project management rules related to phased approval of the CAPEX portions. In that regard, a sequential real option to invest in the construction of the Wind farm and PV plant project will be examined first. In case of a negative outcome of the sequential option valuation (negative eNPV value), it will be decided to abandon further activities in the project and to try to sell already obtained permits and engineering design for a salvage price. In case of a positive eNPV value of the sequential option – construction and commissioning will be executed and the plant will start to operate in one year[48].

After two years of operation, following three options will be considered for exercising: (1) to expand the plant capacity in case of positive market response and favorable outcomes in first two years of operation[49] or (2) to abandon the business and to try to sell the plant for a salvage price in case of negative outcomes or (3) to keep the option open, i.e. to continue the business as it is, with unchanged plant capacity. All three mentioned options are mutually exclusive.

After the 2nd year of operation ($T_{op}$=2), there is a bifurcation in the strategy tree model to two independent paths, namely "the blue path" and "the red path". Both paths end in the first year after FiT expiration ($T_{op}$=13), but they consist of different mutually exclusive options.

The following options for "the blue path" have been considered in the Top-13: (1) to repower the whole plant by replacing existing WTG / PV modules with new more efficient ones and with higher capacity in case of favorable outcomes and expectations for further period[50], or (2) to contract half of the plant capacity in case of slightly positive outcomes, but not promising expectations for further period - and to try to sell the half of the plant capacity for a salvage price[51], or (3) to abandon the business and to

---

[48] Due to simplification of the calculation it has been considered that the construction and commissioning phase will take one year.

[49] The author considered two years as a minimum period for proofing capacity factor assumptions used for the ROV, and which are based on the wind speed and selected WTG in case of wind farm project, i.e. on the solar irradiation and selected PV modules in case of the PV plant project.

[50] In that regard in the DCF model we assumed with 50% probability (modeled as Bernoulli Yes-No distribution), that after expiration of the FiT period the government will introduce Feed-in-Premiums (FiP) in total duration of six years.

[51] Option to contract in this case can be easily exercised due to modularity of the wind and PV tecchnologies.

try to sell the plant for a salvage price in case of negative outcomes or (4) to keep the option open, i.e. to continue the business as it is, with unchanged plant capacity till the end of the investment horizon ($T_{op}$=25).

"The red path" considers following options in the $T_{op}$=13: (1) to expand the whole plant with new more efficient WTG / PV modules in case of favorable outcomes and expectations for further period[52], or (2) to abandon the business and to try to sell the plant for a salvage price in case of negative outcomes, or (3) to keep the option open, i.e. to continue the business as it is, with unchanged plant capacity till the end of the investment horizon ($T_{op}$=25).

All the time – from the sequential option in the year $T_{op}$=-1[53] to the first year after FiT expiration $T_{op}$=13, the abandon option is permanently present in the model in the form of an American option. All other options mentioned above are European options, i.e. they are modelled to be exercised exactly at the proposed time ($T_{op}$=-1, $T_{op}$=3 and $T_{op}$=13).

All above mentioned options and paths are illustrated in the multi-phased sequential compound (nested) mutually exclusive path-dependent real options strategy decision tree for the wind farm project in the **Figure 4-13**, while the detailed RO strategy decision tree which includes expansion, repower and contraction factors, and exercise prices per years, is shown in the **Addendum 12**.

Due to simplification, only the strategy decision tree for the wind farm project is depicted, since the author finds the PV plant project as a not right candidate for further real options valuation in details, which will be proven in the next step.

Option to defer is not considered in this business case since the investor decided not to wait but to invest immediately due to strategic positioning in still undeveloped Serbian RES-E market. Option to switch is not applicable in this business case.

---

[52] in that regard in the DCF model it has been assumed with 50% probability (modelled as Bernoulli Yes-No distribution), that after expiration of the FiT period the government will introduce Feed-in-Premiums (FiP) in total duration of six years.

[53] $T_{op}$=-1 and $T_{cf}$=1 have been used interchangeably in this work

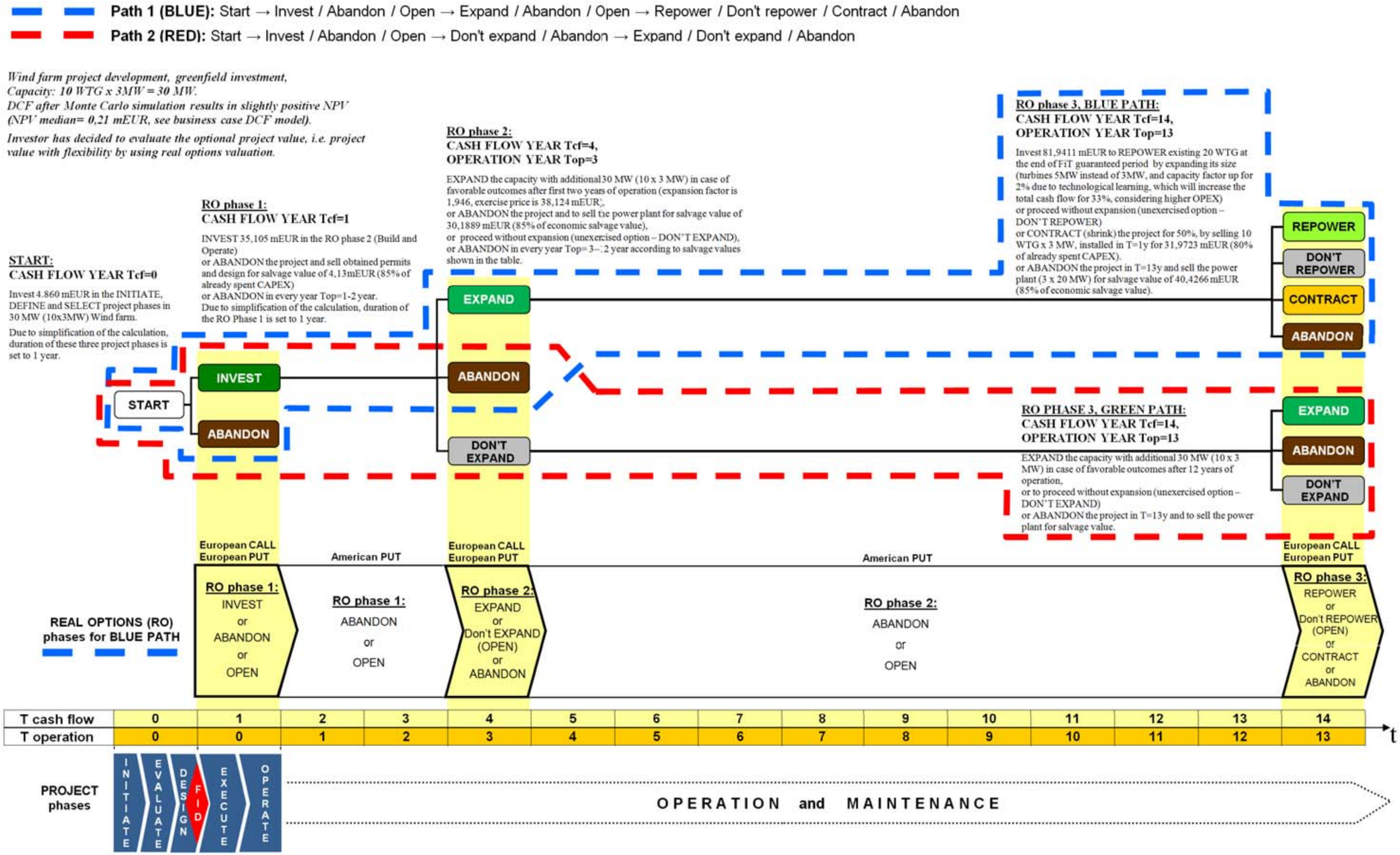



**Figure 4-13: Multi-phased sequential compound (nested) mutually exclusive path-dependent real options strategy decision tree**

*source: the author*

**(6) Risk hedging through real options modeling and analysis**

In this step the full power of ROV will be demonstrated. Firstly, underlying asset value binomial tree have to be calculated in a way explained in the **Addendum 5.2**. The median present value of the base case DCF model after MCS is **$PV_{,P50}$ = 38.985.685 EUR**, and this value is taken as the underlying asset value (the present value of future cash flows) in further calculation. In the **Table 4-3**, inputs for the underlying asset value tree (***u*** and ***d,*** where ***d = 1/u***) have been calculated. Risk neutral probability ***p*** and ***q*** (= ***1-p***) are also shown in the table. These will be used later for the real options value calculation through the backward induction technique.

**Table 4-3: Inputs for the wind farm project binomial tree**

| period: T=1-25yr | |
|---|---|
| Volatility | 13,00% |
| h(T) | 1 god |
| risk free rate | 4,00% |
| u | 1,139 |
| d | 0,878 |
| p | 0,6241 |
| q | 0,3759 |
| Dynamic $PV_{,P50}$ | 38.985.685 |
| Static PVo | 42.169.670 |

The underlying asset value binomial tree of the Wind farm project is shown in the **Addendum 13**. Upper and lower bounds of the underlying asset value binomial tree create cone of uncertainty. As the binomial tree follows log-normal model, the upper and lower bounds in logarithmic scale are straight lines, as shown in the **Figure 4-14**.

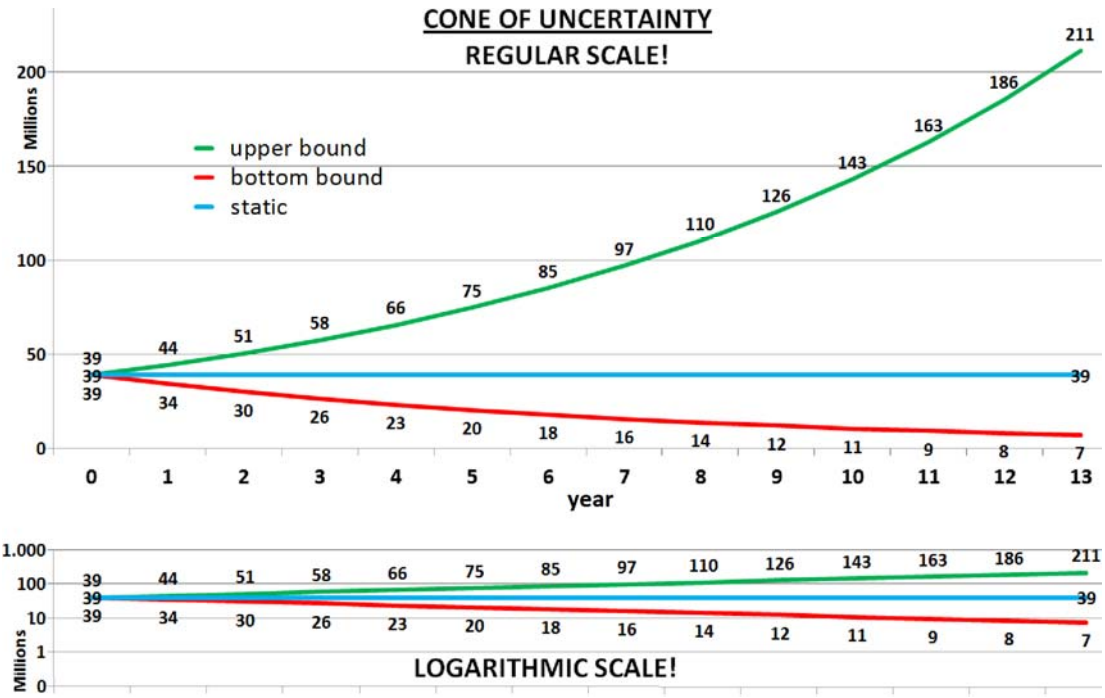



**Figure 4-14: Underlying asset cone of uncertainty**
*source: the author*

Therefore, the cumulative present value of the cash flows in the $T_{op}$=13 without application of the real options (i.e. without flexibility) as well as without implementation costs, is most likely to be within the range between ca. 211 mEUR (upper bound) and ca. 7 mEUR (lower bound).

In the next step, the sequential option to invest in the construction of the Wind farm will be examined, according to the workflow depicted in the **Figure 4-15**. The project is divided into five standard project management phases: Initiate, Evaluate, Design, Execute and Operate. Each of them ends with the key milestone. From real options staging point of view, Initiate Evaluate and Design phases can be grouped into RO phase 1 (during which the feasibility study, basic and detailed engineering, permitting and tendering tasks will be realized) and the last two – Execute and Operate in the RO phase 2 (construction and commissioning). Due to simplification, duration of each of two RO phases is rounded to 1 year.

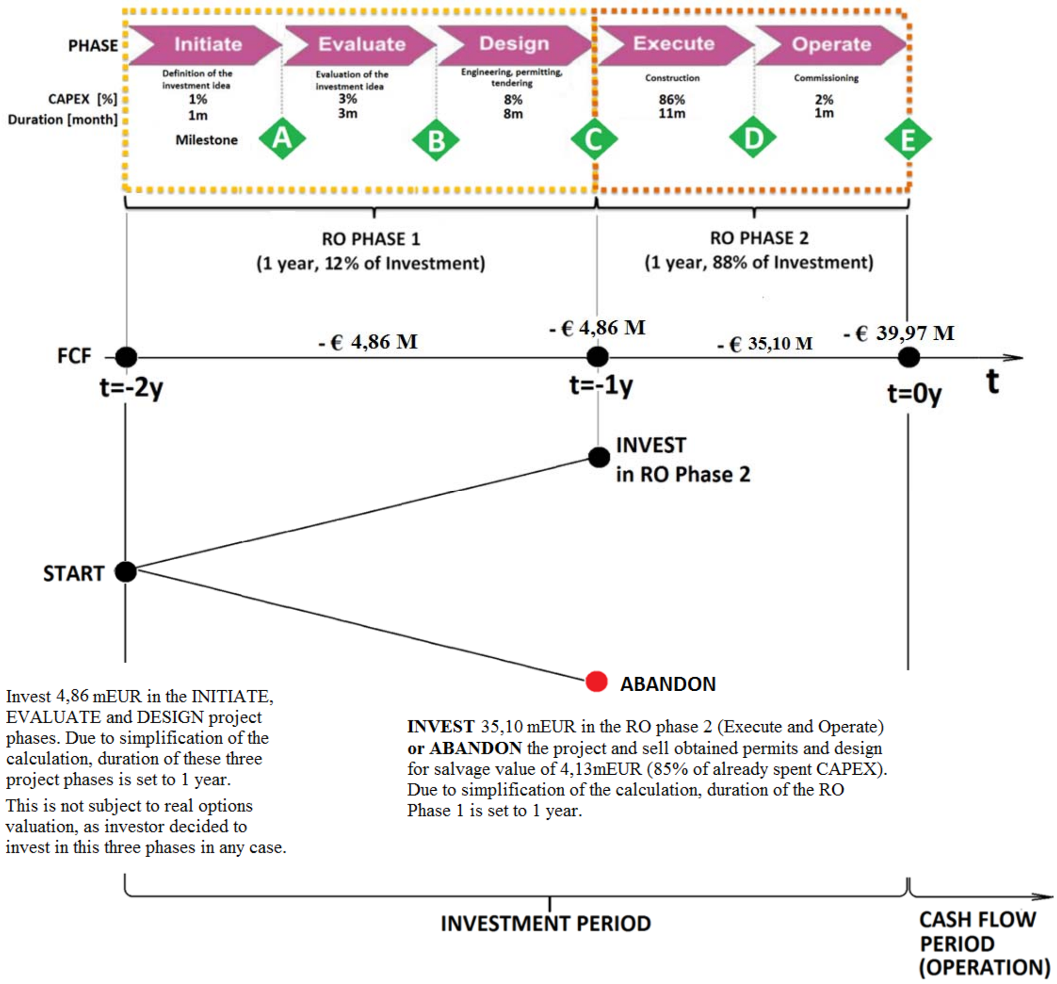



**Figure 4-15: Sequential real option set up for the Wind farm project**

*source: the author*

At the end of the 1st year of the project development, it has to be decided on investment in the construction phase, i.e. on building the wind farm for 35,10 mEUR or not, depending on the successful completion of the RO phase 1. Milestone C represents the FID (Final Investment Decision). An alternative solution is to Abandon the project for the salvage value of 4,13 mEUR. The deferral real option is not considered in the model.

After the valuation, the value of the project with flexibility of 38.985.685 EUR is obtained (which is equal to $PV_{,P50}$), as depicted in the binomial tree in the **Figure 4-16**:

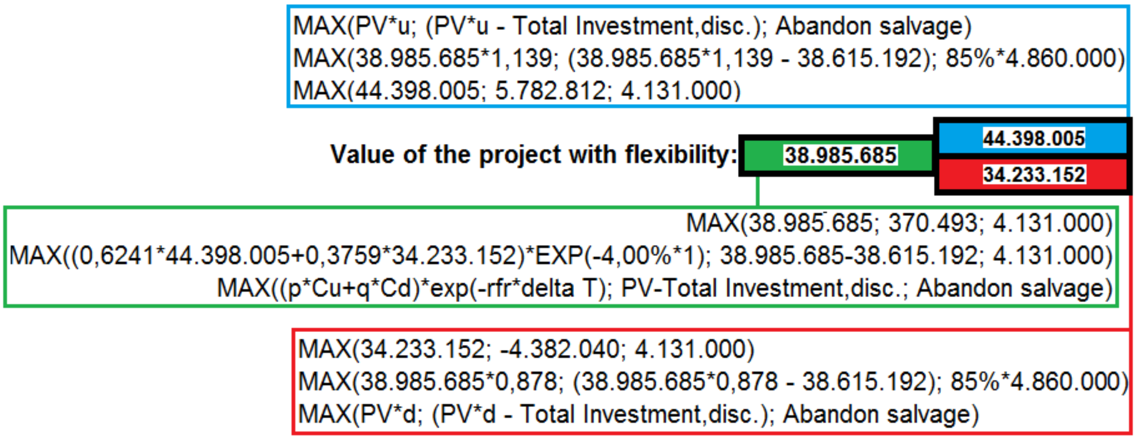



**Figure 4-16: Binomial tree for the wind farm project sequential option valuation**

*source: the author*

Considering that value of the *Project with flexibility* minus *Implementation costs (Invest in the* $1^{st}$*&*$2^{nd}$ *RO phase)*$_{,discounted}$ *= 38.985.685 – 38.615.192 = 370.493 EUR > 0*, it is decided to invest in the 2nd RO phase (Construction) of the Wind farm project!

However, the result of the same calculation performed for the PV project is negative (–1.916.816 EUR), which means that we shall NOT invest in this project, under given assumptions. Therefore, this is the end of the PV project valuation in this business case. The only way how the PV plant project may be turned into the profitable one from real options application perspective, is either by applying a deferral option (i.e. to wait and see what will be the specific cost and FiT price development in the future, and to act accordingly) or by applying a growth option (i.e. to invest now in the loss-making business in order to open the door for possibly profitable follow-up investments in case of favorable market development in the near future), or, finally, by applying learning option (e.g. investing in construction of a small to medium pilot PV plant which may be quickly commissioned in case of favorable market conditions). Numerical example with application of deferral, growth and learn real options is out of the scope of this work, as the author finds the ROV of the wind farm project comprehensive enough for demonstration of the multi-phased compound real options within this scope of this work. For more details on deferral, growth and learning real options see the **Chapter 2.1**: Real options taxonomy.

Before continuing ROV - expansion, repower and contraction factors have to be calculated separately for each of the options, due to different discount rates applied in the model ($r_1$, $r_2$ and rfr). This is shown in the **Addendum 14**. These factors will be used for further ROV, while their $P_{50}$ values will be used for the ROV optimization, together with $P_{50}$ values of the exercise prices of all real options applied in the model.

As already mentioned above, only "the blue path" will be used for the ROV as more complex than "the red path".

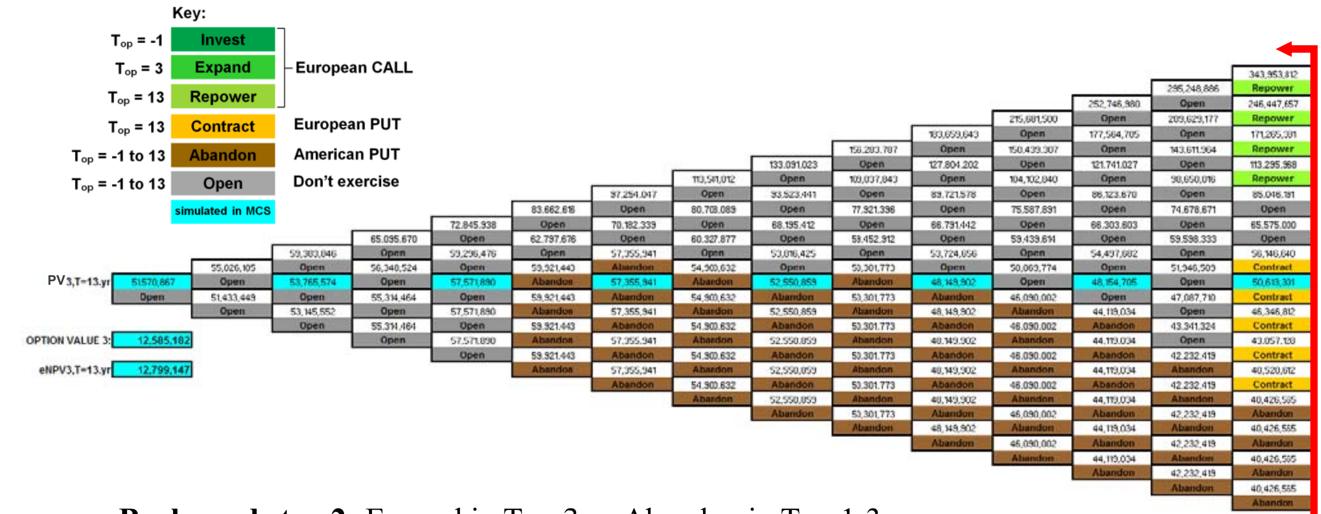
Due to three time periods which exist in the RO model ($T_{op}$=13, 3 and -1), it will be necessary to compute real option value in three steps – one tree per each period, starting from the last year in the period on the right side ($T_{op}$=13) and going backward via ($T_{op}$=3) to the start of the project on the very left side of the tree ($T_{cf}$=1, i.e. $T_{op}$=-1).

The next step is to do real option valuation of the three binomial trees: in the first tree real option value will be calculated, starting from multi nodes in the $T_{op}$=13 and calculating back using backward induction technique in order to come to the first (starting) node on the left side, by using backward induction. Once the strategy tree have been established and accepted by the management, and underlying asset value binomial tree has been computed, real options can be valuated with the backward induction technique, i.e. starting from the Top operation year 13 (first year after FiT period) and going backward, via Expand option in operation year $T_{op}$=3, to the construction phase ($T_{cf}$=1, i.e. $T_{op}$=-1). As depicted in the decision tree, following options will be evaluated in the first tree ($T_{op}$=13): Repower / Contract / Open / Abandon. In the year 3 (after 2 years of operation), Investor should decide whether to Expand its power plant or not. As depicted in the Decision tree, following options will be evaluated in the second tree: Expand / Open / Abandon. In the final tree (third one), option to Invest in the construction phase or Abandon will be evaluated. The final value of the project with flexibility in the third real option tree is the value which accumulates all previous options into one value. All mentioned real options are mutually exclusive.

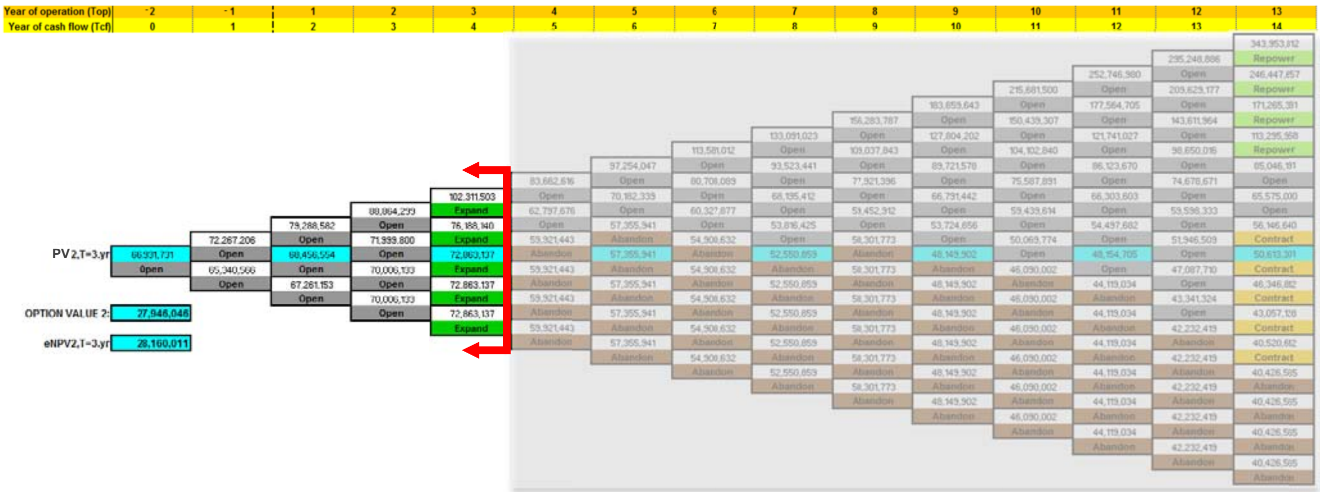
The binomial tree used for the ROV in this work, is an MS Excel based application, developed by the author. As it can be seen in the **Figure 4-17**, it is a user-friendly solution, which shows interactively the values and type of the real options per each node, depicted in different colours for better readability.

Furthermore, sensitivity analysis has been done for all trees and all options and the results are shown in the **Addendum 15** (ROV at $T_{op}$=13), **Addendum 16** (ROV at $T_{op}$=3) and **Addendum 17** (ROV at $T_{op}$=-1). For example, out of the sensitivity chart in the **Addendum 7**, bottom right, it can be noted that due to the real options compoundness, different variables drive the project value (eNPV) in different ranges (exercise price drives from -180% to -90% and expansion factor drives from 45% to 180%), etc.

**Backward step 1:** Repower in Top 13 or Contract in Top 13 or Abandon in Top 4-14




**Backward step 2:** Expand in Top 3 or Abandon in Top 1-3




**Backward step 3:** Invest in $T_{op}$ -1 (=$T_{cf}$ 1) or Abandon in Top -1

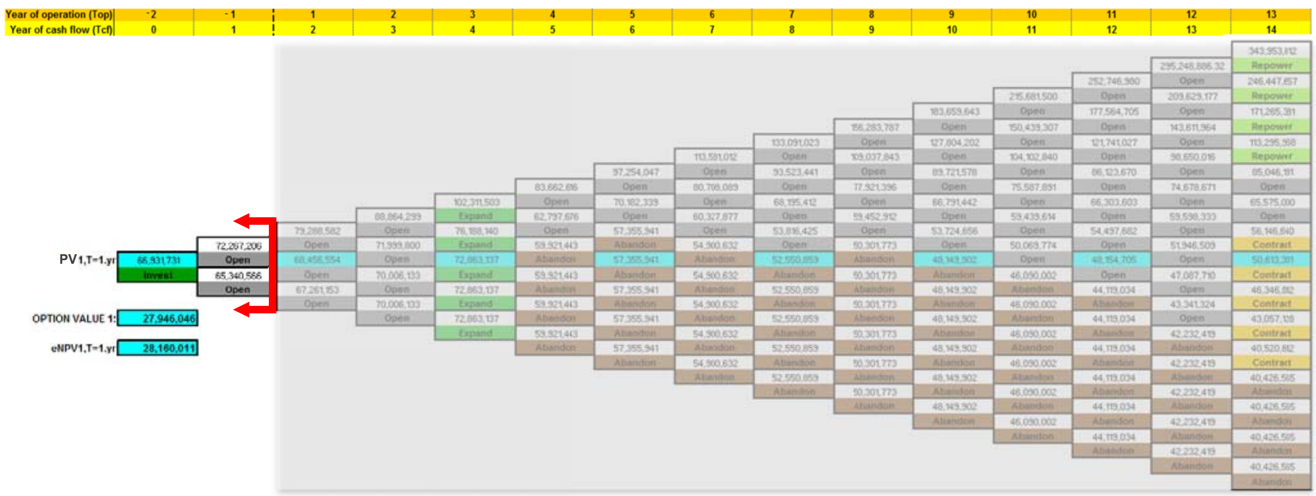
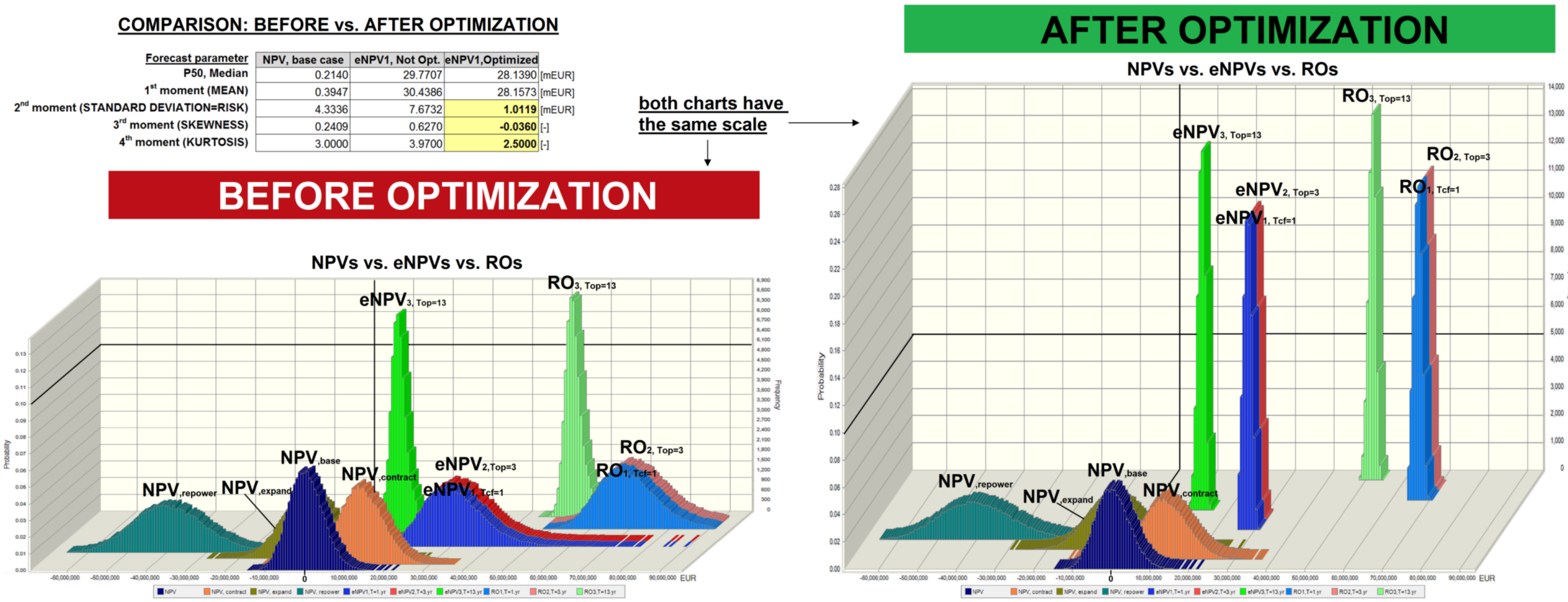



**Figure 4-17: Multi-phased sequential compound mutually exclusive path dependent real options binomial tree**

*source: the author*

The results shown in the previous figure are obtained after the model optimization by using $P_{50}$ (median) values for all exercise prices and factors (expand, repower and contract) applied in the ROV. The figure below illustrates the optimization results, while more detailed results are shown in the **Addendum 19.**



COMPARISON: BEFORE vs. AFTER OPTIMIZATION

| Forecast parameter | NPV, base case | eNPV1, Not Opt. | eNPV1,Optimized | |
|---|---|---|---|---|
| P50, Median | 0.2140 | 29.7707 | 28.1390 | [mEUR] |
| 1st moment (MEAN) | 0.3947 | 30.4386 | 28.1573 | [mEUR] |
| 2nd moment (STANDARD DEVIATION=RISK) | 4.3336 | 7.6732 | 1.0119 | [mEUR] |
| 3rd moment (SKEWNESS) | 0.2409 | 0.6270 | -0.0360 | [-] |
| 4th moment (KURTOSIS) | 3.0000 | 3.9700 | 2.5000 | [-] |



**Figure 4-18: ROV 3D overlay charts with the optimization results**

*source: the author*

**Optimal investment strategy**, after conduction of the optimization, considering given assumptions, is:

***Decision 1:*** **Invest in 1st RO phase** (Initiate, Evaluate and Design) in year $T_{cf}$=0 (=> $T_{op}$=-2). This initial Investment has not been subject to a real option analysis in this work, because the owner decided to do initial investment at its own risk, due to strategic positioning on Serbian electricity market, considering overall market situation (lack of competitors, market liberalization as of 2014/15 and increased demand for electricity in forthcoming period).

***Decision 2:*** **Invest in 2nd RO phase** (Execute, i.e. Construction and Operate i.e. Commissioning) in year $T_{cf}$=1 (=> $T_{op}$=-1).

***Decision 3:*** **Expand** the wind farm with additional 30 MW in the year $T_{op}$=3, after acceptable generation results in previous two years and increased market demand. Due to more efficient project management, EIA, construction and other permits for the extension was provided at the same time for the initial 30 MW installation.

***Decision 4.1:*** **Contract** in year $T_{op}$=13 (in case of less favorable market situation than expected), or **4.2: Repower** in year $T_{op}$=13 (in case of favorable market development, extension of FiT period or introduction of FiT premiums, as assumed in the model with Bernoulli (Yes-No) distribution from $T_{op}$=13 till $T_{op}$=19, or **4.3: Keep the option OPEN** (unexercised) until additional feedback from the market is available, or **4.4: Abandon** the project for a salvage value (in case of bad market situation or due to other strategic reasons).

According to the result of the optimization process done with MCS, by using $P_{50}$ results (median values) from the static model as inputs for the ROV, the best decision in $T_{op}$=13 is to CONTRACT, therefore **optimal strategy is to INVEST in $T_{cf}$=1, to EXPAND in $T_{op}$=3 and to CONTRACT in $T_{op}$=13**.

By comparing this value with the static $NPV_{P50}$ (= 213.965 EUR) which was used as a basis for the whole ROV, it can be noticed that the real option value $RO_1$ has expanded the $NPV_{P50}$ for 27.946.046 EUR:

**$eNPV = NPV_{P50} + RO_1 = 213.965 + 27.946.046 = 28.160.011$ EUR**,

while the project value with flexibility is:

$PV_{P50}$ base case[54] + $RO_1$ = 38.985.685 + 27.946.046 = 66.931.731 EUR

which is equal to the result obtained by the SLS software (**Appendix 18**).

Additional reason to choose the CONTRACT in $T_{op}$=13 as the best option is that it has better results of the Second moment (standard deviation, i.e. risk is lower!) as well as of

[54] Underlying asset value = $PV_{,P50}$ in this case

the Third moment (skewness) as it is negative (left skewed), i.e. there is a higher probability for greater returns. The Fourth moment (kurtosis) which is indication of probabilities of catastrophic events (potential for large gains or large losses) has quite acceptable value of 2,53 (was 3,93 before optimization, i.e. "”calibration”), as already shown in the **Figure 4-18**. Certainty of the static NPV>0 in the base case was 51,9% only, certainty of the non-optimized $eNPV_{,1}$>0 is 100%, but its sensitivity is multivariable dependent, while certainty of the optimized $eNPV_{,1}$ >0 is also 100%, but it is sensitive only to the risk free rate change, as shown in the **Figure 4-19, top.**

Sensitivity analysis of the final eNPV variables shows that ***rfr*** which was used for discounting of the implementation costs as well as for calculation of upside and downside risk neutral probabilities (***p*** and ***q***) in the real option binomial trees is **the only variable which drives the final eNPV value**, as illustrated in the final sensitivity chart of this ROV in the **Figure 4-19, bottom**. This enables much easier risk management and decision making process along the examined ROV period.

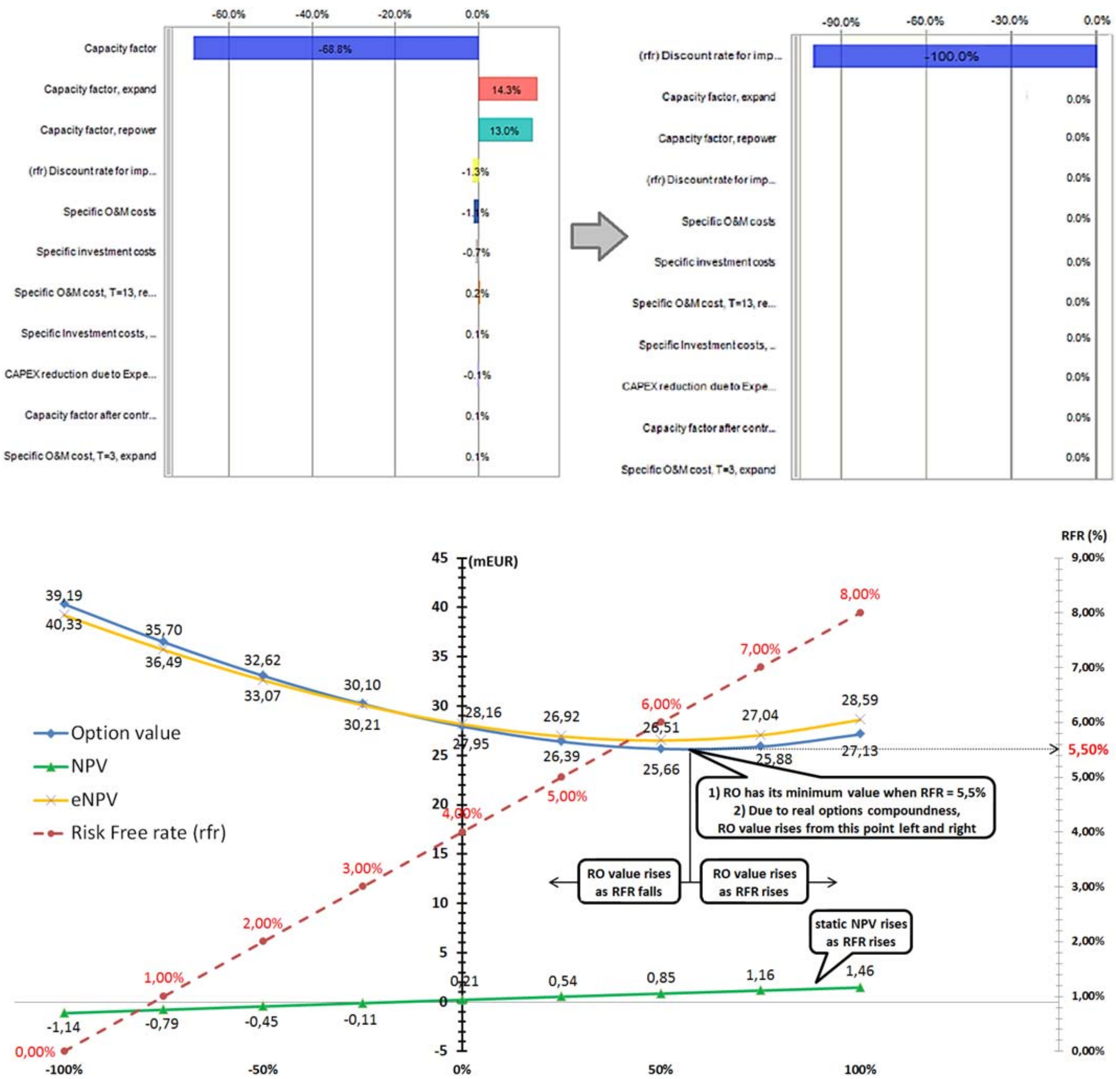



**Figure 4-19: The final sensitivity chart**

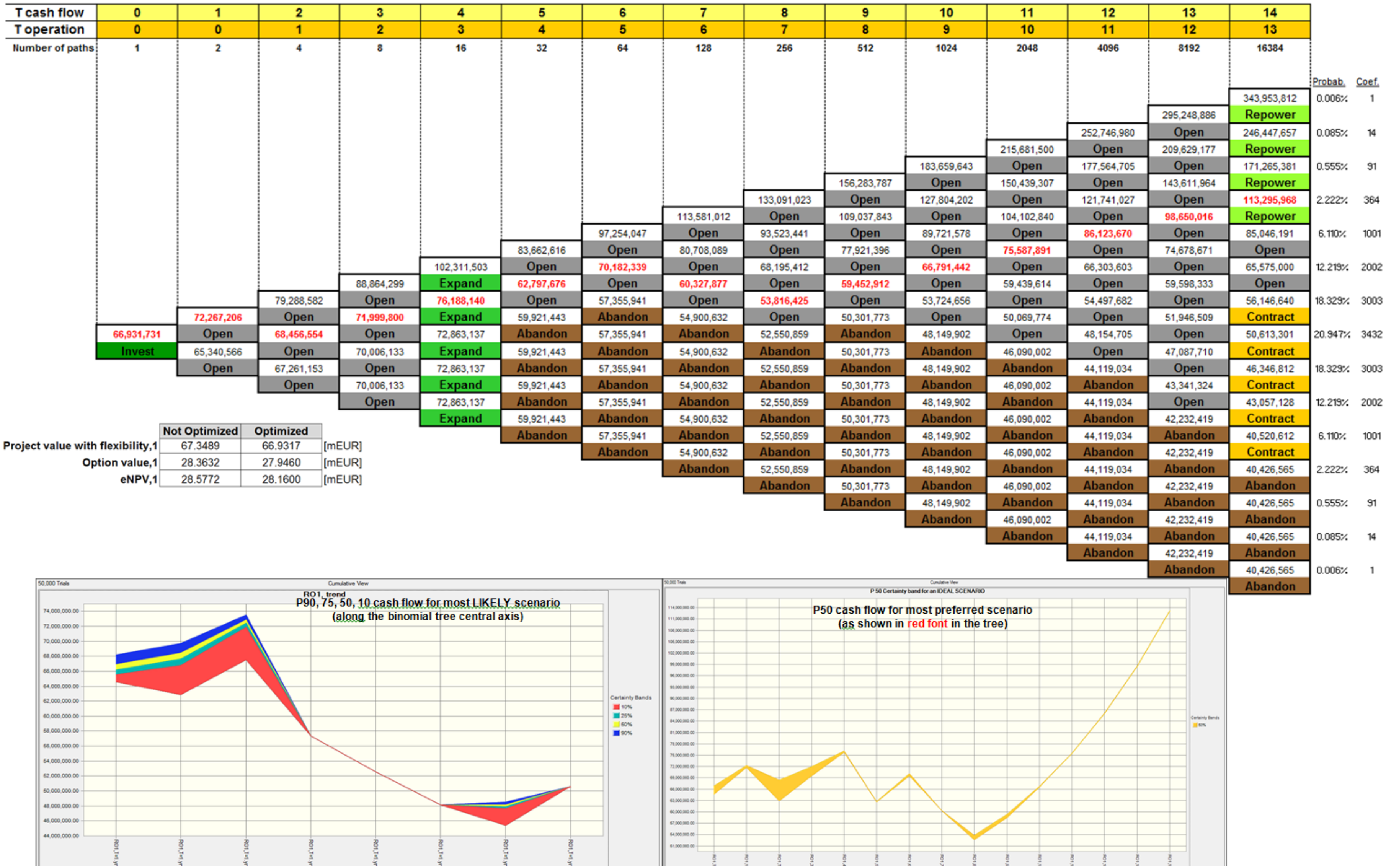
*source: the author*

Furthermore, the management can decide not to execute the Contract option in the $T_{op}$=13, because its value is lower than the Expand option in $T_{op}$=3 and much lower than the Repower option in year $T_{op}$=13. Instead, they can decide to execute more risky path, i.e. to force exercising the Repower option in $T_{op}$=13, with a preferred path per year as close to the binomial tree axis as possible (lower risk!), but always keeping the route towards the Repower node in the $T_{op}$=13 which is closest one to the central binomial tree axis. This path is depicted by red colored fonts in the **Figure 4-20**, while the trend charts with certainty bends are shown below the binomial tree in the same figure.

In order to illustrate complexity of the RO model, the number of possible paths is shown below the time scale – e.g. in the Top13, number of paths is 16.384. Another useful parameter for the analysis is shown on the right side of the binomial tree – it is Pascal triangle coefficient which shows number of possible combinations in the tree, e.g. maximum number of combinations is 3.432. Probability of occurrence of the cash-flow according to the figures stated in the binomial tree is highest for the cash-flow stream along the central axis (20,947%), but it falls constantly as it goes towards upper and lower bounds of the tree, in order to reach its minimum at the end nodes (0,006%).

The probability for the preferred path in its end node (Repower in Top13, fourth node from the top) is only 2,222%.

Nonetheless, by having prepared the RO strategy as shown in the **Figure 4-20**, the management has an opportunity to steer its strategy on an annual (quarterly / monthly) basis and to react immediately if the preferred cash-flow (depicted by red fonts) during the project life is below expected.




| | Not Optimized | Optimized | |
|---|---|---|---|
| Project value with flexibility,1 | 67.3489 | 66.9317 | [mEUR] |
| Option value,1 | 28.3632 | 27.9460 | [mEUR] |
| eNPV,1 | 28.5772 | 28.1600 | [mEUR] |

**Figure 4-20: Preffered RO strategy path per year, which maximizes returns (red fonts)**

*source: the author*

Since there are several real options per node, their **interactions** shown in the **Figure 4-21** have been examined according to the approach from (Trigeorgis, 1993)**,** whereby **the interaction value = the option combined value – the sum of separate option values.** For example, interaction value of *G = 12.040.360 – (9.367.078 + 8.273.388) = -5.600.106 EUR*. It is clear that all options interactions in the Tcf14 (=Top13) are negative due to opposite nature of the related options (call and put) in the same nodes (interactions from G to L). Interactions from C to F are neutral (=0). The figure below also shows that combination (not interaction) of two put options (abandon and contract, H=D&F14) has higher value than combination of a put and a call option (abandon and repower, I=E&F14), considering assumptions for the exercise prices and the factors used in the examined RO model. For better understanding, the real options **interactions charts** are illustrated in the **Addendum 20**.

| | | Combination of options | Tcf 1 (final "S" and "O" values) European backward step 3, American backward step 14 | | |
|---|---|---|---|---|---|
| | | | Project PV,Tcf1 (S,Tcf1) | Exercise price,Tcf1 (X,Tcf1) | Option value,Tcf1 (O,Tcf1) |
| EUROPEAN | 1 | A | 38.985.685 | 0 | 0 |
| | 2 | B | 38.985.685 | Inv 38.615.192 | 0 |
| | 3 | C | 44.658.367 | Inv 35.282.865 | 5.672.682 |
| | 4 | D | 48.352.763 | Inv 35.282.865 | 9.367.078 |
| | 5 | E | 47.259.073 | Inv 35.282.865 | 8.273.388 |
| | 6 | F,14 | 45.737.830 | Inv 35.282.865 | 6.752.145 |
| AME | 7 | F,1,4,14 | 45.753.457 | | 6.767.772 |
| | 8 | F,1-14 | 64.460.393 | | 25.474.408 |
| EUROPEAN | 9 | G | 51.026.045 | Inv 35.282.865 | 12.040.360 |
| | 10 | H | 48.355.730 | Inv 35.282.865 | 9.370.045 |
| | 11 | I | 48.338.537 | Inv 35.282.865 | 9.352.852 |
| | 12 | J | 51.029.012 | Inv 35.282.865 | 12.043.327 |
| | 13 | K | 51.029.012 | Inv 35.282.865<br>Aba 4.130.502 | 12.043.327 |
| AMERICAN | 14 | L | 66.931.731 | Inv 35.282.865<br>Aba 4.130.502 | 27.946.046 |
| | 15 | L, Tcf14,sep | 43.010.060 | Inv 35.282.865<br>Aba 4.130.502 | 4.024.375 |
| | 16 | L, Tcf4,sep | 51.026.045 | Inv 35.282.865<br>Aba 4.130.502 | 12.040.360 |
| | 17 | L, Tcf1,sep | 51.026.045 | Inv 35.282.865<br>Aba 4.130.502 | 12.040.360 |
| | 18 | L, Tcf14,cum | 51.570.867 | Inv 35.282.865<br>Aba 4.130.502 | 12.585.182 |
| | 19 | L, Tcf4,cum | 66.931.731 | Inv 35.282.865<br>Aba 4.130.502 | 27.946.046 |
| | 20 | L, Tcf1,cum | 66.931.731 | Inv 35.282.865<br>Aba 4.130.502 | 27.946.046 |

<u>Key:</u>

| | |
|---|---|
| A | Base case |
| B | Invest in Tcf1 only |
| C | Invest in Tcf1, Expand in Tcf4 |
| D | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14 |
| E | Invest in Tcf1, Expand in Tcf4, Repower in Tcf14 |
| F | Invest in Tcf1, Expand in Tcf4, Abandon in Tcf14 |
| G | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14 |
| H | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Abandon in Tcf14 |
| I | Invest in Tcf1, Expand in Tcf4, Repower in Tcf14, Abandon in Tcf14 |
| J | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon in Tcf14 |
| K | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon in Tcf1,4,14 |
| L | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon in Tcf1-14 |
| M,sep | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon separ. in Tcf1-14 |
| M,cum | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon cumul. in Tcf1-14 |

| | Option value | Combined value | Sum of separate | Interaction value |
|---|---|---|---|---|
| B | 0 | 0 | 0 | 0 |
| C | 5.672.682 | 5.672.682 | 5.672.682 | 0 |
| D | 9.367.078 | 9.367.078 | 9.367.078 | 0 |
| E | 8.273.388 | 8.273.388 | 8.273.388 | 0 |
| F14 | 6.752.145 | 6.752.145 | 6.752.145 | 0 |
| F1,4,14 | 6.767.772 | 6.767.772 | 6.767.772 | 0 |
| F1-14 | 25.474.408 | 25.474.408 | 25.474.408 | 0 |
| G (=D&E) | 12.040.360 | 12.040.360 | 17.640.466 | -5.600.106 |
| H (=D&F14) | 9.370.045 | 9.370.045 | 16.119.223 | -6.749.178 |
| I (=E&F14) | 9.352.852 | 9.352.852 | 15.025.533 | -5.672.681 |
| J (=D&E&F14) | 12.043.327 | 12.043.327 | 24.392.611 | -12.349.284 |
| K (=D&E&F1,4,14) | 12.043.327 | 12.043.327 | 24.392.611 | -12.349.284 |
| L (=D&E&F1-14) | 27.946.046 | 27.946.046 | 43.114.874 | -15.168.828 |

**Figure 4-21: Real options interactions results**
*source: the author*

ROV in 3D space by using **"Tomato garden" approach** according to (Luehrman, 1998), is illustrated in the **Addendum 21.** This approach confirms results of the ROV done with binomial tree, i.e. the most likely sequence of real options according to the "Tomato garden" ends with the *Contract in Top13* (region 3: "Probably later"), the second ranked is *Abandon in Top13* - also region 3: "Probably later", but with less favorable metrics ***NPVq*** (value-to-cost profitability index) and ***σ√t*** (annualized volatility index), while the least likely is to *Repower in Top13* (region 4: "Maybe later").

**(7) Risk diversification - portfolio optimization**

Portfolio optimization is an optional step in the IRMP framework, but it will be shown in this case study, as the author finds it applicable in corporative strategy and capital budgeting. At the same time, it is a useful and logical extension of the real options valuation which was examined in the previous section. More details on theoretical concepts of the portfolio approach to real options are given in the **Addendum 6.7**.

In this example we will demonstrate both: inter–project and intra–project compoundness in the context of portfolios of real options. Intra-project compoundness are examined through *Tomato garden* model executed with the results from already shown real options valuation *(multi-phased sequential compound mutually exclusive path-dependent real options of the wind farm)* in previous section, while the basic principles of the portfolio optimization for inter-project compoundness will be shown by applying *the efficient frontier* method on the portfolio consisting of twelve RES-E projects (Wind and PV) and ranking of best portfolios by *Sharpe ratio* at the end.

Combination of these two technologies is chosen by purpose, as they are complementary technologies from electricity generation point of view, as was explained in the **Chapter 3** (*see* **Figure 3-2**, Fraunhofer 2013).

The RES-E portfolio base case is consisting of two groups of projects – one group of six wind and one group of six PV greenfield projects, each of them additionally segmented in respect to costs – into two small (< EUR 10 million), two medium (EUR 10 – 50 million) and two large (> EUR 50 million) power plant projects, namely:

*WI_L$_1$ (Large Wind plant 1), WI_L$_2$ (Large Wind plant 2), WI_M$_1$ (Medium Wind plant 1), WI_M$_2$ (Medium Wind plant 2), WI_S$_1$ (Small Wind plant 1), WI_S$_2$ (Small Wind plant 2), PV_L$_1$ (Large PV plant 1), PV_L$_2$ (Large PV plant 2), PV_M$_1$ (Medium PV plant 1), PV_M$_2$ (Medium PV plant 2), PV_S$_1$ (Small PV plant 1)* and *PV_S$_2$ (Small PV plant 2),*

with the total estimated CAPEX of EUR 500 million. Project returns are expressed through expanded NPV (eNPV = static NPV + RO value), while the single project risk is expressed through its volatility.

The objective of the portfolio optimization is to select the combination of projects with maximum mean return, considering following constraints:

- maximum available portfolio budget is EUR 400 million (therefore EUR 100 million less than expected CAPEX),
- maximum number of project in the portfolio is 10, consisting of minimum 4 PV and 4 Wind projects – due to diversification,
- the Sharpe ratio (***Sh***) must be ≥ 2.

Due to simplification of this demonstration, we assumed inputs as shown in the **Table 4-4,** with weighted portfolio risk (volatility) of 82% and portfolio returns (eNPV) of EUR 41,00 million.

**Table 4-4: RES-E project portfolio - base case**

*Source: author*

| Project Code | Project name | eNPV [mEUR] | NPV [mEUR] | RO [mEUR] | Cost [mEUR] | Project Risk (Volatility) [%] | Return to Risk Sharpe Ratio [mEUR] | Profitability Index [-] | Selection |
|---|---|---|---|---|---|---|---|---|---|
| PV_L1 | Large PV1 | 4,75 | 1,25 | 3,50 | 92,00 | 35,00% | 13,57 | 1,014 | 1 |
| PV_L2 | Large PV2 | 7,00 | 2,50 | 4,50 | 88,00 | 32,00% | 21,88 | 1,028 | 1 |
| PV_M1 | Medium PV1 | 0,50 | 0,50 | 0,00 | 42,00 | 10,00% | 5,00 | 1,012 | 1 |
| PV_M2 | Medium PV2 | 2,50 | 0,50 | 2,00 | 35,00 | 15,00% | 16,67 | 1,014 | 1 |
| PV_S1 | Small PV1 | 1,75 | 0,75 | 1,00 | 9,00 | 25,00% | 7,00 | 1,083 | 1 |
| PV_S2 | Small PV2 | 2,50 | 0,50 | 2,00 | 5,00 | 11,00% | 22,73 | 1,100 | 1 |
| WI_L1 | Large Wind1 | 7,50 | 2,50 | 5,00 | 80,00 | 40,00% | 18,75 | 1,031 | 1 |
| WI_L2 | Large Wind2 | 5,00 | 1,00 | 4,00 | 75,00 | 30,00% | 16,67 | 1,013 | 1 |
| WI_M1 | Medium Wind1 | 1,50 | 0,50 | 1,00 | 35,00 | 12,00% | 12,50 | 1,014 | 1 |
| WI_M2 | Medium Wind2 | 3,75 | 0,75 | 3,00 | 28,00 | 13,00% | 28,85 | 1,027 | 1 |
| WI_S1 | Small Wind1 | 2,00 | 0,50 | 1,50 | 7,00 | 22,00% | 9,09 | 1,071 | 1 |
| WI_S2 | Small Wind2 | 2,25 | 0,25 | 2,00 | 4,00 | 12,00% | 18,75 | 1,063 | 1 |
| | | 41,00 | | | | | | | |
| | Project Portfolio Total | 41,00 | | Total Costs | 500,00 | 82% | | Total number of projects | 12 |
| | Goal | MAX | | Total Costs max: | 400,00 | | | Total number of projects, max: | 10 |

Project portfolio optimization has been executed by applying ***efficient frontier*** method, which is done by the *OptQuest* tool in the Crystal Ball software. After 100 simulations been performed over different combinations of "yellow" variables (column *Selection*) set either to 0 or 1 (the binary or Bernoulli distribution), each of them consisting of 50.000 trials randomly taken from "green" assumptions (columns *eNPV* and *Project risk)*, we got the result, i.e. the optimal portfolio **P1,** consisting of the following 9 projects (5 wind and 4 PV): $WI\_L_1$, $WI\_L_2$, $WI\_M_2$, $WI\_S_1$, $WI\_S_2$, $PV\_L_1$, $PV\_L_2$, $PV\_S_1$ and $PV\_S_2$. Therefore, projects $WI\_M_1$, $PV\_L_1$ and $PV\_L_2$ are excluded from the optimal portfolio. Total return (eNPV) of the P1 is EUR 36,50 million, total risk is 79% and total costs are EUR 388 million, as illustrated in the **Table 4-5** as well as in the bubble chart (**Figure 4-22**). Total number of simulated projects combinations is extremely high: 12! (= 479.001.600). This means that such analyses could not be performed without comprehensive software and hardware support.

**Table 4-5: The optimal RES-E project portfolio**

*Source: the author*

| Project Code | Project name | eNPV [mEUR] | NPV [mEUR] | RO [mEUR] | Cost [mEUR] | Project Risk (Volatility) [%] | Return to Risk Sharpe Ratio [mEUR] | Profitability Index [-] | Selection |
|---|---|---|---|---|---|---|---|---|---|
| PV_L1 | Large PV1 | 4,75 | 1,25 | 3,50 | 92,00 | 35,00% | 13,57 | 1,014 | 1 |
| PV_L2 | Large PV2 | 7,00 | 2,50 | 4,50 | 88,00 | 32,00% | 21,88 | 1,028 | 1 |
| PV_M1 | Medium PV1 | 0,50 | 0,50 | 0,00 | 42,00 | 10,00% | 5,00 | 1,012 | 0 |
| PV_M2 | Medium PV2 | 2,50 | 0,50 | 2,00 | 35,00 | 15,00% | 16,67 | 1,014 | 0 |
| PV_S1 | Small PV1 | 1,75 | 0,75 | 1,00 | 9,00 | 25,00% | 7,00 | 1,083 | 1 |
| PV_S2 | Small PV2 | 2,50 | 0,50 | 2,00 | 5,00 | 11,00% | 22,73 | 1,100 | 1 |
| WI_L1 | Large Wind1 | 7,50 | 2,50 | 5,00 | 80,00 | 40,00% | 18,75 | 1,031 | 1 |
| WI_L2 | Large Wind2 | 5,00 | 1,00 | 4,00 | 75,00 | 30,00% | 16,67 | 1,013 | 1 |
| WI_M1 | Medium Wind1 | 1,50 | 0,50 | 1,00 | 35,00 | 12,00% | 12,50 | 1,014 | 0 |
| WI_M2 | Medium Wind2 | 3,75 | 0,75 | 3,00 | 28,00 | 13,00% | 28,85 | 1,027 | 1 |
| WI_S1 | Small Wind1 | 2,00 | 0,50 | 1,50 | 7,00 | 22,00% | 9,09 | 1,071 | 1 |
| WI_S2 | Small Wind2 | 2,25 | 0,25 | 2,00 | 4,00 | 12,00% | 18,75 | 1,063 | 1 |
| | | 41,00 | | | | | | | |
| | Project Portfolio Total | 36,50 | | Total Costs | 388,00 | 79% | | Total number of projects | 9 |
| | Goal | MAX | | Total Costs max: | 400,00 | | | Total number of projects, max: | 10 |

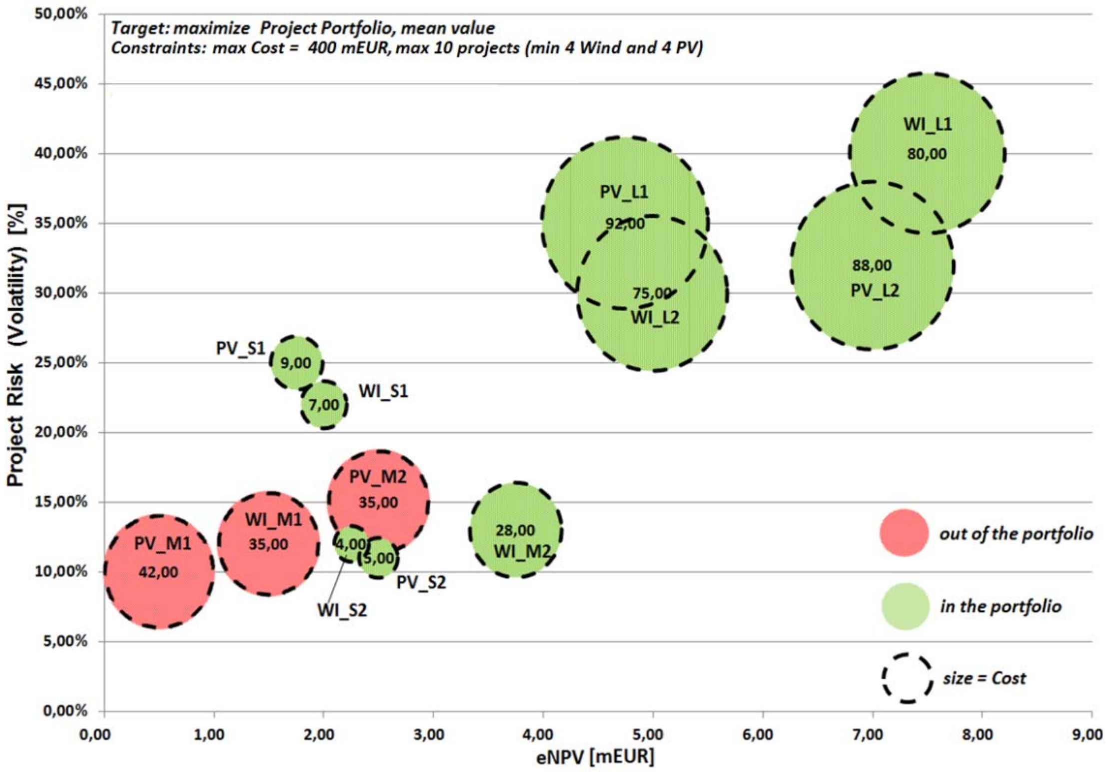
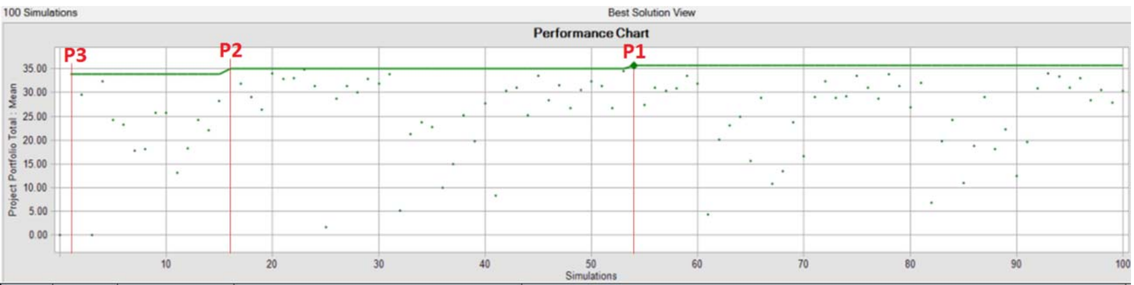



**Figure 4-22: The optimal project portfolio selection metrics**

*Source: the author*

In the bubble chart, size of the bubble shows costs, on the x-axis there is eNPV project returns, and project risks on the y-axis. Optimal portfolio P1 is consisting of "green" bubbles, while the red bubbles, i.e. projects PB_$M_1$, WI_$M_1$ and PV_$M_2$ are excluded from the optimal portfolio. Projects PB_$M_1$ and WI_$M_1$ are excluded due to lowest eNPV return and PV_$M_2$ due to predefined constraints of holding the total costs ≤ EUR 400 million and maximum number of projects ≤ 10. In the *efficient frontier* chart (**Figure 4-23**), the bold green line is called *efficient frontier*, where, on the frontier, all the portfolio combinations of projects will yield the maximum returns (portfolio eNPV). There are three portfolios located on the *efficient frontier*: P1, P2 and P3.




| | | Objective | Constraints | | | | | | Decision Variables | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Rank | Solution # | Maximize Mean Project Portfolio Total | Total Cost Sheet1!G16 <= Sheet1!G17 | | | Total number of projects Sheet1!K16 <= Sheet1!K17 | | | WI_L2 | WI_M1 | WI_M2 | WI_S1 | WI_S2 | PV_L1 | PV_L2 | PV_M1 | PV_M2 | PV_S1 | PV_S2 | WI_L1 |
| P1 | 54 | 35.77 | 388 | <= | 400 | 9 | <= | 10 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 | 1.00 |
| P2 | 16 | 35.03 | 366 | <= | 400 | 10 | <= | 10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| P3 | 1 | 33.81 | 399 | <= | 400 | 10 | <= | 10 | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 | 1.00 | 0.00 | 1.00 | 1.00 |

**Figure 4-23: *Efficient frontier* simulation result for the three top ranked portfolios**

*source: the author, chart generated in the Crystal Ball*

Top ranked portfolio according to the mean eNPV returns maximization criterion is P1, which was found in the 54th simulation. It is consisting of 9 projects as mentioned above. The next ranked portfolio is P2 which was found in the 16th simulation. It is consisting of 10 projects – 6 wind and 4 PV ($WI\_L_1$, $WI\_L_2$, $WI\_M_1$, $WI\_M_2$, $WI\_S_1$, $WI\_S_2$, $PV\_L_2$, $PV\_M_2$, $PV\_S_1$ and $PV\_S_2$) with mean eNPV of EUR 35,03 million. The 3rd ranked portfolio P3 was found in the 1st simulation. It also has 10 projects – 6 wind and 4 PV ($WI\_L_1$, $WI\_L_2$, $WI\_M_1$, $WI\_M_2$, $WI\_S_1$, $WI\_S_2$, $PV\_L_2$, $PV\_M_1$, $PV\_M_2$ and $PV\_S_2$). All other portfolios which are below the *efficient frontier* (green dots) are suboptimal solutions, i.e. less profitable portfolios.

As we can see, the P3 portfolio utilizes available budget better than other two portfolios (P3: EUR 399 million vs. P2: EUR 366 million vs. P1: EUR 388 million).

Nevertheless, for the right selection of the best portfolio among these three, we have to introduce another metrics called Sharpe ratio.

***Sharpe ratio*** (Sharpe, 1994), named after Nobel laureate William Sharp, also known as *reward-to-variability ratio,* is a risk adjusted measure of return used to evaluate a portfolio performance. Sharpe ratio (***Sh***) shows volatility of the assets which constitute a portfolio. It makes performance of one portfolio comparable to another portfolio by adjusting for risk. It allows determining whether portfolio's returns are due to smart investment decision or just due to a higher level of risk. The greater a portfolio's ***Sh***, the better its risk-adjusted performance is. The general rule of thumb is $1 \leq Sh < 2$ is considered as a good risk adjusted portfolio return, $2 \leq Sh < 3$ is very good and $Sh \geq 3$ is excellent. A negative ***Sh*** means that a risk-free asset would perform better than the analyzed portfolio. Using this ratio shows how much additional return the investor gets for the added volatility of holding a risky asset over a risk free asset, enabling him to see how comfortable he is with that level of risk. The simplified formula for ***Sh*** is:

$$Sh = (r_x - r_f) / \sigma$$

where:

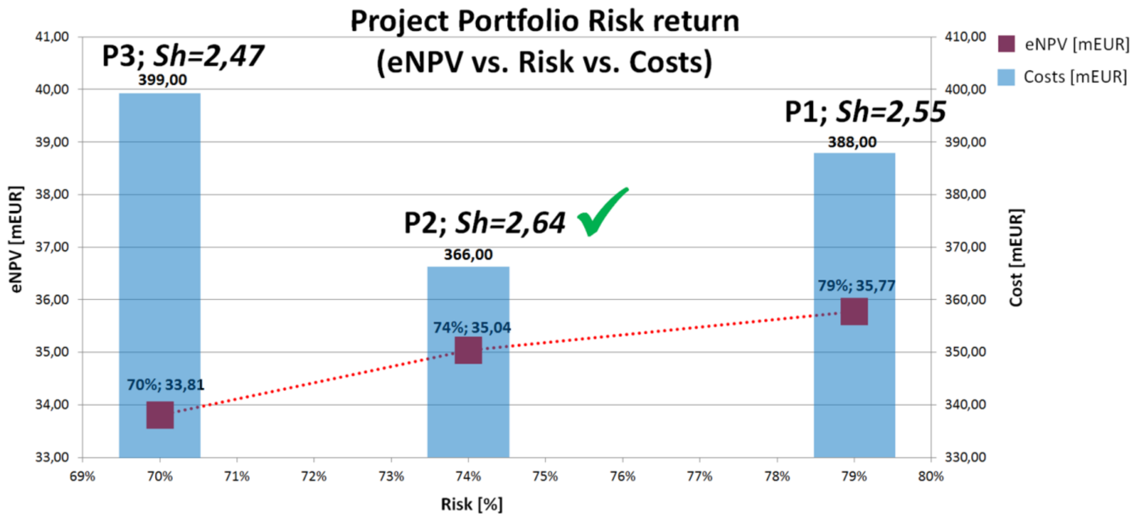
$Sh$ – Sharpe ratio

$r_x$ – average rate of return of the portfolio;

$r_f$ – risk free rate (best available rate of return of a risk free security);

$\sigma$ – standard deviation of the portfolio's returns

**Figure 4-24** illustrates a comparison of three portfolios from previous example, in respect to eNPV mean returns, risks, costs and *Sh*. Obviously, portfolio P3 is not a desirable solution, due to the low returns and high costs. Therefore, candidates for the best performing portfolio are P1 and P2.




| Portfolio | Portfolio eNPV [mEUR] | Total risk [%] | Costs [mEUR] | Sharpe ratio | Total projects | Portfolio projects |
|---|---|---|---|---|---|---|
| P1 | 35,77 | 79% | 388,00 | 2,55 | 9 | PV_L1, PV_L2, PV_S1, PV_S2, WI_L1, WI_L2, WI_M2, WI_S1, WI_S2; |
| **P2** | **35,04** | **74%** | **366,00** | **2,64** | **10** | **PV_L2, PV_M2, PV_S1, PV_S2, WI_L1, WI_L2, WI_M1, WI_M2, WI_S1, WI_S2;** |
| P3 | 33,81 | 70% | 399,00 | 2,47 | 10 | PV_L2, PV_M1, PV_M2, PV_S2, WI_L1, WI_L2, WI_M1, WI_M2, WI_S1, WI_S2; |

**Figure 4-24: Project portfolio risk return ranked according to the Sharpe ratio**

*source: the author*

Now, we have come to the point when management should decide on the best performing portfolio, as only one portfolio can be chosen for the execution. In real corporate life, what risk-return combination is preferable, depends on the risk appetite and risk averse of the decision makers. P1 has the highest return but also higher risks and higher costs than P2, while P2 seems to be more balanced portfolio, as it has only 2% lower returns then P1 (35,04 mEUR vs. 35,77 mEUR), 5% lower risk, ~ 7% lower total costs, and – what is the most significant in this case – portfolio P2 has the highest Sharpe ratio among all three portfolios. Therefore, P2 ($WI\_L_1$, $WI\_L_2$, $WI\_M_1$, $WI\_M_2$, $WI\_S_1$, $WI\_S_2$, $PV\_L_2$, $PV\_M_2$, $PV\_S_1$ and $PV\_S_2$) is selected as the best performing portfolio.

Out of previous example, we could also find out that selection of the portfolio projects according to the PI (Profitability Index)[55] ranking method is not applicable in this case.

Furthermore, this portfolio optimization process can be extended by considering priorities in the execution of particular projects. Namely, as the portfolio is consistent of different projects, it is unlikely to expect that their execution could start and be realized simultaneously for all the projects which constitute one portfolio. Some of the projects, especially those of small and medium size are exposed to lower uncertainties than those of large size, therefore the focus in the portfolio execution should be on managerial flexibility in order to respond to such uncertainties.

As the following seven projects ($WI\_L_1$, $WI\_L_2$, $WI\_M_2$, $WI\_S_1$, $WI\_S_2$, $PV\_L_2$ and $PV\_S_2$) are present in all three portfolios, they will be treated as of high priority (A),

[55] For more details on PI, refer to the Addendum 1: Traditional approaches in project valuation.

which means that managerial focus on their execution should be of highest importance. In the group of medium priority (B), there are remaining three projects from the portfolio P2 ($WI\_M_1$, $PV\_M_2$ and $PV\_S_1$), whereby $WI\_M_1$ and $PV\_M_2$ are also present in the P3, while $PV\_S_2$ is part of the P1. The remaining two projects $PV\_L_1$ and $PV\_M_1$ are of the lowest importance (C), as they are not part of the winning P2 portfolio, but are present only in a single portfolio: $PV\_L_1$ in P1 and $PV\_M_1$ in P3. Project portfolio prioritization is shown in the **Table 4-6**.

**Table 4-6: Project portfolio prioritization**

*source: the author*

| | $WI\_L_1$ | $WI\_L_2$ | $WI\_M_1$ | $WI\_M_2$ | $WI\_S_1$ | $WI\_S_2$ | $PV\_L_1$ | $PV\_L_2$ | $PV\_M_1$ | $PV\_M_2$ | $PV\_S_1$ | $PV\_S_2$ | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| P1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 9 |
| **P2** | **1** | **1** | **1** | **1** | **1** | **1** | **0** | **1** | **0** | **1** | **1** | **1** | **10** |
| P3 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 10 |
| | A | A | B | A | A | A | C | A | C | B | B | A | |

Priority: A - high, B - medium, C - low

As we have learned out of the real options valuation in previous sections, management can leave the option open to execute remaining projects ($PV\_L_1$ from P1 and $PV\_M_1$ from P3), if they decide to pursue P1 and/or P3 later.

**(8) Risk management, reporting and permanent update analysis**

The last step in the IRMP framework, following portfolio optimization, is ***reporting and update analysis***. Reporting is important in order to transform black-box set of analytics into reports transparent and understandable to the management. Update analysis is a permanent process, which assumes that the management has the right to update the results each time when the assumed uncertainties and risks become known. This is especially important for long-horizon projects, such as RES-E projects, where the forecasts are updated with the latest data and assumptions.

Due to complexity of the ROV process, the reports are attached as **Addendums 10-21** to this work.

# 5. CONCLUSION

According to Copeland and Antikarov (2003), ROV is the most applicable when following three conditions come together: (1) high uncertainty about the future, (2) high room for managerial flexibility and (3) NPV without flexibility near zero. In that regard, the applicability of the ROV approach in RES-E projects has been proven in this work, as follows:

(1) In RES-E projects, which are subsidized by different support measures (FiT, TGC, etc.), there is rather medium than high level of uncertainty of project revenues, mainly driven by technological uncertainties sublimated in volatility of the capacity factor and specific investment costs of respective renewable technology, as well as by uncertainty of electricity market price after expiration of the subsidy period, as explained in the **Chapters 3** and **4**. In the countries where the respective renewable technology has already reached "grid-parity" i.e. market electricity price, this price (revenue) uncertainty is present in the project cash-flow from the beginning.

(2) As demonstrated in the numerical example in the **Chapter 4**, there is a high room for managerial flexibility in RES-E projects, due to variety of real options which could be reasonably applied during project development phases (sequential invest, defer, abandon), as well as during power plant operation (defer, expand, repower, contract, abandon). Risk hedging and mitigation technics which are part of the IRMP framework are also applicable in RES-E projects, as shown in the numerical example in the **Chapter 4**.

(3) Static NPV is often close to zero in RES-E projects, but with a reasonable application of real options they can be transformed to profitable projects if the previous two conditions are fulfilled. This has been demonstrated in numerical example of ROV of a large wind farm project in Serbia. Sometimes, NPV of RES-E projects is too negative, that even application of real options cannot make it profitable, as explained in the **Chapter 4**, for large ground–mounted PV projects in Serbia, referring to given assumptions and the types of real options applied in the model.

Considering calculated real option values in the final binomial tree for the wind farm project, as well as its four moments (mean, standard deviation, skew and kurtosis), it is shown that the proposed sequence of options, after being optimized, increases project value by transforming higher risk and lower returns in the initial discounted cash flow (DCF) model – to lower risk and higher returns in the optimized RO model.

Taking all above mentioned into account, application of ROV in RES-E projects is a reasonable decision which could significantly improve strategic thinking, capital budgeting and decision making process in corporates, willing to invest in RES-E power plant projects.

Combination of different real options within a single RES-E project (intra-project compoundness) as well as combinations of projects based on different renewable technologies within a portfolio of RES-E projects (inter-project compoundness), additionally increases flexibility and uncertainty which are underlying drivers of the real options value. This has been demonstrated in the **Chapter 4**, firstly by using “Tomato garden” approach for valuation of combinations of real options within a single project of the wind farm in Serbia, and after that by using *efficient frontier* for the optimization and *Sharpe ratio* for the ranking of portfolios consisted of possible combinations of six wind and six PV projects, under the budget and diversification constraints.

The author’s general remark to the IRMP framework is that it can be improved by more detailed inter-organizational aspects, such as assignment of responsibilities among key players for foundation and implementation of real options approach within a corporate – strategy, finance and engineering departments. In that regard, coupling of existing real options methodologies and frameworks with project management standards proven in practice (e.g. PMI’s PMBoK), could be an optimal solution for tying up corporative strategy, finance and capital project management, largely supported by the corporate’s CEO, CFO and CTO[56].

The author believes that corporations all around the world will become more open to real options only if they acquire an extensive understanding of an impressive arsenal of strategies which stems from the real options valuation process. In that regard, the business case demonstrated in the **Chapter 4.2** is the author’s attempt to illuminate the real options analytics black-box in order to make it more applicable in real world of the capital investment projects, such as RES-E projects.

[56] Chief Technology Officer, if such position exists in the corporate organization.

## References


Adner, R., & Levinthal, D. A. (2004). What is not a real option: considering boundaries for the application of real options to business strategy. *Academy of Managment Review, 291*, 74-85.

AERS. (n.d.). *Electricity*. Retrieved from AERS: www.aers.rs

Altran & Arthur D. Little. (2011). *Risk quantification and risk management in renewable energy projects.* IEA - RETD (International Energy Agency - Renewable Energy Technology Deployment).

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

Arthur D. Little consulting agency in cooperation with the Chair of Energy Economics at Dresden University of Technology and Opexis GmbH. (2008). *Real Options for the Future Energy Mix.* Energy & Utilities Insight.

Avinash, D., & Pindyck, R. (1995, May). The options approach to capital investment. *Harvard Business Review*.

Blanco, C., & Soronow, D. (2001, Jun). Mean Reverting Processes - Energy Price Processes, Used for Derivatives Pricing & Risk Management. pp. 68-72.

Borison, A. (2003). Real Options Analysis: Where are the Emperor's Clothes? *Real Options Conference.* Washington, DC: Stanford University.

Brach, M. A. (2003). *Real options in practice.* John Wiley & Sons, Inc., Hoboken, New Jersey, USA.

Bräutigam, J., Esche, C., & Mehler-Bicher, A. (2003). Uncertainty as a key value driver of real options.

Brosch, R. (2008). *Portfolios of real options.* Springer-Verlag Berlin Heidelberg.

Cesena, E. A. (2012). Real Options Theory Applied to Renewable Energy Generation Projects Planning. *A thesis submitted to the University of Manchester for the degree of Doctor of Philosophy in the Faculty of Engineering and Physical Sciences*. University of Manchester.

Copeland, T., & Antikarov, V. (2003). *Real options – A practitioner's guide.* Cengage Learning, USA.

Copeland, T., & Tufano, P. (2004, March). A Real-World Way to Manage Real Options. *Harvard Business Review*.

Courtney, H., Kirkland, J., & Viguerie, P. (1997, Nov). Strategy under uncertainty. *Harvard Business Review*.

Cox, J. C., Ross, S. A., & Rubinstein, M. (1979). Option pricing, a simplified approach. *Journal of financial economics*.

Damodaran, A. (2013). *Country Risk Premiums*. Retrieved from http://pages. stern.nyu.edu/~adamodar/

de Lovinfosse, I. (2013). RES-E support schemes in Europe. *Rencontre thématique de l'énergie CWAPE.* Namur, Belgium: Ecofys.

de Maeseneire, W. (2003). *The Real Options Approach to Strategic Capital Budgetting and Company Valuation.*

de Maeseneire, W. (2004). *The Real options approach to strategic capital budgeting and company valuation.* Erasmus University Rotterdam.

de Neufville, R. (2001). Hybrid real options valuation of risky product development projects.

de Neufville, R. (2003). Real Options: Dealing with uncertainty in systems planning and design. *Integrated Assessment, 4*(1), pp.26-34.

de Neufville, R., & al., e. (2003). *Engineering systems analysis for Real options.* M.I.T., Cambridge.

Ecofys, Fraunhofer ISI, TU Vienna EEG, Ernst&Young. (2011). Financing renewable energy in the European energy market. 81-83. Ecofys.

Emery, K. (2009). *Uncertainty Analysis of Certified Photovoltaic Measurements at the National Renewable Energy Laboratory.* NREL (National Renewable Energy Laboratory), Ministry of energy, USA.

EU Directive 2009/28/EC. (2009, 04 23). EU Directive 2009/28/EC on the promotion of the use of energy from renewable sources. European Comission.

Frank, M. (1999). Treatment of uncertainties in space nuclear risk assessment with examples from Cassini mission implications. *Reliability Engineering and System Safety, 66*, 203-221.

Fraunhofer: Burger, Bruno. (2013). *Electricity production from solar and wind in Germany in 2012.* Freiburg: FRAUNHOFER INSTITUTE FOR SOLAR ENERGY SYSTEMS ISE.

Haahtela, T. (2012). Differences between financial options and real options. *4th International Conference on Applied Operational Research. 4*, pp. 169–178. Tadbir Operational Research Group Ltd.

Haugh, M., & Iyenga, G. (2013). *Coursera Financial Engineering & Risk management Webinar, Week 8: The volatility surface in action.* Retrieved from Columbia University.

Heutte, F. (2012). *Experience Curves and Solar PV*. NW Energy Coalition.

Houssin, D. (2012). *Medium-Term Renewable Energy Market Report 2012, Market trends and rpojections to 2017*. IEA.

Huld, T., Müller, R., & Gambardella, A. (2012). A new solar radiation database for estimating PV performance in Europe and Africa. *Solar Energy*. EU: PVGIS © European Union.

IEA-ETSAP & IRENA. (2013, 01). Solar Photovoltaics. *Technology brief*. IEA-ETSAP (Energy Technology Systems Analisys Programme) & IRENA.

IRENA. (2013). *Renewable Power Generation Costs in 2012: An Overview*. IRENA.

KEMA Consulting GmbH. (2011, August). Renewable Energy Sector Study Serbia. Bonn, Germany: DEG – Deutsche Investitions- und Entwicklungsgesellschaft mbH / OeEB – Oesterreichische Entwicklungsbank AG.

Klessmann, C., & al., e. (2011, December). Status and perspectives of renewable energy policy and deployment in the European Union—What is needed to reach the 2020 targets? *Energy Policy, 39*(12), pp. 7637–7657.

Knight, F. H. (1921). *Risk, uncertainty and profit*. University of Chicago.

Kobialka, M. (2011, Mar). Economic Basics: Valuation and Financing of Energy Projects. *MSc Program – Renewable Energy in CEE: Module 6 – Economic Frameworks*. Vienna, Austria: TU Wien.

Lackner, M. A., Rogers, A. L., & Manwell, J. F. (2010). Uncertainty Analysis in Wind Resource Assessment and Wind Energy Production Estimation. Amherst, MA, 01003, USA: Renewable Energy Research Laboratory, University of Massachusetts, American Institute of Aeronautics and Astronautics .

Loncar, D. (2011). Applicative model for appraisal of investment projects based on real options methodology. *Serbian Journal of Management, 6*(2), 269-282.

Luehrman, T. A. (1998). Investment Opportunities as Real Options: Getting Started on the Numbers, Strategy as a Portfolio of Real Options. *July–August, September–October*.

Markowitz, H. (1952, Mar). Portfolio Selection. *The Journal of Finance, 7*(1), pp. 77-91.

Mattar, M. H., & Cheah, C. (2006). Valuing large engineering projects under uncertainty: private risk effects and real options. *Construction Management and Economics, 24*(8), 847-860.

McNulty, J. J., Yeh, T. D., Shulze, W. S., & Lubatkin, M. H. (2002, Oct). What's Your Real Cost of Capital? *Harvard Business Review*.

Merrow, E. W. (2011). *Industrial mega projects - concepts, strategies and practices for success.* Hoboken, New Jersey: John Wiley & Sons, Inc.

Ministry of energy, development and environmental protection. (2013, Feb 04). Decree on Incentive Measures for Privileged Energy Producers . *RS Official Gazette, No. 8/13*. Belgrade, Serbia: Official Gazette of teh Republic of Serbia.

Mousavia, S. M., Ghanbarabadia, M. B., & Moghadamb, N. B. (2012, March). The competitiveness of wind power compared to existing methods of electricity generation in Iran. *Energy Policy, 42*, pp. 651–656.

Mun, J. (2006). *Real options analysis – Tools and techniques for valuing strategic investments and decisions, 2nd edition.* John Wiley & Sons, Inc., USA.

Mun, J. (2010). *Modeling risk - Applying Monte Carlo Risk Simulation, Strategic Real Options, Stochastic Forecasting and Portfolio Optimization.* John Wiley & Sons, Inc., USA.

Mun, J. (2010). *Real options - Super Lattice Solver, User manual.* Real Options Valuation, Inc.

Myers, S. C. (1977, July). Determinants of Corporate Borrowing. *Journal of Financial Economics*, 147-175.

Neftci, S. (2000). *An Introduction to the Mathematics of Financial Derivatives.* Academic Press Advanced Finance.

Neubauer, M. (2011). Development and Planning of Wind Energy Projects. *MSc Program Renewable Energy in CEE, Module 4*. TU Wien, CEC.

NL Agency, Utreht, Nederland. (2013, Mar). National renewable energy action plan of the republic of Serbia in accordance with the template as per directive 2008/29/EC (decision 2009/548/EC). *Development of Renewable Energy Framework in Serbia, Serbian-Dutch Government-to-Government (G2G10/SB/9/2)*. Belgrade, Serbia: Republic of Serbia, Ministry of Energy, Development and Environmental Protection.

Olsson, N. O. (2008). External and internal flexibility – aligning projects with the business strategy and executing projects efficiently. *International Journal for Project Organisation and Management, 1*(1), 47-64.

Olsson, R. (2006). Managing project uncertainty by using an enhanced risk management process. *Mälardalen University Dissertations, 34*. Department of Innovation, Design and Product Development, Mälardalen University.

Oxera. (2011). *Discount rates for low-carbon and renewable generation technologies.* Oxera Consulting Ltd.

Project Management Institute (PMI). (2008). *PMBoK (Project Management - Body of Knowledge), 4th edition.* Project Management Institute.

Radjenovic, T. (2008). Real options UDC 005.8. *FACTA UNIVERSITATIS, Series: Economics and Organization, 5*(1), 83-92.

Raizada, R. (2013, Mar-Apr). De-risking Wind: Hedging Against Variability. *Renewable Energy World*, 24-26.

Rakic, B., & Stosic Mihajlovic, L. (2010). Planning and application of renewable energy sources - possibilities and conditions. *Horizont 2020*, (pp. 277-282).

Randers, J. (2012). *2052: A global forecast for the next forty years - a report to the Club of Rome.* Chelsea Green Publishing, USA, also University of Cambridge, Programme for sustainability leadership.

REN 21. (2012). *REN21 – Renewables 2012 Global status report.* REN21 - Renewable Energy Policy Network for the 21st Century.

Republic of Serbia. (2011/2012). Energy Law. Official Gazette of the Republic of Serbia, No. 57/11, 80/11 – correction, 93/12 i 124/12.

Ruiz-Romero, S., Colmenar-Santos, A., Gil-Ortego, R., & Molina-Bonilla, A. (2013, May). Distributed generation: The definitive boost for renewable energy in Spain. *Renewable Energy, 53*, pp. 354–364.

Sharpe, W. F. (1994, Fall). The Sharpe Ratio. *The Journal of Portfolio Management*.

Smit, H. T., & Trigeorgis, L. (2004). *Strategic Investment: Real Options and Games.* Princeton University Press, USA.

Smith, J. E., & Nau, R. F. (1995). Valuing Risk Projects: Option Pricing Theory And Decision Analysis. *Management Science, 41/1995*.

The Economist Intelligence Unit. (2011). *Managing the risk in renewable energy - a report from the Economist Intelligence Unit Sponsored by Swiss Re.* The Economist - Intelligence Unit Limited 2011.

Triantis, A., & Borison, A. (2001). Real options: State of the practice. *Journal of applied Corporate Finance*.

Trigeorgis, L. (1993). The Nature of Option Interactions and the Valuation of Investments with Multiple Real Options. *The Journal of Financial and Quantitative Analysis, 28*(1), pp. 1-20.

Trigeorgis, L. (1996). *Real Options: Managerial Flexibility and Strategy in Resource Allocation.* Asco Trasde Typesetting Ltd., Hong Kong.

Trigeorgis, L. (2002, May). Real options and investment under uncertainty: What do we know? *NBB Working Paper, 22*. Belgium: National Bank of Belgium.

Trigeorgis, L. (2005). Making use of real options simple: An overview and applications in flexible/modular decision making. *The Engineering Economist, 50*, 25-53.

Van Putten, A., & MacMillan, I. (2004). Making real options really work. *Harvard Business Review, 82*(12), 234.

Vollert, A. (2003). *A Stochastic Control Framework for Real Options in Strategic Valuation.* Birkhaeuser Boston, USA.

Walker, W. (2003). Defining Uncertainty: A Conceptual Basis for Uncertainty Management in Model-Based Decision Support. *Integrated Assessment, 4*(1).

Wang, A., & Hallal, W. (2010, May). Comparison of Real Asset Valuation Models: A Literature Review. *International Journal of Business and Management, Vol. 5*(No. 5).

Wang, T., & de Neufville, R. (2006). Identification of Real Options "in" Projects. *16th Annual International Symposium of the International Council on Systems Engineering (INCOSE).* Orlando.

Wong Too, Philip; Harman, Keir; GL Garrad Hassan. (2013). *Wind Farm Loss Factor Assumptions: Experience From Operational Data.* Wellington: GL Garrad Hassan, Renewable energy conultants.

Yang, M., & Blyth, W. (2007). *Modeling Investment Risks and Uncertainties with Real Options Approach.* IEA - International Energy Agency Working Paper Series.

**The Internet references:**

http://finance.yahoo.com

http://pages.stern.nyu.edu/~adamodar/

http://sdw.ecb.europa.eu

http://thismatter.com/money

http://www.2052.info

http://www.aers.rs

http://www.eia.gov

http://www.ecb.europa.eu

http://www.ems.rs

http://www.enercon.de

http://www.eps.rs

http://www.ewea.org

http://www.indexmundi.com

http://www.investopedia.com

http://www.irena.org

http://www.heritage.org/index

http://www.realoptionsvaluation.com

http://www.ren21.net

http://www.siepa.gov.rs

http://www.sunpowercorp.com

http://www.wikipedia.org

http://www.worldbank.org

## Addendums

### *Related to the Chapter 2:*

**Addendum 1: Traditional approaches in project valuation with the focus on DCF**

DCF

Comparison of traditional dynamic KPIs for project valuation

**Addendum 2: Modern approaches to project valuation**

Decision Tree Analysis (DTA)

Monte Carlo simulation (MCS)

**Addendum 3: Discount rate vs. risk-free rate**

WACC

Discount rate as a sum of risk premiums

Risk-free rate

**Addendum 4: (Financial) Options**

Definition and key features

Payoff charts

Application of options as non-trading securities

**Addendum 5: Option pricing models**

Black-Scholes model

Binomial model

**Addendum 6: Real options theory - basics**

Definition

Historical background

When managerial flexibility is valuable?

Differences between risk and uncertainty

Volatility as a key value driver in ROV

Real options “In projects” and “On projects”

Portfolio approach in real options

### *Related to the Chapter 3:*

**Addendum 7: PV Sunpower E20 datatsheet**

**Addendum 8: WTG Enercon 101 datasheet**

### *Related to the Chapter 4.1:*

**Addendum 9: Serbia FiT policy 2013**

***Related to the Chapter 4.2 (ROV numerical example):***

**Addendum 10:** List of assumptions for the basic scenario for DCF model for Wind farm and PV power plant project

**Addendum 11:** DCF analysis – Base case

**Addendum 12:** RO Strategy decision tree with datasheet

**Addendum 13:** Underlying asset value binomial tree and cone of uncertainty

**Addendum 14:** Expansion, Repower and Contraction factor calculation

**Addendum 15:** ROV at $T_{op}$=13 binomial tree with sensitivity charts

**Addendum 16:** ROV at $T_{op}$=3 binomial tree with sensitivity charts

**Addendum 17:** ROV at $T_{op}$=-1 ($T_{cf}$=1) binomial tree with sensitivity charts

**Addendum 18:** SLS output – proof of the ROV results obtained by the author's MS Excel based software solution

**Addendum 19:** RO model optimization, including the four moments datasheet

**Addendum 20:** RO interactions

**Addendum 21:** RO in the 3D "Tomato garden" model

## Addendum 1: Traditional approaches in project valuation with the focus on DCF

Value is the material, monetary or assessed worth of an asset, a service or a commodity. Both the physical (tangible) and non-physical (intangible) features of an asset identify its real true value and therefore can create extrinsic - monetary or intrinsic - strategic value.

Mun (2006) distinguishes three main traditional approaches to valuation: market, income and cost approach.

**The market approach** compares corresponding prices of assets in the market and the tendency to keep the market price at an equilibrium level assuming that it represents the fair market value, taking into account the adjustment of risk differentials and transaction costs.

**The income approach** is used to estimate the future potential profit or potential of generating free cash-flow of the asset. It attempts to forecast, quantify and discount these net free cash flows to a present value (PV) by employing discounted cash flow (DCF) methodology. In order to compute a net present value (NPV), the present value of cash flows is then reduced by the cost of implementation, acquisition and development of the asset. These costs are known as capital expenditures (CAPEX), while in some cases the costs related to exploration activities (e.g. in oil E&P business), can be separately booked as exploration expenditures (EXPEX) due to different accounting treatment of exploration and other implementation costs. There are also historical firm risks, project specific risks or general business risks which affect the cash flow stream resulting in its discounting at a risk-adjusted discounted rate or at a firm specified hurdle rate or at the weighted average cost of capital (WACC).

**The cost approach** compares the cost a firm would have if it were to replace or reproduce the asset's future profitability potential, including the cost of its strategic intangibles if the asset were to be created from the scratch. One of the most important metrics in the cost approach in energy projects is Levelized Cost of Energy (LCoE), i.e. LRGC (Long Run Generation Costs) and SRGC (Short Run Generation Costs) in [€/MWh] in case of electricity generation.

***DCF***

Since its introduction by the World Bank[57] in the 1960's, DCF became the most widely used project valuation method in corporate finance. It discounts future free cash flow projections by using a discount rate in order to determine a present value (PV), which is used to evaluate the potential for investment. If the PV obtained in that way is higher than the CAPEX, the project may be acceptable.

The DCF formula is denoted as:

$$DCF = \frac{CF_1}{(1+r)^1} + \frac{CF_2}{(1+r)^2} + \cdots + \frac{CF_n}{(1+r)^n}$$

which implies the future value, denoted as:

$$FV = DCF * (1+i)^n$$

which further implies discounted present value $PV_{disc}$, denoted as:

$$PV_{disc} = \frac{FV}{(1+i)^n} = FV * (1-r)^n$$

where:

***$CF_n$*** – cash flow in year *n*

***$PV_{disc}$*** – discounted present value of the future cash flow;

***FV*** – nominal value of a cash flow amount in a future period;

***i*** – interest rate for the future value calculation;

***r*** **-** discount rate (also referred to as the required rate of return);

***n*** - time in years before the future cash flow occurs.

Besides its obvious advantages (DCF considers time value of money, it has consistent decision criteria, it is widely accepted and relatively simple to explain to management: "If discounted benefits are greater than discounted costs, do it!"), there are certain disadvantages which makes deterministic DCF approach inadequate for **strategic** project valuation.

As shown in the **Figure Ad1-1**, actual cash flow is never a straight line as DCF method assumes. Actual cash flow fluctuation depends on volatility, which is used to estimate the risk by quantifying uncertainties. The higher the risk, the higher the volatility, and vice versa.

[57] *http://www.worldbank.org/*

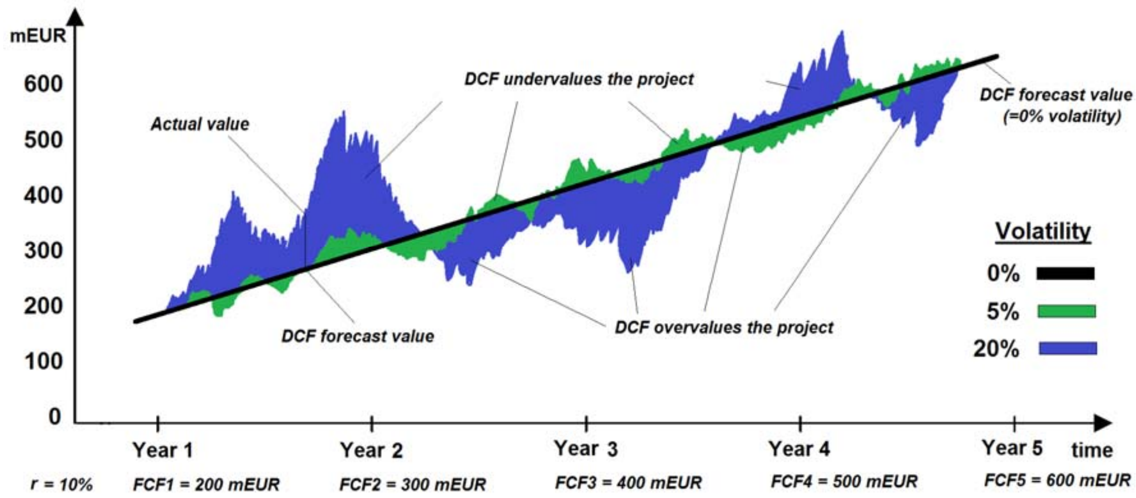



**Figure Ad1-1: DCF shortcomings**

Actually, DCF analysis is a special case of real options analysis, when there is no uncertainty in the project. By assigning a quantifiable value to uncertainties, ROV enables decision makers to measure project cash flow volatility and react to risk over time. This is discussed in details in the **Addendum 6**.

*Comparison of traditional dynamic KPIs for project valuation*

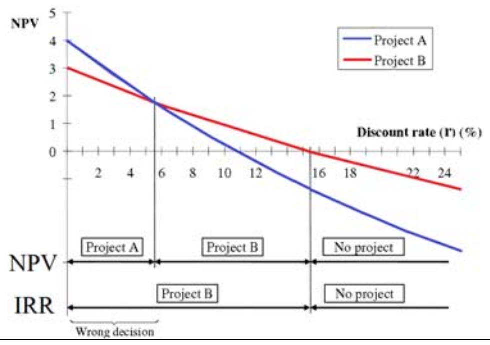
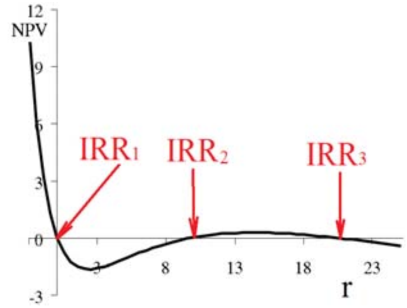
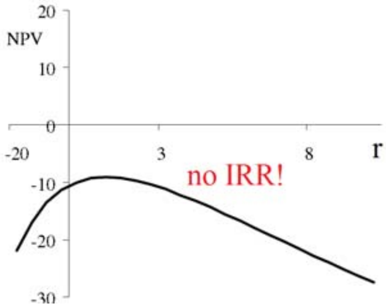
In the income approach there are metrics, i.e. Key Performance[58] Indicators (KPI) of an investment which are commonly divided into static and dynamic. Static are those which neglect the concept of time value of money. Usually the static indicators include: Accounting Rate of Return (ARoR) and Payback Period (PP). The dynamic indicators, which are based on the DCF method, are: Net Present Value (NPV), Internal Rate of Return (IRR), Profitability Index (PI), Discounted Payback Period (DPP), Annuity (Ann) and Expected Monetary Value (EMV). Their comparison is shown in the **Table Ad1-1**.

**Table Ad1-1: Comparison of traditional project valuation KPIs**

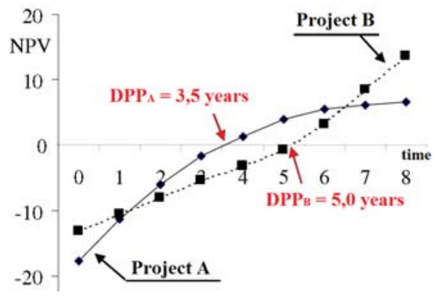
*source: the author*

| KPI | Description, formula and decision rule | Shortcomings |
| --- | --- | --- |
| **Net Present Value**<br><br>**NPV [€]** | ▪ NPV is the single most widely used traditional KPI for large investments made by corporations.<br>▪ It is a difference between the present value of future cash inflows and the present value of future cash outflows. It uses discount rate for conversion of future cash flows to present values.<br>▪ NPV is a direct estimate of the increase of shareholders wealth. If the NPV of a project is zero, it will earn enough money to pay back the providers of invested capital (equity, including all dividends as well as debt, including interest), but if the NPV of the project is one euro, then this entire extra euro goes to shareholders.<br><br>**Formula:**<br><br>$\boldsymbol{NPV = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t} - C_0}$<br><br>$\boldsymbol{C_o}$ –Implementation costs [€],<br>$\boldsymbol{C_t}$ – Cash flow in year t [€],<br>$\boldsymbol{t}$ – Time [years elapsed],<br>$\boldsymbol{r}$ – Discount rate [%],<br>$\boldsymbol{PV} = \sum_{t=1}^{T} \frac{C_t}{(1+r)^t}$ = present value (PV) [€].<br><br>**Decision rule:**<br>▪ Invest in the project if NPV > 0 | ▪ NPV is highly sensitive to discount rate (r) assumption, which is subject to manipulation in order of NPV result adjustment.<br>▪ There is uncertainty of cash flows.<br>▪ Managerial flexibility to act in case of unexpected situations during the project life is not considered.<br>▪ Life time must be identical in case of multi project comparison. |

[58] Performance = Profitability, in this case

| | | |
|---|---|---|
| **Internal Rate of Return**<br><br>**IRR[59] [%]** | ▪ The IRR is the interest rate that brings a series of cash flows (positive and negative) to a net present value (NPV) of zero (or to the current value of cash invested), i.e.:<br><br>**<u>Iterative formula:</u>**<br><br>$r_{n+1} = r_n - NPV_n * \left(\frac{r_n - r_{n-1}}{NPV_n - NPV_{n-1}}\right)$<br><br>where $r_n$ [%] is considered the $n^{th}$ approximation of the IRR (i.e. $r$ when NPV=0)<br><br>▪ IRR can be calculated only iteratively.<br><br>▪ In MS Excel, there is a built-in IRR function which calculates IRR with an accuracy of 0.00001%.<br><br>**<u>Decision rule:</u>**<br><br>▪ Invest in the project if IRR ≥ hurdle rate.<br><br>▪ Hurdle rate is determined by a company and it must be > discount rate used in the NPV calculation.<br><br>▪ IRR should only be used to decide whether a single project is worth of investing in, but not to rate mutually exclusive projects as it can lead to wrong decisions, as shown below:<br><br> | ▪ IRR is not reliable KPI for making decision as, in some cases, there can be more than one IRR value for one project:<br><br><br><br>▪ also there are projects where IRR doesn't exist<br><br><br><br>▪ IRR is not additive.<br><br>▪ Managerial flexibility to act in case of unexpected situations during the project life is not considered.<br><br>▪ There is uncertainty of cash flows. |
| **Discounted Payback Period**<br><br>**DPP [years]** | ▪ DPP is time until cumulative discounted net cash flows = initial investment (implementation costs).<br><br>▪ Simplest valuation method, very popular, especially in small firms.<br><br>**<u>Formula</u>**<br><br>$DPP = L + (C_{L+1}/C_L)$<br><br>$L$ – Last year of negative cash flow [year]<br><br>$C_L$ – Cash flow in year L [€]<br><br>$C_{L+1}$ – Cash flow in year L+1 [€] | ▪ The cutoff point is arbitrary: there are no precise guidelines concerning the "optimal" payback period.<br><br>▪ Cash Flow after the DPP is not considered, which can lead to wrong decisions, as shown below: |

59 IRR is based on non-discounted cash flow

| | | |
|---|---|---|
| | **Decision rule:**<br>▪ Accept the project if DPP is below a certain maximum cutoff period. | <br><br>▪ Managerial flexibility to act in case of unexpected situations during project life is not considered.<br>▪ Quantification of project risks is neglected. |
| **Profitability Index**<br>**PI [-]** | ▪ PI is a division of the sum of discounted cash inflows and the sum discounted cash outflows.<br>▪ PI has advantage over other KPIs in projects ranking, especially when there is an ambiguity between IRR and NPV results<br>**Formula:**<br>$$\boldsymbol{PI = \frac{\sum_{t=1}^{n} \frac{E_t}{(1+i)^t}}{\sum_{t=1}^{n} \frac{C_t}{(1+i)^t}}}$$<br>$\boldsymbol{E_t}$ – Cash inflows [€],<br>$\boldsymbol{C_t}$ – Cash outflows [€],<br>$\boldsymbol{t}$ – Time [years elapsed],<br>$\boldsymbol{r}$ – Discount rate [%],<br>**Decision rule:**<br>▪ Invest in the project if PI > 1. | ▪ There is uncertainty of cash flows.<br>▪ Managerial flexibility to act in case of unexpected situations during the project life is not considered.<br>▪ PI is not additive.<br>▪ In case of multi project comparison, the life time of all projects must be identical. |
| **Annuity**<br>**Ann[€]** | ▪ Annuity is a product of NPV and CRF, i.e. it is a (virtual) average constant annual return of an investment project over the investment period, taking into account the time value of money.<br>**Formula:**<br>$$\boldsymbol{ANN = NPV * \frac{r*(1+r)^t}{(1+r)^t - 1}}$$<br>$\boldsymbol{NPV}$ – Net Present Value<br>$\boldsymbol{t}$ – Time [years elapsed],<br>$\boldsymbol{r}$ – Discount rate [%],<br>$\boldsymbol{\frac{r*(1+r)^t}{(1+r)^t-1} = CRF}$, (Capital Recovery Factor)<br>**Decision rule:**<br>Invest in the project if Ann>0 | ▪ Ann is highly sensitive to discount rate (r) assumption, which is subject to manipulation.<br>▪ There is uncertainty of cash flows.<br>▪ Managerial flexibility to act in case of unexpected situations during the project life is not considered.<br>▪ High dependence on accuracy of discount rate selection.<br>▪ Life time must be identical in case of multi project comparison |

| | | |
|---|---|---|
| **Expected Monetary Value**<br><br>**EMV[€]** | EMV introduces risk quantification through expected probability of success and loss of the future cash flows, which enhances classic NPV calculation.<br>**<u>Formula:</u>**<br>***EMV = Gain * p + Loss*q***<br>Gain = NPV [€],<br>Loss = Sunk costs [€],<br>p – Probability of success [%],<br>q – Probability of loss (sunk costs). q=1-p [%].<br>**<u>Decision rule:</u>**<br>Invest in the project if EMV>0 | ▪ Accuracy of risk, since probability of success/loss is quantified in a subjective way – therefore it is subject to manipulation.<br>▪ Managerial flexibility to act in case of unexpected situations during the project life is not considered. |

Beside regular NPV and IRR, there are Modified NPV (MNPV) and modified IRR (MIRR), which have to be calculated if there is a difference between the discount rate of the project and the rate at which project cash flows are reinvested.

## Addendum 2: Modern approaches to project valuation

For the purpose of strategic valuation and decision making in the capital budgeting process, several approaches were developed in the last decades - so called "new analytics" - quantitative (financial) and qualitative (structural) tools, such as Monte Carlo simulation (MCS), Decision Tree Analysis (DTA), Real options, Business Model Dynamics (BMD), etc., see **Figure Ad2-2**. The analytical approach indicates that the decisions can be made either top-down (focus on macro variables) or bottom-up (focus on micro variables). The analysis may involve a single project or portfolio of projects.

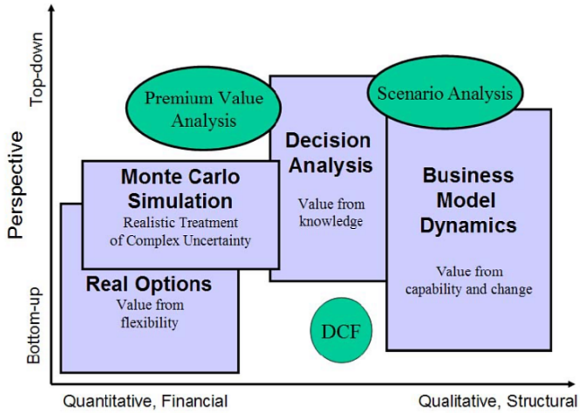



**Figure Ad2-2: DCF vs. new tools for project valuation**
*source: (Mun, 2006)*

The key feature which is common for new tools in comparison to DCF, is the treatment of uncertainties. According to Courtney et al. (Courtney, Kirkland, & Viguerie, 1997), in the strategic investment projects four levels of uncertainties can be recognized and for each of them, they proposed adequate analytic tool, as shown in the **Figure Ad2-3**. In case of alternate futures, ROV is one of three proposed analytic tools. Other two tools are Decision analysis (which is discussed later in this section) and Game theory (which is beyond the scope of this work).

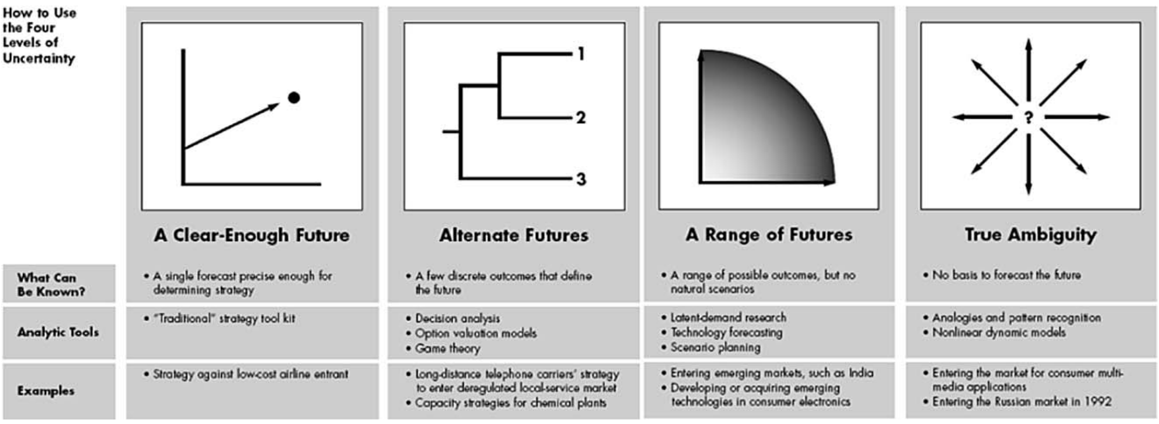



**Figure Ad2-3: How to use four levels of uncertainties**
*source: (Courtney, Kirkland, & Viguerie, 1997)*

***Decision Tree Analysis (DTA)***

A common modern approach to modeling and evaluating investment projects is decision tree analysis (DTA).

In order to briefly illustrate the DTA approach, assume that a company wants to decide whether or not to undertake an R&D project. The decision process is often illustrated with decision nodes. The decision is based on the expected outcomes of undertaking the particular course of action in the respective node (true/false, yes/no, launch/don't launch, etc.), which determines the next step. The final results indicating a range of possible values are depicted in the end nodes, e.g. as shown in the **Figure Ad2-4**, in case of licensing there is a 30% probability that the project will earn 30 million USD and 20% probability that it will earn 80 million USD.

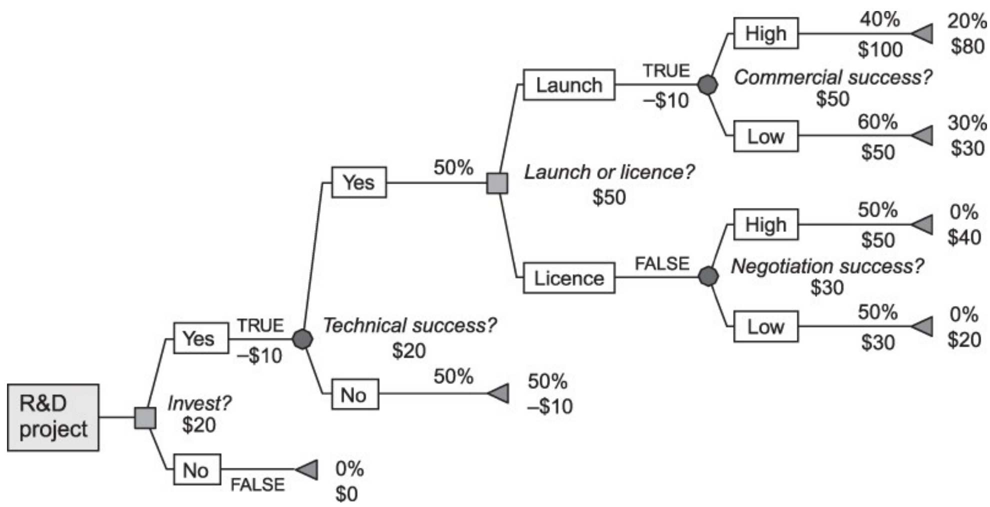



**Figure Ad2-4: Example of a decision tree for an R&D project**

*source: investopedia.org*

DTA refers to forecasting of future results by assigning probabilities to those events. Assigning probabilities is often based on subjective estimation, which is one of disadvantages of the DTA approach.

One of the basic applications of DTA is for the option pricing. However, DTA itself is insufficient for solving real options, but it can be useful for depiction of different strategic paths, i.e. scenarios. In any case, in each decision node in the decision tree different discount rates have to be estimated at different times because different projects at different times have different risk structures (different probabilities) – and this makes DTA model complex to calculate. Estimation errors will then be compounded on a large DTA number of nodes. For example, chance nodes may indicate a 30% chance of a positive outcome, a 45% chance of a neutral one, and a 25% chance of a downturn. Then events and payoffs are associated with these chances. Back-calculating these nodes using risk-neutral probabilities will be incorrect because these are chance nodes, not strategic options. Because these three events are complementary — that is, their respective probabilities add up to 100% — one of these events must occur, and given enough trials, all of these events must occur at one time or another. Binomial trees (lattices) using risk-neutral probabilities avoid this error. In addition, as shown in the **Addendum 5.2**, binomial lattices are a much better way to solve real options problems, and because these lattices can also ultimately be converted into decision trees, they are superior to using decision trees as a stand-alone application for real options.

Therefore, decision trees are a useful tool for depicting strategic pathways that a company or project can take, showing graphically a decision road map of management's strategic decisions over time. Nevertheless, for solving real options problems, it is better to combine decision tree analytics (in the form of binomial tree) with real option analytics, and not to replace it with decision trees.

*Monte Carlo simulation (MCS)*

MCS in its simplest form is a random number generator that is useful for forecasting, estimation and risk analysis. Basic principles of NPV estimation using MCS is shown in the **Figure Ad2-5**.

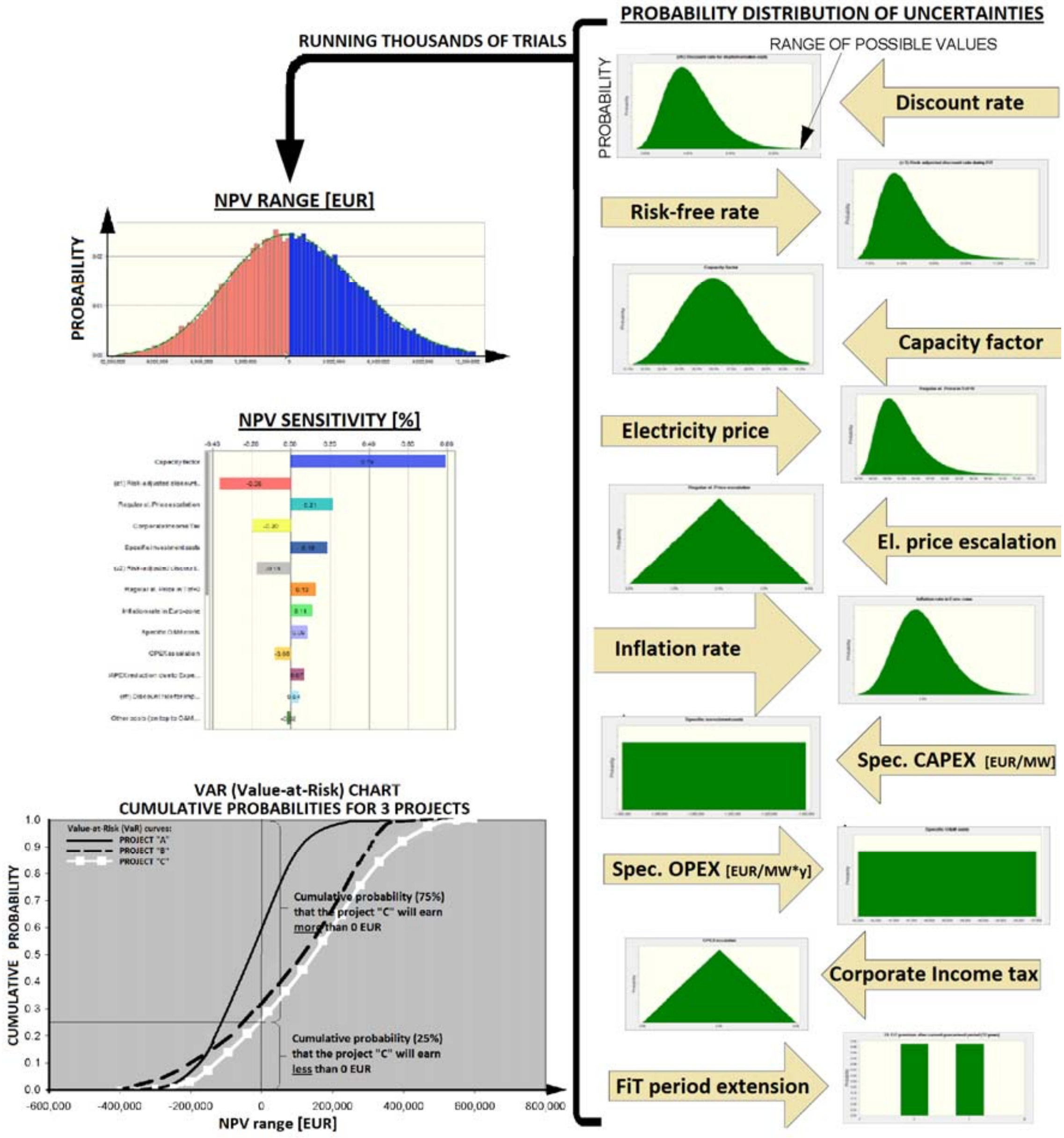



**Figure Ad2-5: Basic principles of Monte Carlo simulation (MCS)**

*source: the author, adapted from (Loncar, 2011)*

Monte Carlo simulation is named after the city in Monaco, worldwide known by its casinos that have gambling games which exhibit random behavior.

In fact, the essence of the MCS approach is to derive probability distribution of the KPI values (NPV, IRR, ...) for entire project, based on simulations (multiple trial runs) of probability distributions of random variables i.e. *public (market) uncertainties*, such as discount rate, risk free rate, electricity price, electricity price escalation, inflation rate, corporate income tax, market growth, etc., and *private (project) uncertainties*, such as: capacity factor, specific CAPEX and OPEX costs, OPEX escalation, other costs, extension of FiT period, CAPEX reduction due to experience and learning rate, etc., as it can be the case in RES-E projects. In other words, MCS converts uncertainties into risk probabilities and allows us to look how the NPV (or other project's KPI) is changed when the project inputs change simultaneously. The focus should be on appropriate selection of probability distribution for each of the particular uncertainties and finding correlations among them as well as on sensitivity of the project's KPIs (e.g. NPV) on the project inputs. One of very useful outputs of the MCS is *Value-at-Risk* (*VaR*) chart with cumulative distribution, which can be used either on a single project level or for comparison of several projects, as shown in the **Figure Ad2-5, bottom left**.

Nowadays, there is a variety of software tools for MCS available on the market, such as Crystal Ball, Risk Simulator, @Risk, MS Excel add-in Insight.xla, etc.

MCS can be used as an independent project valuation tool, but in this thesis it is used for ROV as a part of the IRMP framework (step 4: Risk analysis, see the **Chapter 1.2**).

## Addendum 3: Discount rate vs. risk-free rate

Discount rate is the rate of return that investors require as a reward for the accepted level of the project risk. More specifically, it is the rate of return an investor miss by investing money in a specific project, and not in another project or stock with the same or similar level of risk, or in other words - discount rate is the minimum expected rate of return from an investment. This is why some authors use terms hurdle rate or opportunity cost of capital as synonyms for discount rate.

Since the introduction of the DCF methodology, the key question has become how to determine the discount rate? The worst possible answer to this question is: choose the same standardized discount rate for all projects within the company, no matter on their size, scope, life time and location, which is wrong and potentially very dangerous in the context of project decision-making, because the discount rate, especially for projects with longer time horizon may have a huge impact on the investment value of dynamic investment criteria. Namely, the lower discount rate increases the amount of discounted cash flows, because it less depreciates future cash inflows. On the other hand, higher discount rate significantly reduces the present value of future cash inflows. For example, the projected cash flow of EUR 1 million in 15 years has a present value of EUR 239,392 for the discount rate of 10%, EUR 122,895 for the discount rate of 15% and EUR 64,905 for the discount rate of 20%! Therefore, computation of an adequate discount rate is very sensitive topic in the capital budgeting.

For the purpose of simplicity in this master thesis, two ways of discount rate calculations will be explained: WACC (Weighted Average Cost of Capital) and Sum of risk premiums.

***WACC***

WACC is calculated when the prices of individual sources of funding are weighted by their size share in the total value of all sources of project funding. Suppose that the project is financed from three sources: debt, stocks and equity. Weighted average cost of capital is calculated as:

$$WACC = w_d * k_d * (1-t) + w_p * k_p + w_e * k_e$$

where:

$k_d$ – cost of debt before tax,

$k_p$ – the cost of preferred stocks,

$k_e$ – the cost of equity,

$t$ – corporate effective tax rate,

$w$ – weights of individual sources of funding, such as debts ($w_d$), preferred stocks ($w_p$) and common equity ($w_e$).

WACC is usually calculated for the whole company, and then adjusted to specific project if the risk of the project deviates from the overall risk for the company as a whole. Cost of debt is determined after tax due to the fact that interest has the status of the business cost, and thus reduces the corporate tax base.

However, the most difficult problem in WACC calculation is to determine the cost of equity. Unlike debt, which the company (debtor) must pay to the creditor at a predefined interest rate, equity does not have a precise price that the company must pay, which doesn't mean that there is no cost of equity. Equity shareholders expect to obtain a certain return on their equity investment in a company. From the company's perspective, the equity holders' required rate of return is a cost, because if the company does not obtain this expected return, shareholders will simply sell their shares, causing the fall of the share price. Therefore, the cost of equity is the required rate of return of owners of common shares, i.e. it is the cost that the company must bear in order to maintain a share price at least on the level which is satisfactory to the shareholders.

There are three methods which are most commonly used to determine the cost of equity:

1. CAPM (Capital Asset Pricing Model) approach

2. DDM (Dividend Discount Model) approach

3. Interest on long-term debt plus risk premium.

which will be briefly explained in following text; however a detailed discussion on these three approaches exceeds the scope of this master thesis.

**CAPM (Capital Asset Pricing Model) approach** derives cost of equity by using econometric model that has the following form:

$$k_e = r_f+\beta^*[E(Rm)–r_f]$$

where:

$k_e$ – the cost of equity;

$r_f$ – risk-free rate of return,

$\beta$ – the degree of common stock price movements in relation to the shift of the entire stock index value as a representative of the market portfolio,

***E(Rm)*** – the expected rate of return on the market portfolio.

Since parameter $\beta$ doesn't include the risk of the country (country risk), there is another – revised CAPM formula, which includes the country risk premium (CRP):

$$k_e = r_f+\beta^*[E(Rm)– r_f +CRP]$$

Despite it is widely used for determination of the opportunity cost of equity, CAPM model is based on a number of unrealistic assumptions. The CAPM model refers to a premise the rate of return on any asset is expected to be equal to the rate of return on a riskless asset plus a premium that is proportional to the asset's risk relative to the market.

Additionally, the CAPM calculation takes into account only the systematic or market risk (measured by historical yield on the market indices such as *S&P 500*) and completely ignores unsystematic (company and project-specific) risks, assuming that it can be diversified.

There are new attempts to adequately conceptualize calculation of the discount rate, using the logic of CAPM approach. One of them is an attempt of McNulty at al. ( (What's Your Real Cost of Capital?, 2002), who defined MCPM (Market-derived Capital Pricing Model), the model which has several advantages in comparison to the CAPM:

- It takes company-specific risk into account, not just market risk
- It is based on forward-looking market expectations, not historical data
- It gives more objective values for discount rates, especially in high-risk business.

**DDM (Dividend Discount Model) approach** determines the cost of equity by assuming constant growth of dividends on common shares. DDM has the following form:

$$k_s = (D_1 / P_0) + g$$

where:

$k_e$ – cost of equity;

***$P_0$*** – current price of common stock;

***$D_1$*** – dividend paid in the following year;

***g*** – expected constant growth rate of dividends.

The unknown in the above formula is the constant growth rate. It is usually determined as the product of return on equity (ROE) and retention rate (proportion of net profit reinvested in the company, i.e. not paid in the form of dividends).

**Interest on long-term debt plus risk premium** is the third approach for determining the cost of equity, and the simplest one. It is based on the idea that the cost of equity can be derived as a sum of interest on long-term company's debt and estimated risk premium that is specific to particular project. Empirically, specific risk premium should be ranging from 3 to 5%. Therefore, if the interest on long-term debt is 8% and the risk premium is estimated at 5%, the cost of equity will be 13%.

Use of WACC which has been explained in this section, makes sense only if the risk of the project is similar to the risk of the entire company, because the project-specific risks are usually not the same as overall company's risk structure.

***Discount rate as a sum of risk premiums***

Discount rate as a sum of risk premiums is more applicable in practice than previous two approaches. It defines the discount rate as a sum of three key components: (1) Country risk premium – a yield which should compensate the risk of the country where we invest, (2) Risk-free rate – a yield earned on 'risk-free' placements (placements in government bonds) and (3) Project specific risk premium – a yield which should compensate the specific risk of a particular project, as shown in the **Table Ad3-2**.

**Table Ad3-2: Example of calculating the discount rate by adding risk premiums**

*source: the author*

| | Discount rate component | | Rate |
|---|---|---|---|
| 1 | **Country risk premium** | | **4,00%** |
| 2 | **Risk free rate** | | **5,00%** |
| 3 | **Project (company) specific risk premiums** | | **5,98%** |
| | ***Criteria (0% - best, 5% - worst):*** | | |
| **3.1** | ***Company size*** | ***1,33%*** | |
| 3.1.1 | *Number of employees* | *1,00%* | |
| 3.1.2 | *Asset value* | *2,00%* | |
| 3.1.3 | *Competitive position* | *1,00%* | |
| **3.2.** | ***Quality of organization, management and staff*** | ***1,10%*** | |
| 3.2.1 | *Organizational structure* | *1,00%* | |
| 3.2.2 | *Management team* | *1,50%* | |
| 3.2.3 | *Strategic planning* | *1,00%* | |
| 3.2.4 | *Dependence on specific knowledge of a single expert* | *1,00%* | |
| 3.2.5 | *Resistence to working councel and unions influence on management decision* | *1,00%* | |
| **3.3.** | ***Financial position*** | ***1,17%*** | |
| 3.3.1 | *Fixed asset/Total asset* | *1,00%* | |
| 3.3.2 | *Fixed asset and inventories/Long-term asset* | *1,00%* | |
| 3.3.3 | *Equity/Asset* | *1,50%* | |
| 3.3.4 | *Gross margin/Revenue* | *1,00%* | |
| 3.3.5 | *Financial expenses/Profit* | *1,00%* | |
| 3.3.6 | *Debt/Service coverage ratio* | *1,50%* | |
| **3.4.** | ***Operating and sales potential*** | ***1,00%*** | |
| 3.4.1 | *Contribution of individual products to revenue* | *1,00%* | |
| 3.4.2 | *Existence of long-term contracts* | *1,00%* | |
| 3.4.3 | *Share of export in total sales* | *1,00%* | |
| 3.4.4 | *EU market accessibility* | *1,00%* | |
| 3.4.5 | *Customer base distribution* | *1,00%* | |
| **3.5** | ***Ability to predict business trends*** | ***1,38%*** | |
| 3.5.1 | *Company age* | *1,00%* | |
| 3.5.2 | *Stability of operating results* | *1,00%* | |
| 3.5.3 | *Discontinuity of business* | *1,50%* | |
| 3.5.4 | *Changes in industry / technology settings* | *2,00%* | |
| | | **Total discount rate** | **14,98%** |

**The country risk premium (CRP)** is a risk associated with investing in a specific foreign market rather than in the US market. Macroeconomic factors such as unstable government and variable exchange and inflation rates cause that investors require a premium for investing in such countries. The CRP is higher for less stable countries.

There are lots of data available on the Internet for determination of the Country Risk premiums. The author recommends Damodaran's[60] web site (Damodaran, 2013).

$$CRP_{,country} = DS_{,country} * (SDE_{,country} / SDGB_{,country})$$

$DS_{,country}$ – Default Spread of the country

$SDE_{,country}$ – Standard Deviation in Equity of the country

$SDGB_{,country}$ - Standard Deviation in Government Bonds of the country

In most of cases, *default spread (DS)* of the specific country is derived from official country ratings assessed by one of four global credit rating agencies (Moody's, Standard and Poor's - S&P, Fitch and DBRS), or by international organizations (OECD, ...). In the **Table Ad3-3**, there is a convention for long- and short-term ratings.

**Table Ad3-3: Convention for long- and short-term ratings**

*source: www.wikipedia.org*

| Moody's | | S&P | | Fitch | | DBRS | | |
|---|---|---|---|---|---|---|---|---|
| Long-term | Short-term | Long-term | Short-term | Long-term | Short-term | Long-term | Short-term | |
| Aaa | P-1 | AAA | A-1+ | AAA | F1+ | AAA | R-1H | Prime |
| Aa1 | | AA+ | | AA+ | | AA(high) | | High grade |
| Aa2 | | AA | | AA | | AA | R-1M | |
| Aa3 | | AA- | | AA- | | AA(low) | | |
| A1 | | A+ | A-1 | A+ | F1 | A(high) | R-1L | Upper medium grade |
| A2 | | A | | A | | A | | |
| A3 | P-2 | A- | A-2 | A- | F2 | A(low) | | |
| Baa1 | | BBB+ | | BBB+ | | BBB(high) | R-2H | Lower medium grade |
| Baa2 | P-3 | BBB | A-3 | BBB | F3 | BBB | R-2M | |
| Baa3 | | BBB- | | BBB- | | BBB(low) | R-2L, R-3 | |
| Ba1 | Not prime | BB+ | B | BB+ | B | BB(high) | R-4 | Non-investment grade speculative |
| Ba2 | | BB | | BB | | BB | | |
| Ba3 | | BB- | | BB- | | BB(low) | | |
| B1 | | B+ | | B+ | | B(high) | | Highly speculative |
| B2 | | B | | B | | B | R-5 | |
| B3 | | B- | | B- | | B(low) | | |
| Caa1 | | CCC+ | C | CCC | C | CCC(high) | | Substantial risks |
| Caa2 | | CCC | | | | CCC | | |
| Caa3 | | CCC- | | | | CCC(low) | | |
| Ca | | CC | | | | CC(high) | | Extremely speculative |
| | | | | | | CC | | |
| | | | | | | CC(low) | | |
| | | C | | | | C(high) | | |
| | | | | | | C | | |
| | | | | | | C(low) | | |
| C | | D | / | DDD | / | D | D | In default |
| | | | | DD | | | | |
| | | | | D | | | | |

[60] **Aswath Damodaran** is a professor of corporate finance and valuation at the Stern School of Business at New York University, USA.

Damodaran uses Moody's figures in his calculations. According to currently[61] valid Moody's long-term ratings, Austria has ***Aa1*** rating, Serbia has ***B1***, and neighboring countries: Slovenia ***Ba1***, Croatia ***Baa3***, Bulgaria ***Baa2***, Romania ***Baa3***, Hungary ***Ba1***, Bosnia and Herzegovina ***B3***, but Greece has ***C***, due to a huge impact of global economic crisis to Greek's economy.

According to Damodaran (2013), currently[62] valid Country Risk Premium (CRP) for Austria is 1,30%, Bulgaria 2,99%, Romania 3,73%, Hungary 4,69%, Croatia 4,83%. There is no valid CRP for Serbia in Damodaran's report, but according to OECD estimation, it is ca. 6%[63].

In order to determine **project (company) specific risk premiums**, besides abovementioned four credit rating companies, there are another companies such as Dun and Bradstreet, i.e. D&B *(www.dnb.com)*, Creditreform *(www.creditreform.com)*, COFACE *(www.coface.com)*, KSV (*www.ksv.at*), which can provide (from the author's experience – often unreliable!) comprehensive data on company's risk profile. It is recommended that company develops an own methodology for project (company) specific risk premium determination; an idea for that is given in the **Table Ad3-2**.

[61] Sep 2013

[62] Sep 2013

[63] OECD (The Organisation for Economic Co-operation and Development) estimation methodology is not quite comparable to Damodaran's.

### *Risk-free rate*

**Risk-free rate (RFR, or $r_f$)** is a consisting part of the discount rate calculation if *sum of risk premiums* approach is used. As explained later in this section as well as applied in the case study in the **Chapter 4**, the risk free rate is used for the risk-neutral probability calculation, which is one of the main components in ROV.

RFR is the hypothetical rate of return an investor would expect from an investment with no risk of financial loss, over a given period of time. Another interpretation is that the risk free rate is the compensation is the compensation for systematic risk which cannot be eliminated by holding a diversified market portfolio.) The latter interpretation is applied in the CAPM.

The key question is which risk-free rate should be used in capital budgeting and valuation, for instance if an Austrian company invest in RES-E projects in Serbia? According to Damodaran (2013), if cash flows are estimated in nominal EUR terms, the risk free rate will be the long-term bond yield of the national bank of that currency, i.e. the ECB[64] bond rate in this case (see **Figure Ad3-6**). This will remain the case, whether the analyzed company is an Austrian, Chinese or Russian company. This also implies that the choice of a risk free rate doesn't depend on where the project or firm is located, but on the currency in which the cash flows on the project or firm are estimated. Thus, a project invested by an Austrian company can be valued using cash flows estimated in EUR, discounted back at an expected return estimated using a Euro area government bond rate as the risk-free rate, or it can be valued in US dollars, with both the cash flows and the risk free rate being US dollar related.

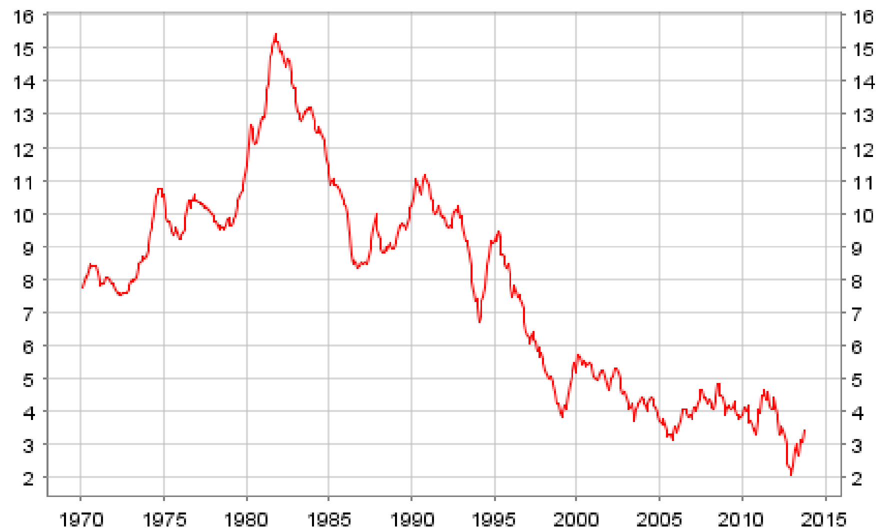



**Figure Ad3-6: Euro area 10-year Government Benchmark bond yield [%]**
*source: ECB, http://sdw.ecb.europa.eu*

[64] ECB – European Central Bank

Since the average 10y bond yield in euro zone was ca. 4% in last 10 years (as shown on the **Figure Ad3-6**), as well as since the currency in the DCF case study model in the **Chapter 4** is EUR, the author has assumed risk free rate of 4%. As explained in the **Chapter 4**, this RFR was used both – for discounting of implementation costs only in the static DCF model – as recommended by Mun (Real options - Super Lattice Solver, User manual, 2010), as well as for calculation of volatility of the project cash flows as a input for real option valuation, where RFR is being applied in the calculation of probability for up/down movements in the binomial tree.

Summary on discount rates – in projects with sequential decision making process, financial managers may apply different discount rates for evaluation of different phases of the same project (***risk-adjusted discount rates***). If decision makers estimate that different project phases bear different level of risk, then it is recommendable for each of the specific phase to use risk-adjusted discount rate. This approach makes sense only if the risks of different phases differ significantly. Otherwise, a single fixed discount rate should be used for all project phases.

In the DCF models for RES-E projects, it is reasonable to use two discount rates due to different treatment of cash inflows (revenues) during the project life time – one (lower) discount rate during the period covered with FiT subsidies as a kind of revenue hedging instrument, and another discount rate (higher) after the FiT period – until end of the project life. This is presented in the DCF business case modeling in the **Chapter 4**.

## Addendum 4: (Financial) Options

Options (or financial options) come from the financial world of *derivatives*[65], i.e. securities whose value is derived from the values of other assets. One of the most commonly used are energy derivatives which underlying asset are energy products such as oil, natural gas and electricity. They can be traded either on a stock exchange or over-the-counter (OTC)[66] markets. The value of a derivative will vary based on the changes of the price of the underlying asset. Energy derivatives can be used for both speculation and hedging against fluctuations of underlying energy prices.

Besides forward contracts, futures contracts and swaps, options are the most common type of derivatives.

65 "**Derivatives** are contracts between two or more parties and can be used as an underlying asset. Their main purpose is risk hedging, but they can also be used by market traders for speculative purposes. For more on derivatives see *http://www.investopedia.com/terms/d/derivative.asp*

66 "**OTC markets** are stable during normal times, but their lack of transparency can be an issue during financial crisis, as was the case during the latest 2008 global financial crisis". For more on OTC see *http://www.investopedia.com/terms/ o/over-the-countermarket.asp*

***Definition and key features***

***Option*** is a contract sold by one party (option writer, i.e. a seller) to another party (option holder, i.e. a buyer or owner). One options contract represents 100 shares of the underlying stock, and option holder pays a fee, called the option premium, to the option writer at the moment of buying the options in order to receive the right to buy/sell the stock at a specified date or within a specified time frame (the longer the time the higher the premium, i.e. the fee which option holder has to pay). The underlying assets for options may be commodities, foreign currencies, stocks, stock indices, debt instruments, futures contracts, etc.

Structured option trading started when the first listed option exchange — the Chicago Board Options Exchange (CBOE) — was organized in 1973 to trade standardized contracts, greatly increasing the market and liquidity of options. In 2003, the electronic International Securities Exchange (ISE), based in New York, took over the leading position in the options trading from the CBOE. Most options sold in Europe are traded through electronic exchanges.

An option contract gives the buyer the right, but not the legal obligation, to buy (call) or sell (put) a security or other financial asset at a fixed, previously agreed price (*the strike or exercise price*) at within a certain period of time *(American option)* or on a specific date *(European option)*, that is called *exercise date*. The life time of the right to buy or sell the option is also called the *maturity time*. Unlike in a *Call* option where the buyer prefers stock to go up, in a *Put* option the buyer prefers stock to go down. A difference between strike price and the current price of the underlying stock is called *intrinsic value.*

Besides general division into put and call, and American and European type, options are also divided into ***plain-vanilla*** types (combinations of calls and puts)[67] and ***exotic*** types such as: ***compound options***, which are nested options on options; ***barrier options***, where the payoff depends on whether the underlying asset's price reaches a certain level within a certain period of time; ***Asian options***, which are options where the payoff depends on the average price of the underlying asset during part or all life of the option; ***Bermudan options***, which are similar to American options, i.e. can be exercised at any time before or at expiration, except during vesting or blackout periods, ***basket options***, which depend on the underlying of a portfolio of assets and ***rainbow options*** which are compound options with multiple sources of uncertainties.

All above mentioned exotic options have more or less complex payoffs which sometimes can be path-dependent (commonly in barrier and Asian options).

[67] Common European or American options are sometimes called Vanilla options.

*Payoff charts*

One of the main characteristics of an option is the payoffs (returns) asymmetry, due to the fact that the option is “a right, but not an obligation”.

An option holder can take advantage of the upside risks and limit the loss to the price of the option. In the **Figure Ad4-7**, the payoffs of call and put options on a stock price are given as an example. The basic formulae for call and put options are:

$$\boldsymbol{C = \max\,[0, S - K]}\text{, for Call}$$

$$\boldsymbol{P = \max\,[0, K - S]}\text{, for Put}$$

where:

***S*** – Stock price (underlying asset value), also labeled as ***V*** by some authors,

***K*** – Strike (exercise) price, also labeled as ***X*** by some authors.

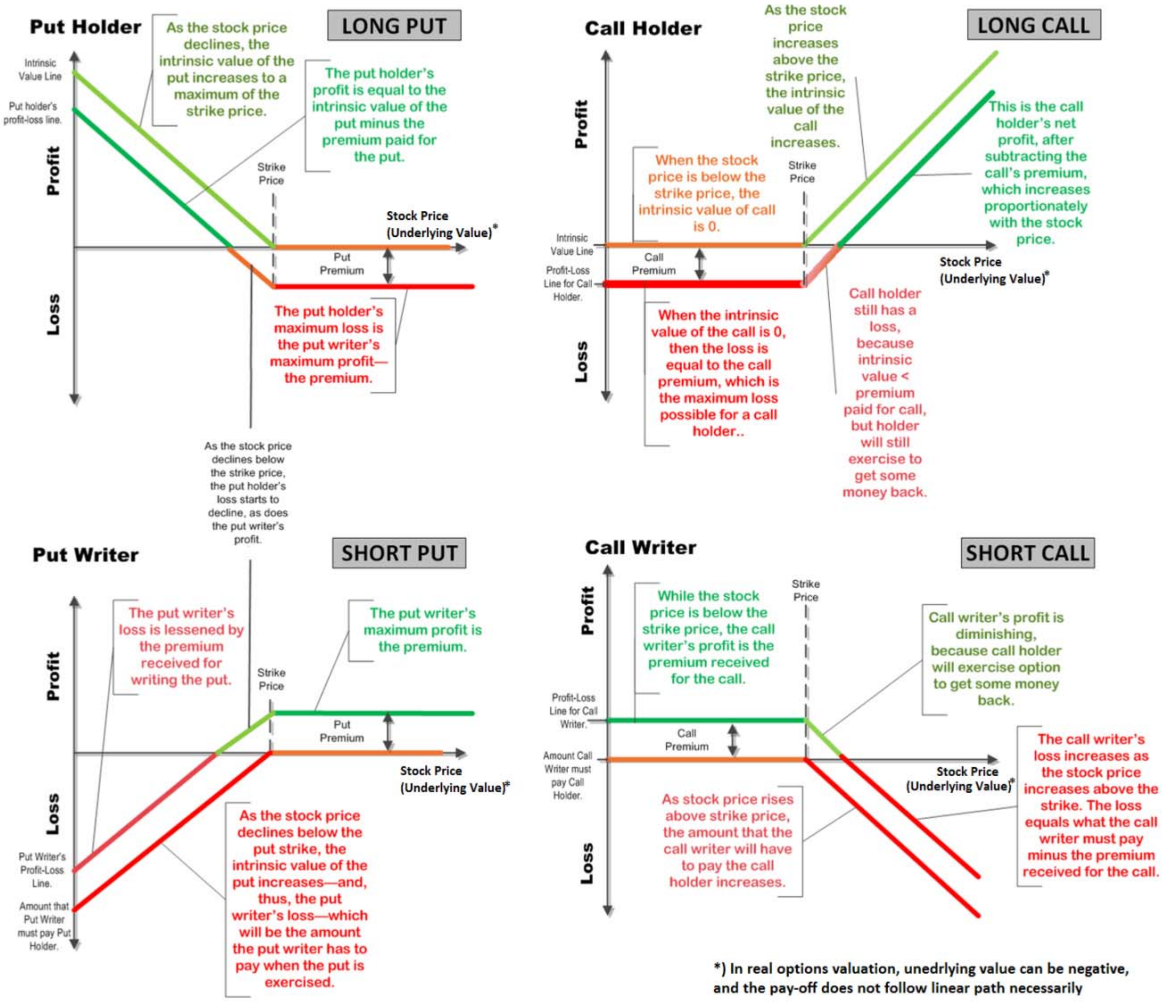



**Figure Ad4-7: Options payoff charts**

*source: modified from http://Thismatter.com/Money*

In case of the “Long Call” European option shown in the **Figure Ad4-7**, a reasonable option holder will not exercise its option if the stock price at maturity is lower than the strike price (S < K). In that case, the loss is limited to the option premium. If the stock price at maturity is higher than the strike price (S > K), the holder will exercise the option, in order to earn a return equal to the reached stock price minus the strike price. There is no upper limit of the return but the lower limit is zero. Therefore, the maximum loss is equal to the option premium.

One of the options features is their moneyness: "in-the-money" (the exercise of an option leads to a profit), "out-of-the-money" (if the exercise of the option leads to a loss) and "at-the-money" (if the underlying asset price is equal to the strike price, means break-even).

***Application of options as non-trading securities***

Options are not limited to trading securities. In retail business, leasing a car with option to buy is an example of the options contract. The lease (holder) decides at end of the contract (maturity date), which is defined up-front (it is typically 3-5 years), if she/he wants to buy the car (exercise call option) or to walk away (to let the option expire). The car purchase price (strike or exercise price) at the maturity date is defined in the lease contract. As the maturity date is not firmly fixed and the required action is buying, this is an example of an American call option. The interest rate can be transparently defined in the lease contract, unlike volatility, which is, in most of cases, hidden in the formula for calculating the car purchase price at the end of the maturity period.

On the other hand, Insurance policy (contract) is an example of put option on insured property. People and companies buy insurance, because they are risk averse. In Insurance policy, a relatively small annual premium (compared to insured property, services or works) ensures protection from potential losses. The return is equal to damage cost minus contractual deductible amount. The option is exercised (claim is placed), if damage total exceeds deductible. As shown in the **Figure Ad4-8**, maximum return (payoff) is insured value minus deductible, while the minimum return is zero. The payoff of the insurance policy holder increases with: a) reduction in the insured property value, b) decreases in deductible (increases in strike value), c) longer timeframe of policy and d) higher probability of damage occurring. The payoff is, on average, lower than premium, otherwise insurance provider might go bankrupt.

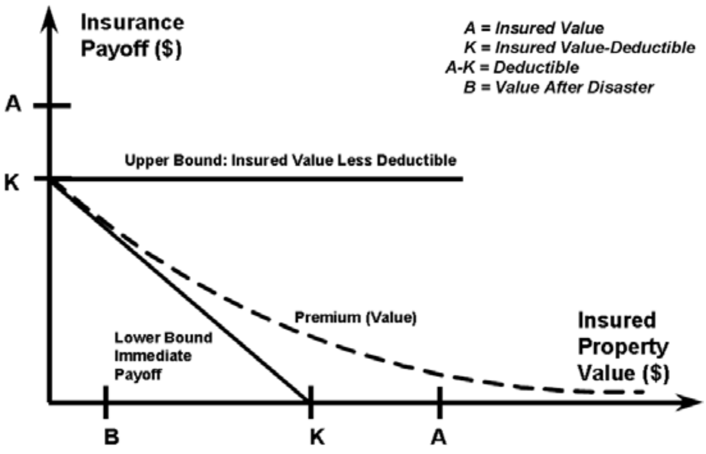



**Figure Ad4-8: Approximate estimate of insurance payoffs**

*source: (de Neufville & al., 2003)*

Insurance is one of possible hedging instruments against risks in RES-E power generation, due to variability and intermittency of renewable sources such as wind and solar in great extent, as discussed in the **Chapter 3**.

## Addendum 5: Option pricing models

Two fundamental option pricing models which are most commonly used in financial world nowadays are Black-Scholes (analytical) and binomial (numerical) models. They are used both in financial and real options pricing, although Black-Scholes is applicable only for simple types of options (call, put), but not for complex options where binomial model is more adequate approach.

***Black-Scholes model***

The Black–Scholes (BS) model was first published by Fischer Black and Myron Scholes in their work *"The Pricing of Options and Corporate Liabilities"* (1973). Robert Merton was the first who published a paper expanding the mathematical understanding of the options pricing model, and coined the term Black–Scholes options pricing model. Merton and Scholes received the 1997 Nobel Prize in Economics for their work. Black died in 1995, but was mentioned as a contributor for the Nobel Prize.

The key idea behind the BS model is to hedge the option (delta hedging) by buying and selling the underlying asset in the right way, and thus eliminating risk. Black and Scholes showed that "it is possible to create a hedged position, consisting of a long position in the stock and a short position in the option, whose value will not depend on the price of the stock".

Some of the initial BS model assumptions have been removed in further extensions of the model. Modern versions account for changing interest rates (Merton, 1976), transaction costs and taxes (Ingersoll, 1976), and dividend payout.

The Black-Scholes formula (BS formula) for an European stock call option value $\boldsymbol{C}$ at time $\boldsymbol{t}$ is denoted as:

$$\boldsymbol{C} = \boldsymbol{SN}(\boldsymbol{d_1}) - \boldsymbol{Ke^{-r(T-t)}N(d_2)}$$

where

$$\boldsymbol{d1} = \frac{\boldsymbol{ln\left(\frac{S}{K}\right) + \left(r + \frac{\sigma 2}{2}\right)(T - t)}}{\boldsymbol{\sigma}\sqrt{T-t}}$$

$$\boldsymbol{d2 = d1 - \sigma}\sqrt{T-t}$$

$\boldsymbol{C}$ – value of the European stock call option,

$\boldsymbol{S}$ – underlying stock price (by some authors labeled as $\boldsymbol{V}$),

$\boldsymbol{K}$ – strike (exercise) price (by some authors labeled as $\boldsymbol{X}$),

$\boldsymbol{\sigma^2}$ – volatility of the stock price,

$\boldsymbol{r}$ – risk-free interest rate (by some authors labeled as $\boldsymbol{rfr}$ or $\boldsymbol{RFR}$),

***T-t*** – maturity, and

***N(.)*** is the cumulative probability of a standard normal probability distribution function[68] (the MS Excel function NORMSDIST computes this value).

The BS pricing model is based on some assumptions; the most important one is that the underlying price follows a geometric Brownian motion (GBM), which implies that the stock price follows a lognormal distribution. It can be expressed as:

$$\boldsymbol{\frac{\delta S}{S} = \mu(\delta t) + \sigma\varepsilon\sqrt{\delta t}}$$

$\boldsymbol{\frac{\delta S}{S}}$ – change in the variable S,

$\boldsymbol{S}$ – underlying stock price,

$\boldsymbol{\mu(\delta t)}$ – deterministic part,

$\boldsymbol{\sigma\varepsilon\sqrt{\delta t}}$ – stochastic part,

$\boldsymbol{\mu}$ – growth parameter (drift) that increases at a factor of time steps $\delta t$,

$\boldsymbol{\sigma}$ – volatility parameter, growing at rate of the square root of time,

$\boldsymbol{\varepsilon}$ – simulated variable, usually following a normal distribution with an average of zero, and a variance of one.

An alternative name for GBM is “random walk”. The main principle for the model is that there is a non-random effect causing growth or decline, and a random movement taken from a distribution. The main input parameters are the volatility, expected variability and the asset price at *t=0*. The GBM implies a lognormal distribution for the prices of the asset, since the price changes are based on a logarithmic change. Another implication is that the price changes are independent from each other (no memory effect) and the mean and volatility are constant. Sample paths of GBM are shown in the **Figure Ad5-9** (fluctuation of the underlying assets prices through time).

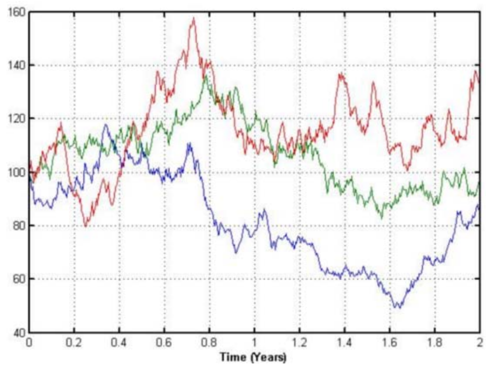



**Figure Ad5-9: Sample paths of geometric Brownian motion (GBM)**
*source: (Haugh & Iyenga, 2013)*

[68] A standard normal distribution has a mean of 0 and a standard deviation of 1.

GBM method is the easiest and most implemented type of model to map financial assets with its uncertainty. The binomial lattice model is a simplified version applying this principle with one up and one down value per time unit specified. The size of the up and down steps is determined by the volatility rate: If an asset is subjected to a large uncertainty, the volatility is larger. This leads to higher possible moves upwards and downwards (Copeland & Antikarov, 2003).

There are several shortcomings related to GBM models:

1. Not all asset price developments follow a lognormal distribution.

2. Extreme price changes cannot be modeled using GBM.

3. Estimating the volatility of the underlying commodity remains complex. Current volatility (based on historical data) may not necessarily be the same as future volatility rates.

4. Volatility rates change over time, which may lead to wrong price modeling in a long-term.

5. Very high volatility rates can make the model inapplicable.

Due to these shortcomings, some authors (Blanco & Soronow, 2001), propose use of **Mean Reversion Processes (MRP)** pricing model as an extension of the GBM model. The MRP considers stock high and low prices as temporary prices and that a stock price will converge to a long term average. Unlike the GBM which does not consider previous changes in the price (no memory effect), the MRP considers this. "Mean Reversion can be thought of as a modification of the random walk, where price changes are not completely independent of one another but rather are related" (Blanco & Soronow, 2001) – and thus resulting in more realistic price movements.

The MRP model can be represented using the following equation:

$$S_{t+1} - S_t = \alpha * (S' - S_t) + \sigma * \varepsilon_t$$

where:

***S*** – Commodity or asset price at $t_i$ or at $t_{i+1}$

***α*** – Mean reversion rate

***σ*** – Standard deviation of returns (volatility)

***S'*** – Mean reversion level or long rung equilibrium price

***ε*** – Random shock to price between $t_i$ and $t_{i+1}$

The "Mean Reversion Rate" (denoted as ***α***) shows how strong the price wants to return to its long run equilibrium. The formula makes sense in that way that when the MRR is modeled as zero, a normal GBM model follows. A difference between these two models is depicted with the sample price paths in the **Figure Ad5-10**.

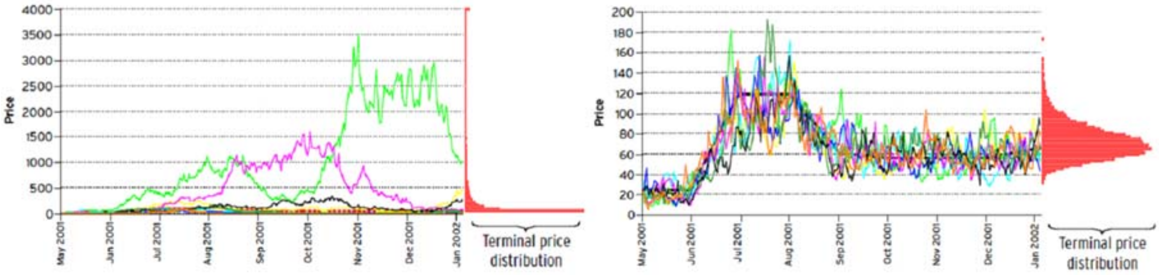



**Figure Ad5-10: Sample price paths according to GBM (left) and MRP (right) model**

*source: (Blanco & Soronow, 2001)*

Extremes (maximum and minimum) of the underlying asset value in its random walk create a boundary of so called ***cone of uncertainty***, which is explained through the idea of increasing uncertainty over time. This cone of uncertainty can be captured using stochastic simulation methods, such as MRP or Brownian motion.

The price modeling is a very sensitive issue in the power sector. When electricity prices reach very high peaks, a generator could make enough profits for the entire year in a few days. Also, when electricity prices are low, it might make sense to shut down the plant temporarily, or alternatively to store the temporary surplus of energy if applicable (e.g. into flywheels, batteries, compressed air storages, water pumped storages, power-to-gas systems based on hydrogen or gas). For the purpose of electricity price modeling, MRP (and its modifications) is better choice than GBM model. Since the subject of this thesis are RES-E projects, which electricity price is regulated, i.e. subsidized and predefined by the government for a period of 10 years or longer[69], electricity price modeling will not be analyzed in details. In the case study in the **Chapter 4**, electricity price after 12$^{th}$ year of wind and solar PV power plant operation is modeled with lognormal distribution and simulated with MCS, but in any case right selection of electricity price modeling (GBM or MRP based) is not of key importance for the final real options value, as discount rate after 12$^{th}$ year significantly decreases incomes as illustrated in the **Figure Ad5-11**, meaning that influence of the right selection of electricity price model to the final result is almost irrelevant. The drop of the FCF (Free Cash Flow) trend between 12$^{th}$ and 13$^{th}$ year is caused by the different discount rates applied after the FiT period (12%, against 8% in previous period). For more details on RES-E business case modeling see the **Chapter 4.2**.

[69] It varies from country to country. In Serbia guaranteed FiT period is 12 years.

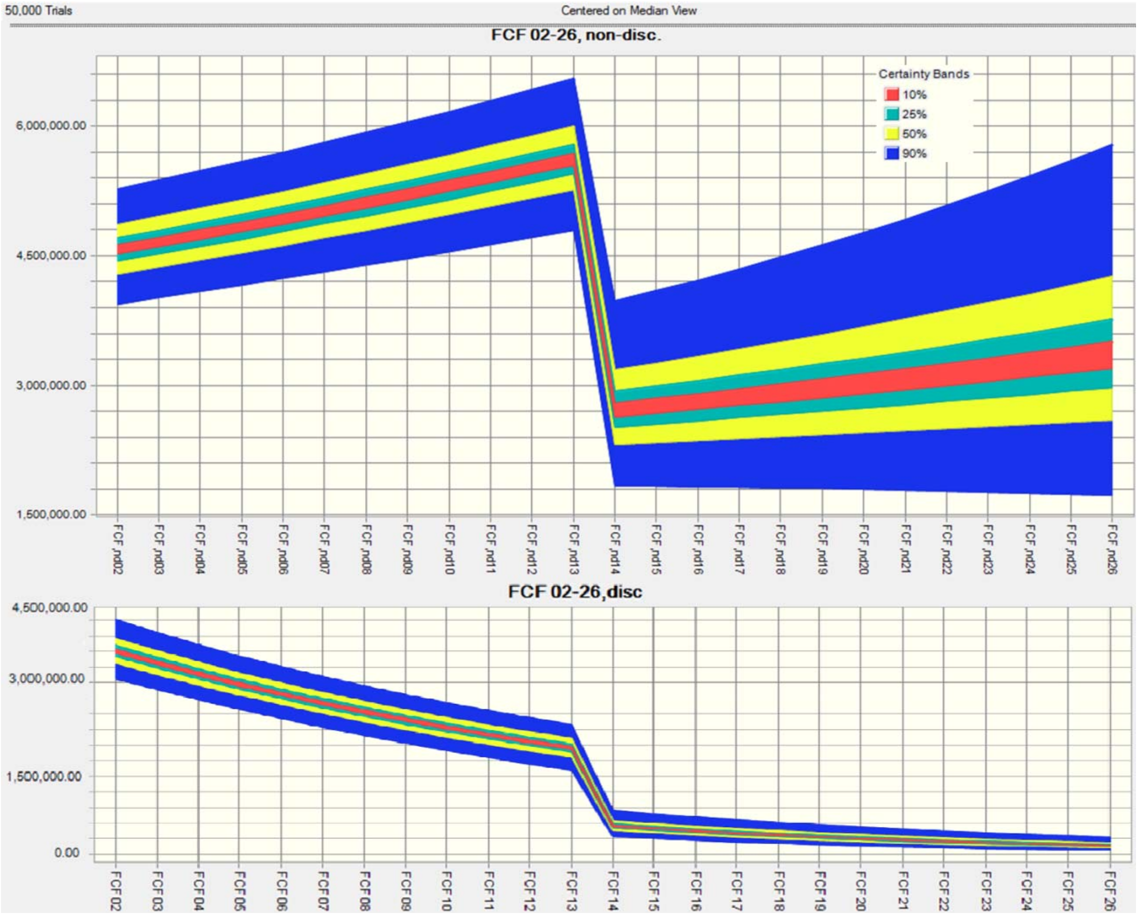



**Figure Ad5-11: Free cash flow certainty band for non-discounted (up) and discounted cash flow (down) of a wind farm project (scale is the same in both charts)**

*source: the author, from the case study, Chapter 4*

***Binomial model***

Binomial model is a discrete numerical method for calculating option prices.

As shown in the **Figure Ad5-12**, granularity of the binomial tree (or binomial lattice) leads to precision, i.e. if number of time periods ***n***$\rightarrow\infty$ then binomial paths will look like the geometric Brownian motion paths (see also **Figure Ad5-9** on GBM for comparison).

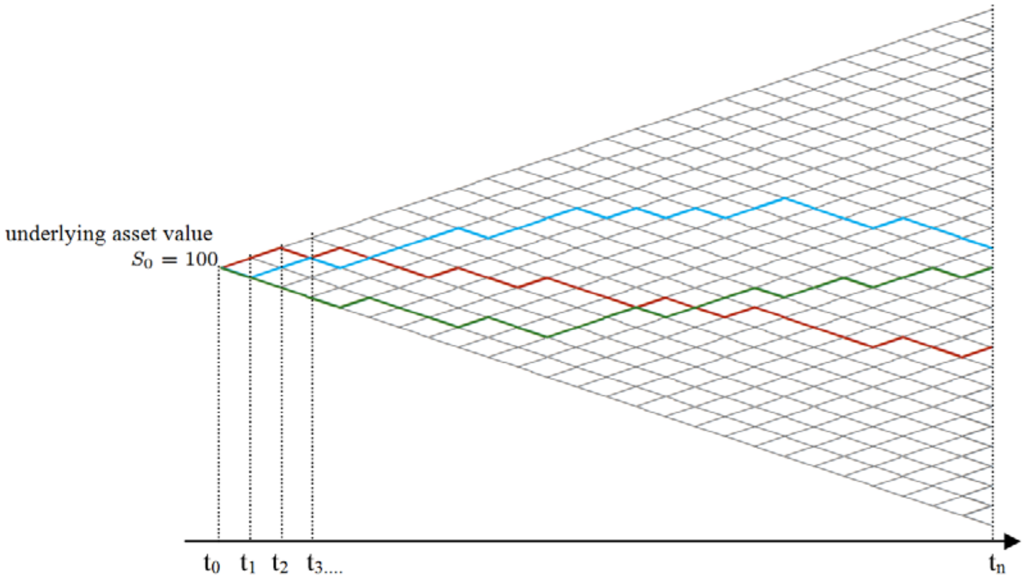



**Figure Ad5-12: Sample paths of a Binomial model**
*source: (Haugh & Iyenga, 2013)*

The binominal approach is based on scenario analysis and a binominal tree to value options. The binominal option pricing formula was developed by Cox, Ross and Rubinstein (1979). The model is discrete, which makes it relatively easy to understand.

For the calculations of the option values following variables are required: ***S*** (Underlying asset value, i.e. present value of the project's cash flow), ***X*** (Strike Price, i.e. project's implementation costs, ***t*** (time to maturity), $\sigma$ (volatility of stock returns, i.e. volatility of the project cash flow) and $r_f$ (risk-free rate).

The binominal lattice model requires two steps: (1) calculation of *the underlying asset value lattice*, and (2) calculation of *the option valuation lattice* in recursive backward induction process.

In the first step we start from the initial (present) value of the underlying asset ($S_0$) on the very left side of the lattice. For upside and downside movement of the underlying asset price, we have to compute sspecific multiplicative factor (***u*** for up or ***d*** for down movement).

When the volatility of the value of the underlying $\sigma$ and the time to maturity $t$ are known, the upside ($u$) and the downside ($d$) movement per each node in the binomial tree can be calculated, as follows:

$$u = e^{\sigma\sqrt{\Delta t}}$$

$$d = e^{-\sigma\sqrt{\Delta t}} \quad \text{(or } d = 1 / u\text{)}$$

Due to consistency in magnitude for the up and down movements as well as due to simplification, we assume a proportionate move both ways, as was originally proposed by Cox, Ross and Rubinstein ($u*d = 1$). If $u$ = 1,25, the upside potential is an increase of 25% of the present value of the underlying. The upside potential ($u$) of an option position is determined by the volatility of the value of the underlying asset and the time to maturity. On the other hand if $d$ = 0,80 (=1/1,25), there is a possible loss of 20% of the value of the asset that is used as the underlying.

Underlying asset value in the tree node $i,j$ can be computed as:

$$S_{i,j} = u^i * d^{i-j} * S_0$$

As the binomial tree model is used in the business case numerical example in the Chapter 4.2, the option valuation technique on a simple model is explained here briefly.

If we assume that underlying asset value $S_0$ is € 100, volatility $\sigma$ = 13%, $\Delta t$ = 1 (year), it implies: $u$ = 1,139 and $d$ = 0,878. Maturity time (when the option will expire) is four time periods (e.g. four years).

The underlying asset lattice in that case looks as shown in the **Figure Ad5-13**.

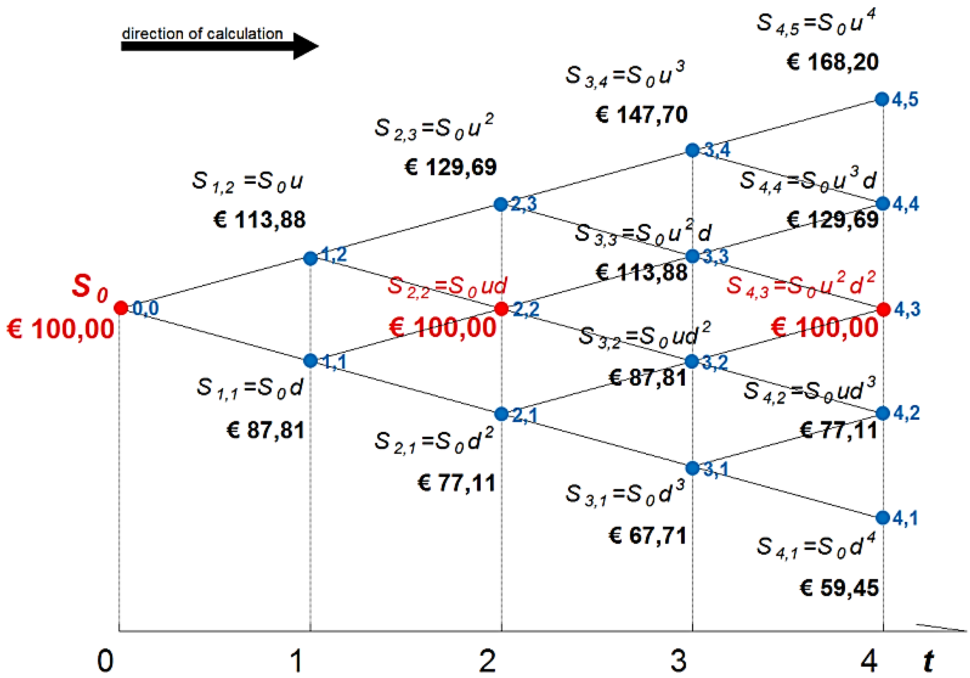



**Figure Ad5-13: Example of the underlying asset lattice calculation**
*source: the author*

As we assumed that $u*d$ = 1, the underlying asset value lattice is recombining, i.e. values along the lattice central axis are always the same, i.e. = $S_0$ (€ 100).

In order to create the option valuation lattice in the second step, we have firstly to compute probability. For a Brownian motion in the risk-neutral world, the probability - called **risk-neutral probability**, for the state variable to go up ($p$), is given as:

$$p = (e^{r_f \Delta t} - d)/(u - d)$$

where $r_f$ is the risk-free interest rate[70]. Probability for the down state is $q = 1 - p$. If we assume $r_f$ = 4,0%, it gives $p$ = 62,5% and $q$ = 37,5%. The example below (**Figure Ad5-14**) is done for an ***"Expand"*** real option (call), where we assumed the exercise price (expansion implementation costs) $X$ = €90, and expansion factor (increase of the present value of the underlying asset due to expansion) $f$ = 2,0.

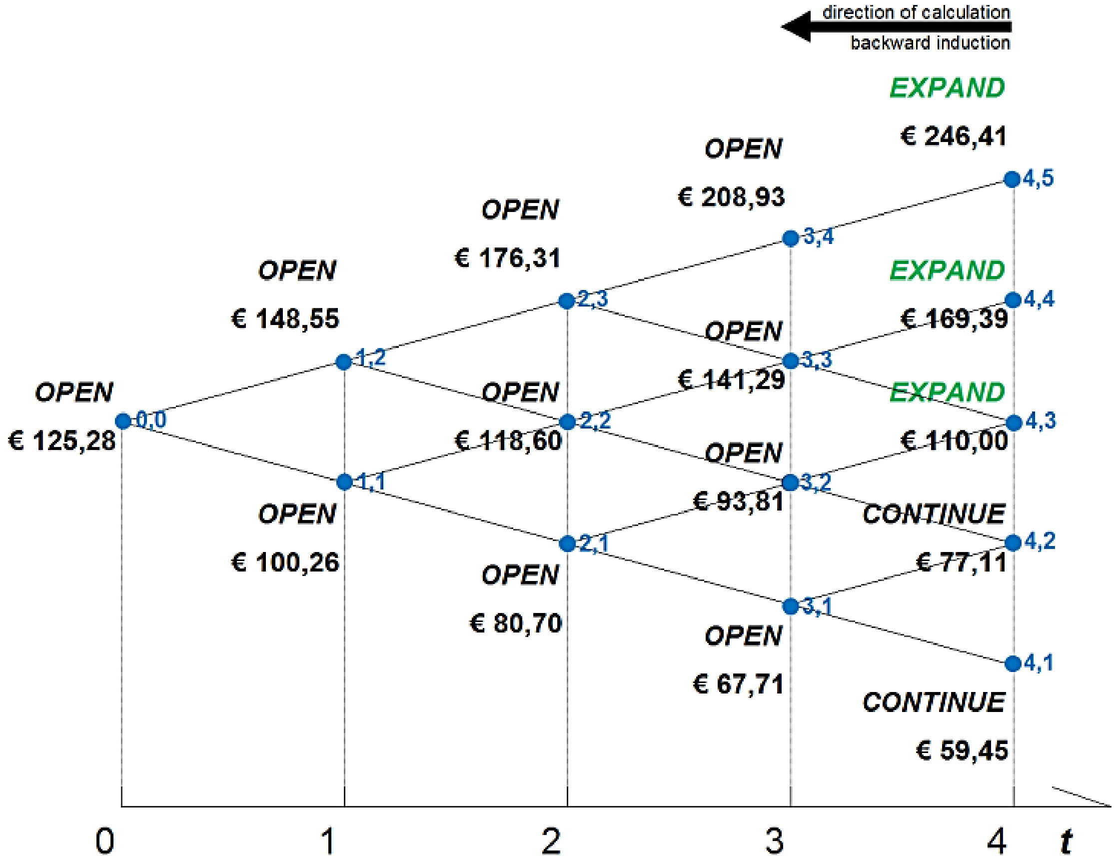



**Figure Ad5-14: Example of the ROV using the binomial tree (lattice)**
*source: the author*

At each final node of the tree, i.e., at expiration of the option, the option value is simply its intrinsic value, Max [(S – X), 0] for a call option and Max [(X – S), 0] for a put option. In the example in the **Figure Ad5-14**, we have to multiply expansion factor $f$ by

70 Average risk free rate in Eurozone based on 10 years governmental bond yields is 4,0%. For more, see Addendum 3.

the underlying asset value $S_{i,j}$ from the corresponding node from the underlying asset tree (e.g. for the node 4,5: [$f*S_{4,5} - X$]) and to compare it with the value of non-exercising the option, i.e. keeping the option "open" in the same node.

Formula for the ending nodes is Max [$S_{i,j}$; ($f*S_{i,j} - X$); 0], e.g. value in the node 4,5 is Max [168,20; (2*168,20 – 90,00); 0] = Max [168,20; 246,41; 0] = € 246,41 → we should exercise "EXPAND" option at that time!

The "open" option value at earlier (intermediate) nodes is calculated using the option values from the latter two nodes (either up or down) weighted by their respective probabilities, $p$ for up, and $q$ for down. For the call options value, following formula is valid:

$$C = (p * Cu + q * Cd) * e^{-r_f \Delta t}$$

$C_u$ = Value of the call if $S$ increases, $C_d$ = Value of the call if $S$ decreases.

By using the recursive backward induction technique, we will compute values at each node, from the last one (at expiration time) to the first node (present, i.e. starting time point). For example, value of the option in the node 3,3 is:

$C_{3,3}$ = Max [(($p*C_{4,4} + q*C_{4,3}$)$*e^{-r_f \Delta t}$); ($f*S_{3,3} - X$); 0]

$C_{3,3}$ = Max [((62,5%*169,39+37,5%*110,00)* $e^{-4\%*1}$); (2*113,88-90,00); 0]

$C_{3,3}$ = Max [(141,29; 137,77; 0]

$C_{3,3}$ = €141,29 → we should keep the option „OPEN", i.e. unexercised at that node!

Using the backward induction technique, the lattice is calculated back to the starting point (i.e. to the present, t=0), to obtain the value of **€ 125,28**. As the underlying asset value $S_0$ = 100,00 for existing operations, and the exercise price $X$ = € 90,00 (implementation cost of expansion activities), the value of expanding business activities today is 2 * € 100,00 - € 90,00 = € 110,00.

Failing or refusing to execute the expansion today, but still having an option for management given great market and economic outlook to expand the business then, the firm is worth more than its static value of € 110,00. The € 110,00 is the static NPV without flexibility, **the €15,28** (= €125,28 - € 110,00) **is the real options value**, and the combined value of **€125,28 is the total strategic value or eNPV (expanded NPV)** or NPV + Option value.

Having a possibility to keep the option open is valuable in highly uncertain business environment. Although the expansion costs ($X$) can change over time, and the expansion factor $f$ (in this example we assumed f = 2, i.e. doubling of the firm's or project present value) can also change accordingly, it is up to the management to decide when to execute this option. This was a simple case of real option valuation using binomial tree model. In the business case in the **Chapter 4.2**, a more complex real option valuation via IRMP framework is presented, which also use binomial tree.

Besides the risk-neutral probability which is applied in the example above, there is another technique to compute the real option value with the binomial tree approach – called the market-replicating portfolios technique. This technique is based on two assumptions: (1) there are many traded assets available in the market which can be obtained to replicate cash flow of the project subject to the valuation, and (2) there are no arbitrage opportunities. A good numerical example of solving a compound real option by applying the market-replicating portfolio technique is given in (Radjenovic, 2008). Nevertheless, this technique is more difficult to understand and apply, and according to Mun (2006), page 128, the results obtained from the market-replicating portfolios technique are identical to those obtained by the risk-neutral probability technique. The latter technique is used in the business case in the **Chapter 4.2**.

Besides binomial lattices, there are also trinomial and quadrinomial lattices (**Figure Ad5-15**) and even pentanomial lattices (**Figure Ad5-16**) for solving complex real options, such as rainbow options with two or more uncertainties, etc. Building and solving a trinomial tree is similar to building and solving a binomial tree, complete with the up/down jumps and risk-neutral probabilities. However, the recombining trinomial tree below is more complicated to build. The results stemming from a trinomial tree are the same as those from a binomial tree at the limit, but the tree-building complexity is much higher for trinomials or multinomial trees.

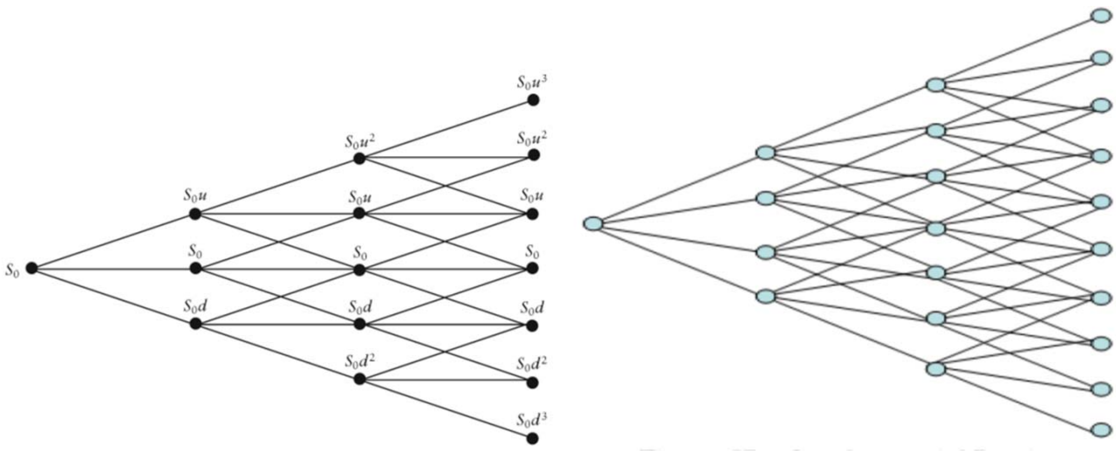



**Figure Ad5-15: Trinomial (left) and quadrinomial (right) lattice**
*source: (Mun, 2006)*

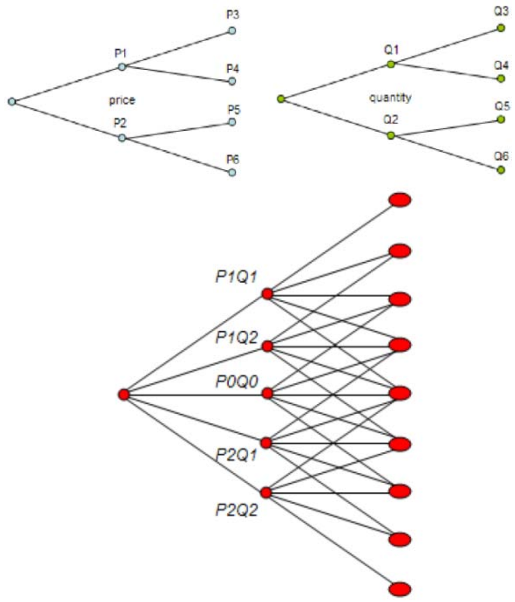



**Figure Ad5-16: Pentanomial lattice as a combination of two binomial lattices**
*source: (Mun, 2006)*

Although recombining lattices are easier to calculate and arrive at identical answers to the non-recombining lattices, there are conditions when non-recombining lattices are required for the analysis. These conditions include circumstances when there are multiple sources of uncertainty or when volatility changes over time, as shown in the **Figure Ad5-17**, the underlying asset lattice (left) and valuation lattice (right) on an American call option with changing volatilities using the risk-neutral probability.

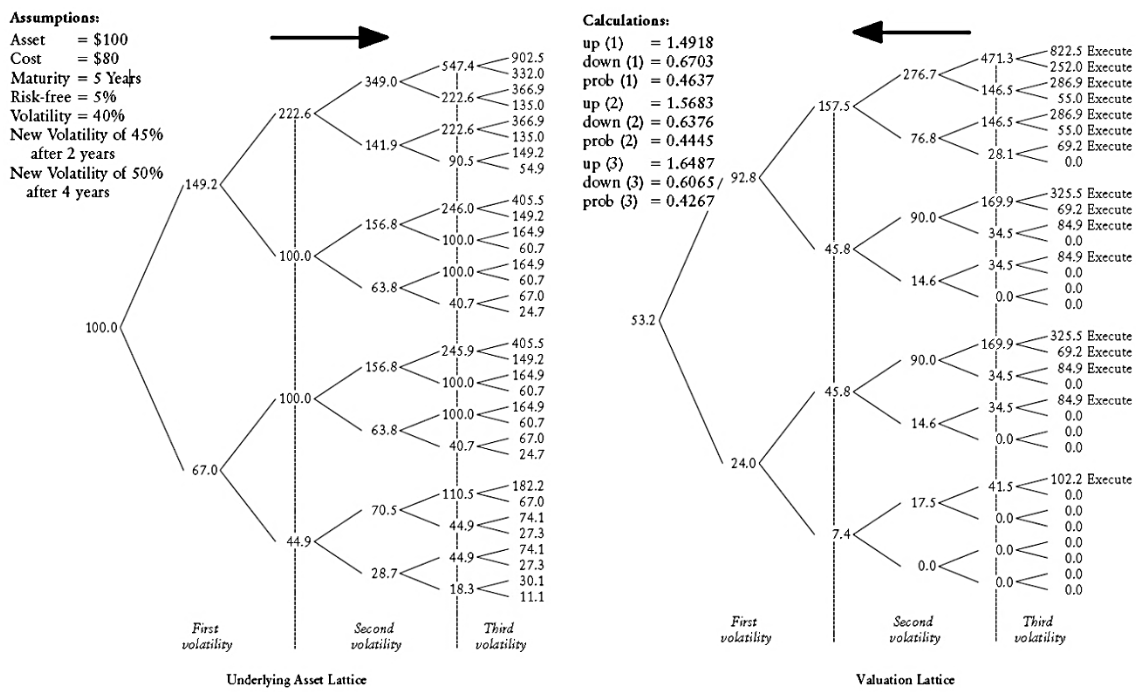



**Figure Ad5-17: Example of non-recombining binomial tree**
*source: (Mun, 2006)*

## Addendum 6: Real options theory - basics

### *Definition*

Regardless that the "real options" as a term dates since 1976, there is still no consensus in the academic community what is the right definition of real options:

Dixit and Pindyck, (Avinash & Pindyck, 1995): *"Opportunities are options – right but not obligation to take some action in the future"*;

Trigeorgis, (Trigeorgis, 1996): *"Similar to options on financial securities, real options involve discretionary decisions on rights, with no obligations, to acquire or exchange an asset for a specified alternative price"*;

Amram and Kulatilaka, (Amram & Kulatilaka, 1999): *"In a narrow sense, the real options approach is the extension of financial option theory to options on real (non-financial) assets"*;

de Neufville, (de Neufville, 2003): *"Real "options deal with physical things rather than financial contracts. Specifically, they refer to elements of a system that provide "rights, not obligations" to achieve some goal or activity. Generally speaking, all elements of a system that provide flexibility can be considered as "real options";*

Copeland and Antikarov, (Copeland & Antikarov, 2003): *"A real option is the right, but not the obligation, to take an action (e.g. deferring, expanding, contracting or abandoning) at a predetermined cost called the exercise price, for predetermined period of time – the life time of the option"*.

Mun, (Mun, 2006):*"Real options are a new paradigm shift in the way of thinking about evaluating projects. They are useful not only in valuing a firm through its strategic business options but also as a strategic business tool in capital investment decisions."*

### *Historical background*

Although the term "real option" was entered into scientific community in 1976 (Myers, 1977)[71], when Stewart C. Myers discussed treatment of non-financial ("real") corporate's assets as "call" options in the context of application of financial options theory[72], the trade of options on real assets is older than money based transactions and it has its roots in ancient times[73]. Myers argued that valuation of investment opportunities using traditional DCF approach ignores the value of options arising in valuation of uncertain and risky investment. A couple of years before Myers coined the term "real options", his colleagues from M.I.T. - the Nobel Prize winners Fischer Black, Robert Merton and Myron Scholes explained the foundation of what has come to be known as the foundation of the real options approach in their winning work on the pricing of financial option contracts. Nevertheless, a significant scientific development of real options started in 1980's when the topic attracted large interest firstly in academic and later in business world, and a number of books, studies, articles, master thesis and PhD dissertation have been published on theory and applications of real options in different industries such as oil & gas, energy, telecommunications, automotive, pharmaceuticals, aircraft, military, government, IT, infrastructure, real estate, M&A, etc., by applying the concept to value not only corporate securities but also corporate strategic investment decisions.

---

[71] Received in Oct 1976, revised version received Jul 1977, pp147-175. An earlier version of this paper ("A note on the determinants of corporate debt capacity", Working Paper), was presented in 1975 at seminars at the London Graduate School of Business Studies, Duke University and the Faculte Universitaire Catholique du Mons, Belgium.

[72] The most commonly used option pricing models today are the Black-Scholes model (Black, Scholes and Merton in 1973 developed the formula to valuate a call option, known as Black-Scholes Formula) and the binomial model. For more about option pricing models, see Addendum 5.

[73] One of the oldest known examples can be found in the Book of Genesis (Old Testimony), when Joseph who was sold into Egypt in 18th century B.C., had interpreted Pharaoh's dream and advised him to invest largely in grain. Joseph recognized this to be the best path into the future: exercising the option and buying all available grain now and during the coming seven years of abundance in order to save it for the seven years of scarcity which will come afterward. The risk Joseph and his contemporaries faced in Egypt was to die of starvation; the real option available to them was to hedge against that risk by saving grain. The exercise price to be paid was the creation of appropriate storage containers to keep the grain (Copeland & Antikarov, Real options – A practitioner's guide, 2003), (Brach, 2003).

***When managerial flexibility is valuable?***

According to Copeland and Antikarov (2003), ROV is the most applicable when following three conditions come together:

1. High uncertainty about the future: It's very likely to receive new information over time;
2. High room for managerial flexibility: Allows management to respond appropriately to the new information;
3. NPV without flexibility near zero: If a project is neither obviously good nor obviously bad (i.e. if it is close to break-even), flexibility to change further direction is more likely to happen and therefore it is more valuable.

Similar is noticed by Brach (2003), who stated that real options do not benefit from uncertainty itself, but only from flexibility to respond to future uncertainty. From this fundamental conceptual difference between real options and financial options, derives the generic rule on the value and exercise of real options. This is illustrated in the **Figure Ad6-18:**

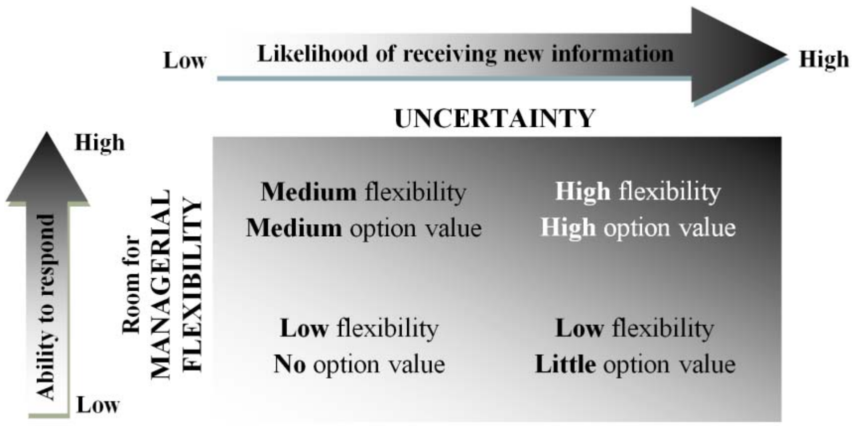



**Figure Ad6-18: When managerial flexibility is valuable**
*source: (Copeland & Antikarov, Real options – A practitioner's guide, 2003), (Brach, 2003)*

Besides these authors, Mun (2006), emphasized that it is not enough for management to have flexibility and strategic options, but they must be rational in executing such options. According to Brach (2003), this requires specific organizational approach in the company, tailor made for real options implementation, as also concluded by Triantis and Borison (2001), who see real options as a way of thinking, as an analytical tool but also as an organizational process, i.e. as a management tool to identify and implement strategic options.

In general, there are only two situations when managerial flexibility does not affect investment decisions:

1) if decision maker has perfect information, i.e. if all relevant information are known with certainty, decision making process is reduced to selection of the best among all available alternatives, and
2) if all decisions that have been made up to the present are completely reversible, i.e. revocable, which means there is no risk to invest.

As any of these two situations are almost impossible in business world nowadays, capital budgeting and valuation techniques have to be enhanced with the tools for quantification of risk and managerial flexibility embedded in investment projects in order to respond to uncertain situations and to limit associated threats of losses.

Managerial flexibility can have a defensive or an offensive character. For instance, expanding existing power plant capacity during operation or expanding business to new markets is offensive approach, whilst switching from one to another type of fuel or abandoning the running power plant due to unfavourable change of market conditions is example of defensive approach.

However, from project management point of view, uncertainty and flexibility have to be minimized, since efficient project execution is often measured in terms of meeting deadlines, budgeted costs and specification settings for the project. This contradicts one of main postulates of real options theory that uncertainty holds value, and introducing more flexibility into projects can allow a higher extraction of value, as the common objective of a project is to increase the value for the project owner.

All project phases can be affected by introducing internal and external flexibility. Internal flexibility refers to a project's efficiency, i.e. how project requirements are to be met, while external flexibility refers to a project's effectiveness, i.e. it aims to define what requirements are to be met within a project (Olsson N. O., 2008). The relative share of external and internal flexibility during the project development and execution is illustrated in the **Figure Ad6-19**.

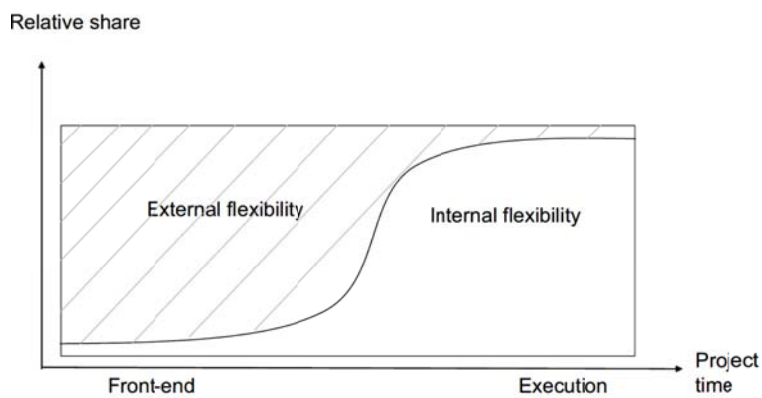



**Figure Ad6-19: External and internal flexibility in the project**
*source: (Olsson N. O., 2008)*

In the early project phases (pre-feasibility and feasibility studies, preliminary designs, setting project deliverables, etc.), flexibility is highly desirable and often encouraged by smart managers. Once the project decision is in place by approving the FID[74], the room for external flexibility is significantly reduced. Changes in later project phases come with consequential cost increases.

[74] Final Investment Decision, i.e. decision for execution (construction, erection) of the project.

***Differences between risk and uncertainty***

Although the terms risk and uncertainty are used in many ways in everyday life, sometimes as synonyms, when talking on ROV we have to make clear difference between risk and uncertainty.

The general meaning of the word risk implies something negative. On the other hand, risk is sometimes suggested to be ambiguous in nature. For instance, PMI (PMBoK, 4th edition, 2008) defines risk as an uncertain event or condition that, if it occurs, has a positive or negative effect on a project's objectives.

Furthermore, some authors (Olsson R. , 2006), use outcome of an uncertainty in a business environment context to distinguish between risk and opportunity, as depicted in the **Figure Ad6-20.**

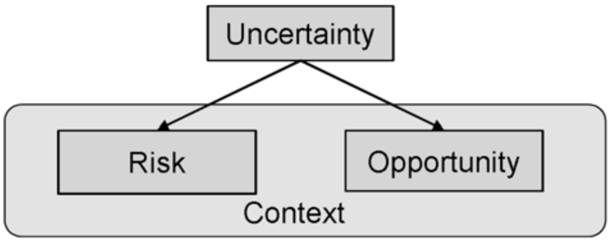



**Figure Ad6-20: Risk and opportunity derive from uncertainty in the specific context**

*source: (Olsson R. , 2006)*

Additionally, Frank (1999) describes uncertainty as either (1) aleatory[75] uncertainty (outcome is unpredictable - like in gambling) or (2) epistemic uncertainty (can predict outcome by employing knowledge).

Uncertainty can be also defined as a lack of certainty, where it is impossible to exactly describe the existing state and future outcome(s). By assigning probability distributions to each of possible uncertainties we can quantify the outcome – either risk or opportunity.

In order to measure the risk in MCS which is part of ROV, each of the project uncertainties must be properly approximated by most suitable probability distribution. For price uncertainties, most applicable is log-normal distribution, for cost is often used either triangular or uniform, depending on input data quality, etc.

For example, if we do not know what is the average wind speed at a future wind farm location, then we have a state of uncertainty. Wind speed probability distribution is crucial for the wind farm projects valuation, since the energy yield increases with the third power of the wind speed! Weibull's distribution is the most commonly used for wind speed approximation (**Figure Ad6-21**).

[75] from the Latin alea, meaning die (pl. dice)

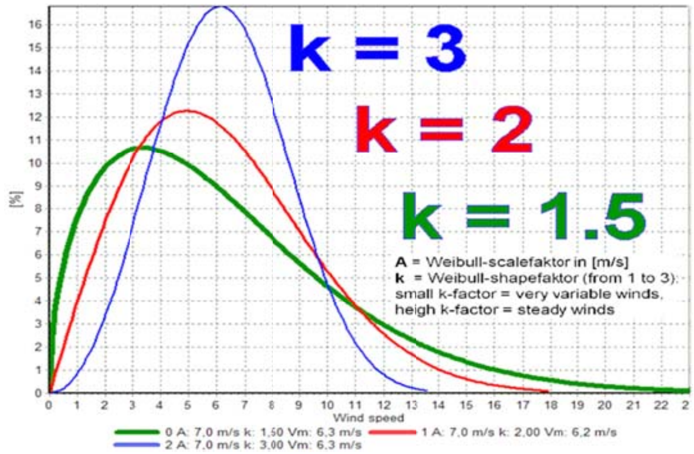



**Figure Ad6-21: Weibull's and Rayleigh's probability distribution of wind speed**
*source: (Neubauer, 2011)*

It has two inputs: scale factor ***A***[76] in [m/s] and shape factor ***k*** which goes from 1 (variable winds) to 3 (steady winds). Rayleigh's distribution is a special case of Weibull's, where the shape factor ***k*** = 2. This distribution is often assumed when only the mean wind speed is known.

If we apply probabilities to the possible outcomes using historical wind data through a calibrated probability assessment, we have quantified the uncertainty. Suppose we quantify uncertainty as 80% chance (P80) of wind speed ≥ 6 m/s. In that case, we have a risk since there is a 20% chance of wind speed < 6 m/s.

According to Mun (2006), uncertainty is different from risk as it becomes resolved through time, i.e. during project development and operation. Risk is something which one bears and is the outcome of uncertainty. Considering uncertainty and risk, events can be divided into three levels:

- ***known*** – when we are certain of occurrence of planned events (e.g. contractual obligations),
- ***unknown*** – when we don't know what will happen, but for the purpose of ROV we can simulate certainty of planned events by using appropriate probabilistic distributions (*discrete:* Bernoulli Yes-No, binomial, geometric, Pascal, Poisson, ... and *continuous:* normal, lognormal, triangular, uniform, beta, gamma, logistic, exponential, power, Student's, parabolic, Weibull's, ...), as inputs for sophisticated simulation tools such as MCS. These events carry with them some risks which will be reduced or eliminated over time.
- ***unknowable*** – these events carry both uncertainty and risk that are almost unpredictable, cannot be simulated and cannot be reduced or eliminated over time, e.g. natural disasters (earthquakes, tsunami, ...), terroristic acts, nuclear

[76] By some authors denoted as "***c***"

power plant disaster, ... In economic theory, this unknowable uncertainty which is immeasurable is called Knightian uncertainty, after prof. Frank Knight (University of Chicago, USA), who distinguished between what he called 'risk' and 'uncertainty' in his book "Risk, Uncertainty and Profit" (Knight, 1921). According to Knight *"uncertainty must be taken in a sense radically distinct from the familiar notion of risk, from which it has never been properly separated. The term 'risk,' as loosely used in everyday speech and in economic discussion, really covers two things which... are categorically different... 'Risk' means in some cases a quantity susceptible of measurement... A measurable uncertainty, or 'risk' proper, as we shall use the term, is so far different from an unmeasurable one that it is not in effect an uncertainty at all. We shall accordingly restrict the term 'uncertainty' to cases of the non-quantitative type. It is this 'true' uncertainty, and not risk, as has been argued, which forms the basis of a valid theory of profit and accounts for the divergence between actual and theoretical competition."*

Unknowable events are also known as *black swan*[77] *events*, i.e. events hard-to-predict, that are beyond the normal expectations in history, science, finance and technology and that have an extreme impact.

Considering relationship between impact and uncertainty, Bräutigam et al. (2003) proposed impact–uncertainty matrix, as shown on the **Figure Ad6-22**. In order to roughly assess the added value of an uncertainty, proposed uncertainty rating (II – VI) may be used.

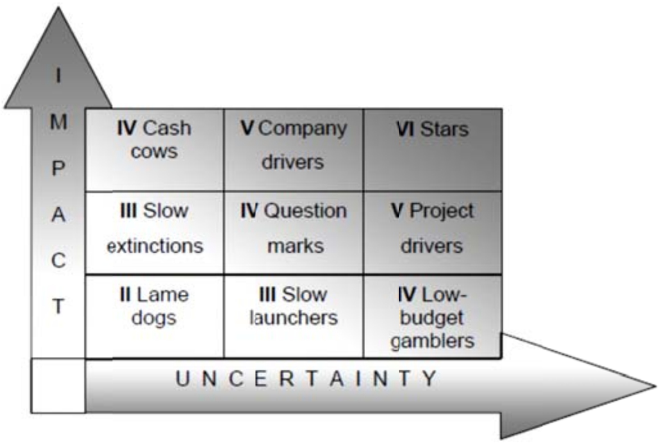



**Figure Ad6-22: Impact–uncertainty matrix**
*source: (Bräutigam, Esche, & Mehler-Bicher, 2003)*

In 2003, Walker et al. (2003), proposed different leveling of uncertainties in a business environment - they recognized three levels: general, industry and company (**Table Ad6-4**).

---

77 In 17th century in Europe, it was assumed that all swans were white, as no non-white swan had ever been observed.

**Table Ad6-4: Three levels of uncertainties**

*source: (Walker, 2003)*

| | |
|---|---|
| **General environmental uncertainties** | |
| Political | Terrorism, War, Changes in Government |
| Governmental policy | Fiscal and monetary policies, trade restrictions, regulation affecting the business sector, tax policy |
| Macroeconomic | Exchange rates, interest rates, inflation, terms of trade |
| Social | Social unrest, shift in social concerns |
| Natural | Variations in weather conditions, natural disasters |
| **Industry uncertainties** | |
| Input market | Quality and price of inputs, supply relative to industry demand |
| Product market | Consumer tastes, market demand, availability of substitutes and complements |
| Competition | Pricing and other forms of rivalry, new entrants, product and process innovations |
| **Company uncertainties** | |
| Operations | Labor relations, availability of inputs, production variability and downtime |
| Liability | Product liability, emissions of pollutants |
| R&D | R&D activities, regulatory approval on new products |
| Credit | Problems with collectibles |
| Behavioral | Opportunistic behavior by managers or employees |

Further on, according to Bräutigam et al. (2003), uncertainty is divided into endogenous and exogenous, and each of them have been assessed in the options-uncertainty matrix in terms of applicability to some of key real options types such as options to defer, abandon, expand, contract and switch[78], as shown in the **Table Ad6-5**:

**Table Ad6-5: Options-uncertainty matrix**

*source: (Bräutigam, Esche, & Mehler-Bicher, 2003)*

Exogenous

Endogenous

| | | REAL OPTION | | | | | |
|---|---|---|---|---|---|---|---|
| | | Defer | Abandon | Expand | Contract | Switch | |
| **Project** | Time | 1 | 1 | | 1 | | 3 |
| | Complexity | 1 | 1 | 1 | 1 | | 4 |
| **Intangibles** | Workforce productivity | | | | | 1 | 1 |
| | Workforce fluctuation | | 1 | 1 | 1 | | 3 |
| | Knowledge | 1 | 1 | 1 | 1 | | 4 |
| | Brand | | 1 | 1 | 1 | | 3 |
| **Financial** | Cost | 1 | 1 | 1 | 1 | 1 | 5 |
| | Liquidity | 1 | 1 | | | | 2 |
| **Product** | Quality | | 1 | 1 | 1 | | 3 |
| | Performance | | 1 | 1 | 1 | | 3 |
| | Property rights | 1 | | | | 1 | 2 |
| | Standards | 1 | | | | 1 | 2 |
| **Market** | Quantity | 1 | 1 | 1 | 1 | | 4 |
| | Price | 1 | 1 | 1 | 1 | | 4 |
| | Competition | 1 | 1 | 1 | 1 | 1 | 5 |
| **Regional** | Armed conflicts | 1 | | | | 1 | 2 |
| | Regulatory | 1 | | | | 1 | 2 |
| | Taxation | 1 | | | | 1 | 2 |
| | Legal | 1 | | | | 1 | 2 |
| | Natural phenomena | | | | | | 0 |
| | Infrastructure | | | | | | 0 |
| | Social | | | | | | 0 |
| **Unknowable uncertainties** | | | | | | | 0 |
| | | 14 | 12 | 10 | 11 | 9 | |

[78] Key features of these real options have been already discussed in the section 2.6.4 (Real options taxonomy).

It implies that the most applicable real options considering different type of uncertainties are deferral and abandon option. Most applicable uncertainties considering different type of real options are cost and competition related uncertainties.

*Volatility as a key value driver in ROV*

In the financial options pricing, volatility is a measure of the fluctuation of the underlying asset price between present and the option's maturity date. Volatility for the financial options is expressed either through standard deviation $\boldsymbol{\sigma}$ of the underlying asset price or through market index, such as ^VIX[79]. Beta ($\boldsymbol{\beta}$)[80] is a measure of relative volatility, i.e. volatility of an underlying asset's returns against the returns of a relevant market benchmark (e.g. the S&P 500).

To make stock (underlying asset) price volatility values more understandable, the difference between volatility of 20% and 60% for various lognormal stock price paths is shown in the **Figure Ad6-23**.

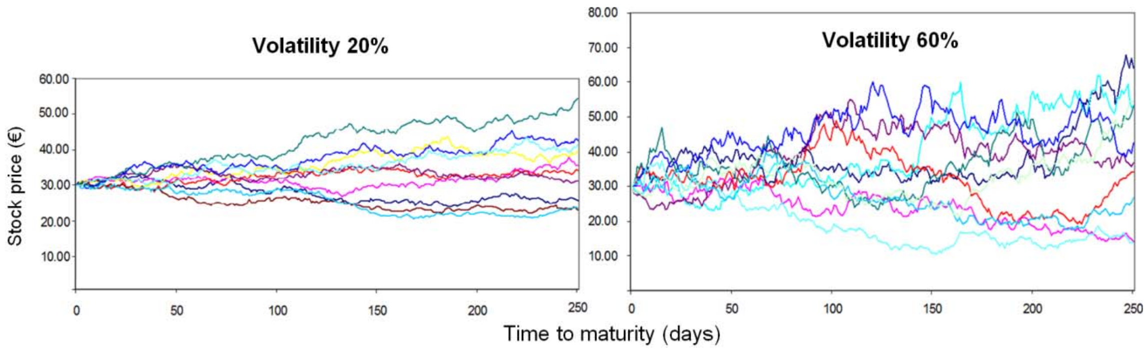



**Figure Ad6-23: Various log-normal stock prices in case of 20% and 60% volatility (scale is the same in both charts)**

One of the most illustrative examples of volatility change can be seen in 3D implied volatility surface charts of S&P Index in period 2007 to 2009 (Haugh & Iyenga, 2013), i.e. before global financial crisis started and after stabilization of the stock exchanges (**Figure Ad6-24**). On the vertical axis there is volatility index ^VIX, on the left horizontal axis there is moneyness[81] index and on the right horizontal axis there is time to maturity in days.

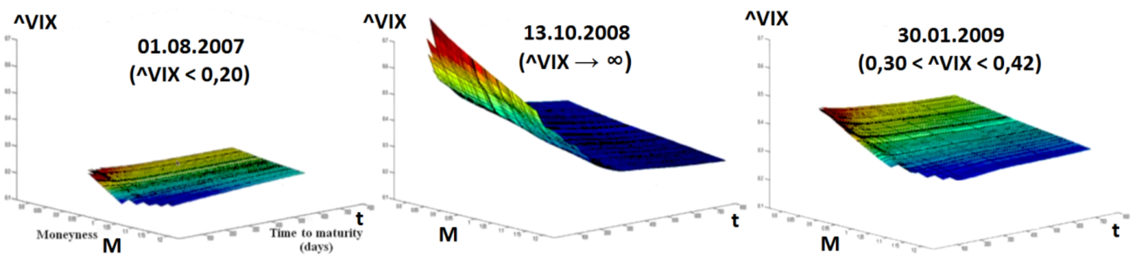



**Figure Ad6-24: 3D implied volatility surface charts of S&P Index 2007 to 2009**
*source: (Haugh & Iyenga, 2013)*

79 see footnote 2) **^VIX** (Market Volatility Index)

80 **Beta** = 1 if the underlying asset's volatility is equal to the overall market volatility. If the beta < 1 means that underlying asset is more stable than the market, which implies lower risk but also lower returns, while the opposite is valid if the beta > 1. Beta is used in the CAPM for the cost of equity determination, see the Addendum 3.

81 **Moneyness** has been explained in the Addendum 4.

As already mentioned in previous sections, higher volatility implies higher returns of financial options, both – puts and calls, while for real options it is not necessarily the case, as it depends on the real options compoundness.

There are several ways to estimate volatility in the options models, available in the literature (Copeland & Antikarov, 2003), (Mun, 2006), such as:

a) ***Logarithmic Present Value Returns***, which has its typical application in ROV, since it is based on the assets with cash flow. It is relatively complex for calculation as it requires Monte Carlo simulation of the project's cash flow to be performed. Standard deviation ($\boldsymbol{\sigma}$) of simulated cash flows is estimated volatility of the project.

b) ***Logarythmic Cash Flow Return*** or ***Logarythmic Stock Price Returns***, which is mainly used for financial options for liquid and tradable assets. Sometimes is used for other traded assets , such as price of electricity or price of oil.

c) ***GARCH (Generalized Autoregressive Moving Average),*** which has similar applicability as previous approach, but is more robust and detailed. It requires a lot of data for calculation, but in contrast, as the outcome it offers best fitting volatility path, with diferrent volatility estimates over time.

d) ***Management Assumptions and Guesses***, which is used both for financial and real options, but as this is a subjective approach, its main drawback is unrealibility.

e) ***Market Proxy Comparables or Indices***, which is mainly used for comparing liquid and non-liquid assets if the appropriate market data are available, which can be difficult in some cases.

Logarithmic Present Value Returns is applied in the business case in the **Chapter 4.2**. Its main advantage in comparison to the other listed below, is that it takes negative cash flow into volatility calculation, as it can be often the case in real projects. In the Copeland & Antikarov: Real options – A practitioner's guide (2003), this approach is called MAD (Marketed Asset Disclaimer). Mun (2006) recommends the risk free rate (***rfr***) to be always applied for discounting investment costs, while the risk adjusted discounted rates should be applied for discounting cash flows from the operation. Furthermore, if decision makers estimate that different project phases bear different level of risk, then it is recommendable for each of the specific phase to use different risk-adjusted discount rate.

***Real options "In projects" and "On projects"***

The fact that the field of real options remains in development is shown by (Wang & de Neufville, 2006). They found distinction between use of real options **"on projects"** and real options **"in projects"**. The options theory development in their vision is illustrated in the **Figure Ad6-25** below.

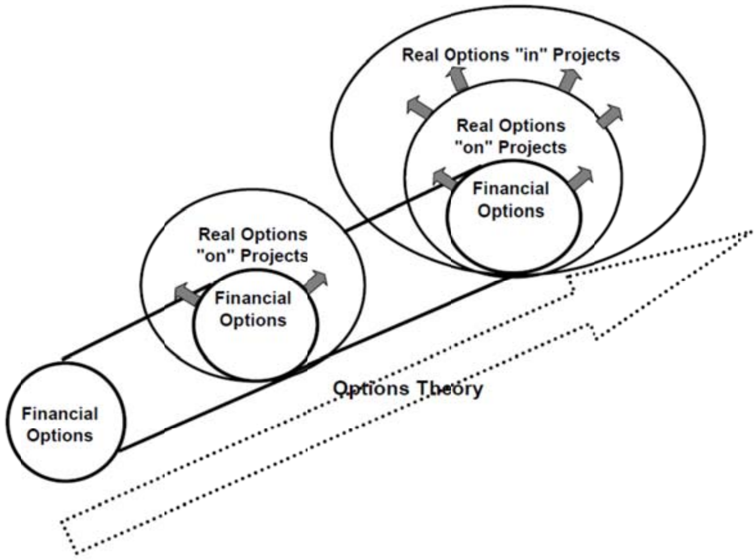



**Figure Ad6-25: Real options "on projects" and "in projects"**
*source: (Wang & de Neufville, 2006)*

Real options "on projects" can be seen as financial options taken on technical projects or investments. The technology itself is treated as a black box model and not affected.

Real options "in projects" are driven by engineering process and refer to the initial design improvements in terms of increased flexibility. These options are more difficult to identify and assess, as they are always technology specific, and therefore in-depth knowledge of the related technology is required.

RO "on projects" are related to the valuation of investment opportunities, while real options "in projects" are mostly related to design of flexibility. The classic cases of RO "on projects" are valuation of mines, power plants, oil fields, R&D projects, and the examples of real options "in projects" are subprojects i.e. technological entities within respective project phases. In the highway/railway design in the very early project phases, there are several paths to be evaluated, which can be treated as RO "in project".

In the **Table Ad6-6** a comparison between real options "on projects" and real options "in projects" is illustrated.

**Table Ad6-6: Comparison between real options "on" and "in" projects**

*source: (Wang & de Neufville, 2006)*

| Real options "on" projects | Real options "in" projects |
|---|---|
| Value opportunities | Design flexibility |
| Valuation important | Decision important ("go" or "no go") |
| Relatively easy to define | Difficult to define |
| Interdependency / Path-dependency less an issue | Interdependency / Path-dependency an important issue |

Due to technological complexity embedded in the RES-E projects, there are many possibilities for RO "in projects". One of interesting studies in that regard is (Cesena, 2012).

*Portfolio approach in real options*

According to Neftci (2000) – "a portfolio is a particular combination of assets in question". Assets in question can be either financial assets such as stocks, bonds, cash and derivatives[82] or real (tangible, physical) assets such as buildings, land, commodity, machinery and equipment and intangible assets, such as patent rights, software, etc.

Project portfolio theory is based on the financial portfolio theory, which is originated from Markowitz (1952). He established the concept of mean–variance analysis, which is based on diversification, in terms of maximizing the return for a respective variance i.e. minimizing the variance of the portfolio return for a respective mean of the return. This can be reached by increasing the number of assets included in the portfolio and in the limit by holding all available assets. He showed that the only relevant risk in this regard is the covariance[83] risk of each asset with the market portfolio. This implies a passive attitude towards risk because it is limited to diversification of the risk over as many assets as possible.

There are numerous definitions of portfolio management. According to Olsson (2006), several names for the same understanding of portfolio management exist, and acronyms as program management and multi-project management are frequently used. Portfolio management is a discipline where combined projects, to a certain extent, utilize the same management, where issues stretch beyond the scope of the project, and where interdependencies not manageable by a single project are to be managed by a portfolio head or "boss of projects". To clarify the author's perception of portfolio management, a short review of the conceptual differences is needed.

Program management is different from multi-project management. PMBoK (2008) refers to program management as the centralized, coordinated management of a group of projects to achieve the program's strategic objectives and benefits. Portfolio management is defined as a collection of projects and programs and other works that are grouped to facilitate effective management of that work to meet strategic business objectives. Therefore, portfolio management is related to strategic objectives and it has a wider scope than program management.

From project management point of view, some corporations group their projects into portfolios because of different reasons such as similarity of technologies or products, geographic location of projects as well as according to differences in the project life cycle. This requires different treatment of risk than for single projects and implies constitution of new standards within corporate risk management.

[82] For more about financial derivatives see Addendum 4.

[83] In probability theory and statistics, covariance is a measure of how much two random variables change together.

On the real options level, it has been shown by Trigeorgis (1993), that options on the same underlying assets interact, requiring a simultaneous valuation of all real options written on the same underlying asset. He defines interactions between real options written on the same underlying asset as "***intra–project compoundness***". Following the same logic, an analogous effect is identified for several, interdependent underlying assets which he denotes as "***inter–project compoundness***".

Both inter–project and intra–project compoundness are examined in the case study in the **Chapter 4**, in the context of portfolios of real options. Intra-project compoundness are examined through *Tomato garden* model executed with the results from already shown real options valuation *(multi-phased sequential compound mutually exclusive path-dependent real options of the wind farm)* in previous section, while the basic principles of the portfolio optimization for inter-project compoundness will be shown by applying *the efficient frontier* method on the portfolio consisting of twelve RES-E projects (Wind and PV). Combination of these two technologies is chosen by purpose, as they are complementary technologies from electricity generation point of view, as it is explained in the **Chapter 3** (see **Figure 3-2**, Fraunhofer 2013).

## Addendum 7: PV Sunpower E20 datasheet

In the **Figure Ad7-26**, a datasheet of one the most efficient mono-crystalline PV modules available in the market (Sunpower E20, SPR-333 and SPR-327) is shown.

**MODELS: SPR-333NE-WHT-D, SPR-327NE-WHT-D**

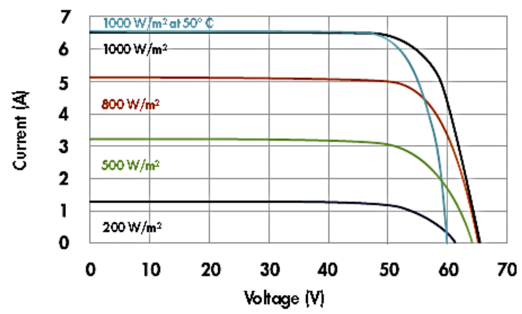
**ELECTRICAL DATA**
Measured at Standard Test Conditions (STC): Irradiance 1000W/m², AM 1.5, and cell temperature 25°C

| | | | |
|---|---|---|---|
| Nominal Power (+5/-0%) | $P_{nom}$ | 333 W | 327 W |
| Cell Efficiency | η | 22.8% | 22.5% |
| Panel Efficiency | η | 20.4% | 20.1 % |
| Rated Voltage | $V_{mpp}$ | 54.7 V | 54.7 V |
| Rated Current | $I_{mpp}$ | 6.09 A | 5.98 A |
| Open-Circuit Voltage | $V_{oc}$ | 65.3 V | 64.9 V |
| Short-Circuit Voltage | $I_{sc}$ | 6.46 A | 6.46 A |
| Maximum System Voltage | IEC | 1000 V | 1000 V |
| Temperature Coefficients | Power (P) | – 0.38%/K | |
| | Voltage ($V_{OC}$) | – 176.6mV/K | |
| | Current ($I_{SC}$) | 3.5mA /K | |
| NOCT | | 45°C +/– 2°C | |
| Series Fuse Rating | | 20 A | |
| Limiting Reverse Current (3 strings) | $I_R$ | 16.2 A | |
| Grounding | | Positive grounding not required | |

**ELECTRICAL DATA**
Measured at Nominal Operating Cell Temperature (NOCT): Irradiance 800W/m², 20° C, wind 1 m/s

| | | | |
|---|---|---|---|
| Nominal Power | $P_{nom}$ | 247 W | 243 W |
| Rated Voltage | $V_{mpp}$ | 50.4 V | 50.4 V |
| Rated Current | $I_{mpp}$ | 4.91 A | 4.82 A |
| Open-Circuit Voltage | $V_{oc}$ | 61.2 V | 60.8 V |
| Short-Circuit Voltage | $I_{sc}$ | 5.22 A | 5.22 A |

**I-V CURVE**




Current/voltage characteristics with dependence on irradiance and module temperature.

**TESTED OPERATING CONDITIONS**

| | |
|---|---|
| Temperature | – 40° C to +85° C |
| Max load | 550 kg/m² (5400 Pa), front (e.g. snow) w/specified mounting configurations<br>245 kg/m² (2400 Pa) front and back (e.g. wind) |
| Impact Resistance | Hail: 25 mm at 23 m/s |

**WARRANTIES AND CERTIFICATIONS**

| | |
|---|---|
| Warranties | 25-year limited power warranty |
| | 10-year limited product warranty |
| Certifications | IEC 61215 Ed. 2, IEC 61730 (SCII) |

**MECHANICAL DATA**

| | | | |
|---|---|---|---|
| Cells | 96 SunPower Maxeon™ cells | Output Cables | 1000 mm cables / Multi-Contact (MC4) connectors |
| Front Glass | High-transmission tempered glass with anti-reflective (AR) coating | Frame | Anodised aluminium alloy type 6063 (black) |
| Junction Box | IP-65 rated with 3 bypass diodes<br>32 x 155 x 128 mm | Weight | 18.6 kg |

**DIMENSIONS**

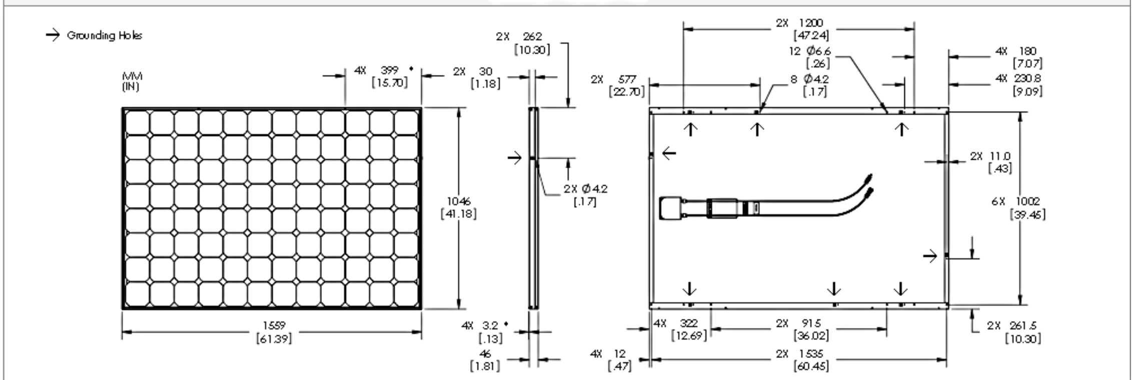
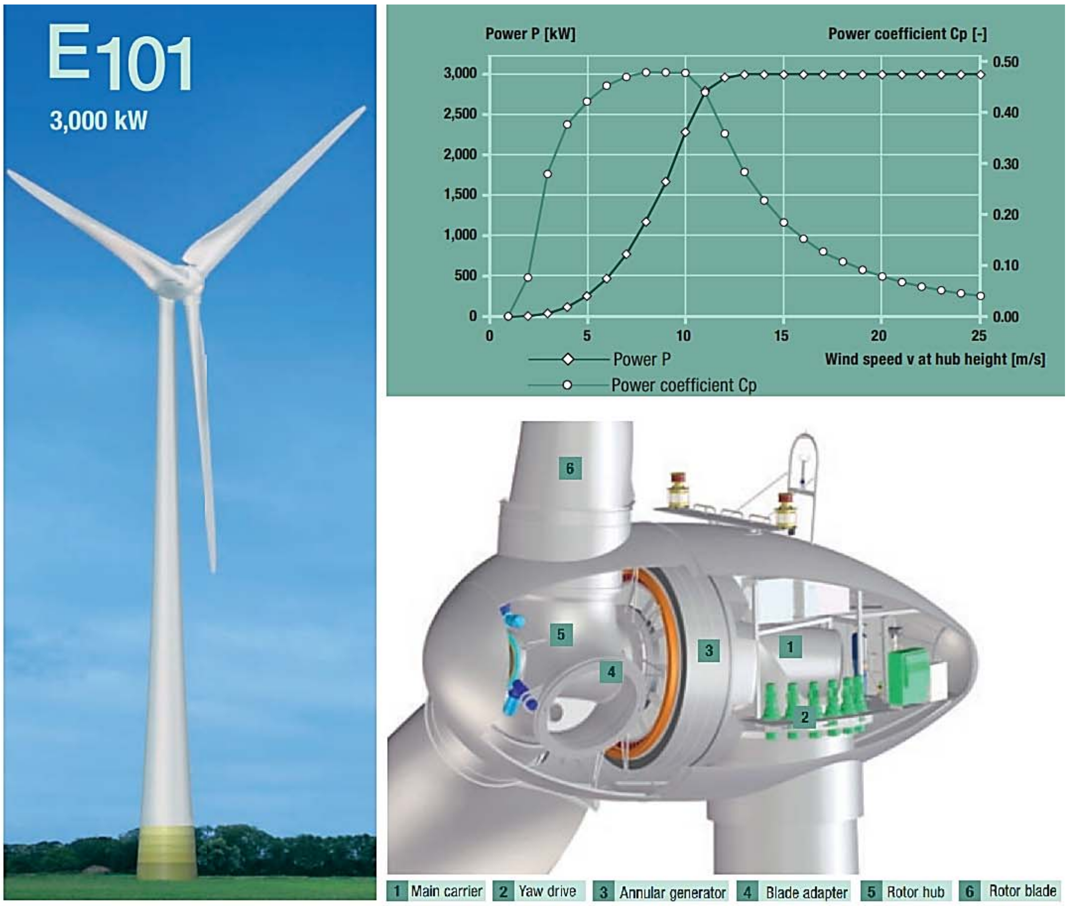



**Figure Ad7-26: Datasheet of the SunPower E20 PV module**
*source: www.sunpowercorp.com*

## Addendum 8: WTG Enercon E101 datasheet

The power curve as well as power factor of Enercon E 101 WTG are depicted in the **Figure Ad8-27,** including the basic technical features.




### Technical specifications E-101

| | |
|---|---|
| Rated power: | 3,000 kW |
| Rotor diameter: | 101 m |
| Hub height: | 99 m / 135 m |
| Wind zone (DIBt): | WZ III |
| Wind class (IEC): | IEC/NVN IIA |
| **WEC concept:** | Gearless, variable speed<br>Single blade adjustment |
| **Rotor** | |
| Type: | Upwind rotor with active pitch control |
| Rotational direction: | Clockwise |
| No. of blades: | 3 |
| Swept area: | 8,012 m² |
| Blade material: | GRP (epoxy resin);<br>Built-in lightning protection |
| Rotational speed: | Variable, 4–14.5 rpm |
| Pitch control: | ENERCON single blade pitch system;<br>one independent pitch system per rotor blade with allocated emergency supply |
| **Drive train with generator** | |
| Hub: | Rigid |
| Main bearing: | Double-row tapered/cylindrical roller bearings |
| Generator: | ENERCON direct-drive annular generator |
| **Grid feed:** | ENERCON inverter |
| **Brake systems:** | – 3 independent pitch control systems with emergency power supply<br>– Rotor brake<br>– Rotor lock, latching (15 °) |
| **Yaw system:** | Active via yaw gear, load-dependent damping |
| **Cut-out wind speed:** | 28–34 m/s<br>(with ENERCON storm control*) |
| **Remote monitoring:** | ENERCON SCADA |

*For more information on the ENERCON storm control feature, please see the last page.

**Figure Ad8-27: Enercon E-101 wind turbine generator**

*source: www.enercon.de*

## Addendum 9: Serbia FiT policy 2013

Serbian RES-E Feed-In-Tariff (FiT) policy came in force in February 2013, through the Decree on Incentive Measures for Privileged Energy Producers (2013).

Incentive measures as defined in this Decree are:

**1) Feed-in tariffs** at which the privileged producer is entitled to sell total amount of power generated during the incentive period to the Public Supplier (e.g. 9,2 €c/kWh for wind, and 16,25 €c/kWh for ground mounted PV, etc., see **Figure Ad9-28**);

| Item No. | Type of power plant | Installed power P (MW) | Feed-in tariff (c€/kWh) |
|---|---|---|---|
| 1. | Hydro power plant | | |
| 1.1 | | up to 0,2 | 12,40 |
| 1.2 | | 0,2–0,5 | 13,727 - 6,633 * P |
| 1.3 | | 0,5–1 | 10,41 |
| 1.4 | | 1–10 | 10,747 - 0,337 * P |
| 1.5 | | 10–30 | 7,38 |
| 1.6 | Using existing infrastructure | up to 30 | 5,9 |
| 2. | Biomass power plant | | |
| 2.1 | | up to 1 | 13,26 |
| 2.2 | | 1–10 | 13,82 - 0,56 * P |
| 2.3 | | over 10 | 8,22 |
| 3. | Biogas power plant | | |
| 3.1 | | up to 0,2 | 15,66 |
| 3.2 | | 0,2–1 | 16,498 - 4,188 * P |
| 3.3 | | over 1 | 12,31 |
| 3.4 | Plant fired by biogas from animal origin waste | | 12,31 |
| 4. | Landfill and sewage gas power plant | | 6,91 |
| 5. | Wind power plant | | 9,20 |
| 6. | Solar power plant | | |
| 6.1 | roof–mounted | up to 0,03 | 20,66 |
| 6.2 | roof–mounted | 0,03–0,5 | 20,941 - 9,383 * P |
| 6.3 | ground–mounted | | 16,25 |
| 7. | Geothermal power plant | | |
| 7.1 | | up to 1 | 9,67 |
| 7.2 | | 1–5 | 10,358 - 0,688 * P |
| 7.3 | | over 5 | 6,92 |
| 8. | Waste fired power plant | | 8,57 |
| 9. | Coal fired co-generation power plant | up to 10 | 8,04 |
| 10. | Gas fired co-generation power plant | up to 10 | 8,89 |

**Figure Ad9-28: FiT in Serbia, valid as of Feb 2013**

*Adapted from (Ministry of energy, development and environmental protection, 2013)*

**2) The incentive period of 12 years** for each of the power plants of the privileged power producers which have been commissioned less than 12 months before conclusion of the Power Purchase Agreement i.e. the 12 years incentive period reduced by difference between the year of concluding the Power Purchase Agreement and the year of commissioning of all the other privileged producers' power plants;

**3) The right of privileged producer** who had previously acquired temporary status of privileged power producer to sell total amount of electricity generated during the incentive period to the Public Supplier at feed-in tariff valid at the time of acquiring temporary status of privileged power producer;

**4) Taking balancing responsibility and balancing costs** from privileged producers during the incentive period by the Public Supplier;

**5) Free of charge monthly notification** of a privileged producer and Public Supplier on the electricity generation in the facility of the privileged producer metered by the relevant System Operator during the incentive period;

**6) The right of a privileged producer to conclude an Agreement with the Public Supplier after the incentive period** on purchase of the total amount of produced electric power at conditions on the organized electric power market in the Republic of Serbia.

Validity of the Decree is by 31.12.2015.

## Addendum 10: List of assumptions for the BASE scenario DCF model for Wind farm and PV power plant project

BASE SCENARIO (T=0-25 year): WIND

| # | Parameter | Unit | Most likely or P50 | Min | Max | Other parameters | Distribution | Risk type |
|---|---|---|---|---|---|---|---|---|
| 1 | Investment horizon (LT) | years | 25 | | | | | |
| 2 | **(r1) Risk-adjusted discount rate during FiT** | **%/y** | **8,00%** | | | Loc:6%, StDev:0.8% | Lognormal | Public (Market) |
| 3 | Capital recovery factor during FiT (α1) | - | 0,094 | | | | | |
| 4 | **(r2) Risk-adjusted discount rate after FiT** | **%/y** | **12,00%** | | | Loc:8%, StDev:1.2% | Lognormal | Public (Market) |
| 5 | Capital recovery factor during FiT (α2) | - | 0,127 | | | | | |
| 6 | **(rfr) Discount rate for implementation costs** | **%/y** | **4,00%** | | | Loc:2%, StDev:0.6% | Lognormal | Public (Market) |
| 7 | Capital recovery factor for implementation costs (αf) | - | 0,064 | | | | | |
| 8 | Wind turbine size | MW | 3,00 | | | | | |
| 9 | **Number of WTG or PV clusters installed** | **pcs** | **10** | | | | | |
| 10 | Rated capacity, el | MW | 30,00 | | | | | |
| 11 | **Capacity factor** | **%/y** | **26,0%** | | | Loc:21%, Sc:5,65%, Sh:2.95 | Weibull^3 | Private |
| 12 | Yearly El.generation | MWh | 68.328 | | | | | |
| 13 | El. Feed-in Tarrif (FiT) | EUR/MWh | 92,00 | | | | | |
| 14 | FIT guaranteed period | years | 12 | | | | | |
| 15 | **Regular el. Price in Tcf=0** | **EUR/MWh** | **50,00** | | | Loc:40, StDev:5 | Lognormal | Public (Market) |
| 16 | **Regular el. Price escalation** | **%/y** | **2,0%** | 0,0% | 4,0% | | Triangular | Public (Market) |
| 17 | **Inflation rate in Euro-zone** | **%/y** | **2,0%** | | | Loc:1%, StDev:0.2% | Lognormal | Public (Market) |
| 18 | **Specific investment costs** | **EUR/MW** | **-1.350.000** | -1.400.000 | -1.300.000 | | Uniform | Private |
| 19 | Phase 1 Investment volume share | - | 0,12 | | | | | |
| 20 | Investment costs (phase 1), Tcf=0 | EUR | -4.860.000 | | | | | |
| 21 | Investment costs (phase 2), Tcf=1 | EUR | -35.105.400 | | | | | |
| 22 | **Total Investment in Base scenario** | **EUR** | **-39.965.400** | | | | | |
| 23 | **Specific O&M costs** | **EUR/MW*y** | **-40.000** | -42500 | -37500 | | Uniform | Private |
| 24 | O&M costs | EUR/y | -1.200.000 | | | | | |
| 25 | Specific O&M costs | EUR/MWh*y | -17,56 | | | | | |
| 26 | **OPEX escalation** | **%/y** | **2,0%** | 1,0% | 3,0% | | Triangular | Private |
| 27 | **Other costs (on top to O&M costs)** | **%/y** | **5,0%** | 4,0% | 6,0% | | Uniform | Private |
| 28 | **Corporate Income Tax** | **%/y** | **15,0%** | 10,0% | 20,0% | | Uniform | Public (Market) |
| 29 | **CAPEX reduction** | **%/y** | **1,5%** | -0,50% | 2,50% | | Uniform | Public (Market) |
| 30 | **El. FiT premium after FiT period** | **EUR/MWh** | **53,0** | 50% | | | Bernoulli (Yes /No) | Public (Market) |
| 31 | **Duration of FiT premium period** | **years** | **6** | 0 | 12 | | Uniform | Public (Market) |

PV

| # | Parameter | Unit | Most likely or P50 | Min | Max | Other parameters | Distribution | Risk type |
|---|---|---|---|---|---|---|---|---|
| 1 | Investment horizon (LT) | years | 25 | | | | | |
| 2 | **(r1) Risk-adjusted discount rate during FiT** | **%/y** | **8,00%** | | | Loc:6%, StDev:0.8% | Lognormal | Public (Market) |
| 3 | Capital recovery factor during FiT (α1) | - | 0,094 | | | | | |
| 4 | **(r2) Risk-adjusted discount rate after FiT** | **%/y** | **12,00%** | | | Loc:8%, StDev:1.2% | Lognormal | Public (Market) |
| 5 | Capital recovery factor during FiT (α2) | - | 0,127 | | | | | |
| 6 | **(rfr) Discount rate for implementation costs** | **%/y** | **4,00%** | | | Loc:2%, StDev:0.6% | Lognormal | Public (Market) |
| 7 | Capital recovery factor for implementation costs (αf) | - | 0,064 | | | | | |
| 8 | Wind turbine size | MW | 5,00 | | | | | |
| 9 | **Number of WTG or PV clusters installed** | **pcs** | **1** | | | | | |
| 10 | Rated capacity, el | MW | 5,00 | | | | | |
| 11 | **Capacity factor** | **%/y** | **14,0%** | 12,0% | 16,0% | | Uniform | Private (Project) |
| 12 | Yearly El.generation | MWh | 6.132 | | | | | |
| 13 | El. Feed-in Tarrif (FiT) | EUR/MWh | 162,50 | | | | | |
| 14 | FIT guaranteed period | years | 12 | | | | | |
| 15 | **Regular el. Price in Tcf=0** | **EUR/MWh** | **50,00** | | | Loc:40, StDev:5 | Lognormal | Public (Market) |
| 16 | **Regular el. Price escalation** | **%/y** | **2,0%** | 0,0% | 4,0% | | Triangular | Public (Market) |
| 17 | **Inflation rate in Euro-zone** | **%/y** | **2,0%** | | | Loc:1%, StDev:0.2% | Lognormal | Public (Market) |
| 18 | **Specific investment costs** | **EUR/MW** | **-1.750.000** | -1.900.000 | -1.600.000 | | Uniform | Private (Project) |
| 19 | Phase 1 Investment volume share | - | 0,12 | | | | | |
| 20 | Investment costs (phase 1), Tcf=0 | EUR | -1.050.000 | | | | | |
| 21 | Investment costs (phase 2), Tcf=1 | EUR | -7.507.500 | | | | | |
| 22 | **Total Investment in Base scenario** | **EUR** | **-8.557.500** | | | | | |
| 23 | **Specific O&M costs** | **EUR/MW*y** | **-28.000** | -30000 | -26000 | | Uniform | Private (Project) |
| 24 | O&M costs | EUR/y | -140.000 | | | | | |
| 25 | Specific O&M costs | EUR/MWh*y | -22,83 | | | | | |
| 26 | **OPEX escalation** | **%/y** | **2,0%** | **1,0%** | 3,0% | | Triangular | Private (Project) |
| 27 | **Other costs (on top to O&M costs)** | **%/y** | **3,0%** | **1,0%** | **5,0%** | | Uniform | Private (Project) |
| 28 | **Corporate Income Tax** | **%/y** | **15,0%** | 10,0% | 20,0% | | Uniform | Public (Market) |
| 29 | **CAPEX reduction** | **%/y** | **2,5%** | -0,50% | 2,50% | | Uniform | Public (Market) |
| 30 | **El. FiT premium after FiT period** | **EUR/MWh** | **64,6** | 50% | | | Bernoulli (Yes /No) | Public (Market) |
| 31 | **Duration of FiT premium period** | **years** | **6** | 0 | 12 | | Uniform | Public (Market) |

**Other Assumptions:**

32 Working capital during operation is negligible.

33 Capital expenditures (CAPEX) during operation is negligible, except for the real options (shown in the separate DCF models for the calculation of the RO expansion and contraction factors

34 Interest is tax deductable, but this deduction won't be calculated in this case, as the interest in not taken into cost calculation at all.

35 Residual value is negligible, as investment horizon is long enough (25 y)

36 Payout of dividends is not considered

37 Revenues from bonuses for GHG reduction are negligible

**Base scenario assumptions and uncertainties**

There are 37 assumptions in each of the DCF models (Wind farm and PV plant). Green colored fields denote most likely, i.e. median (P50) values of the assumptions used for Monte Carlo Simulation, which was done with the Crystal Ball software. Each of the MCS assumptions has its minimum and maximum value which are shown in the "Min" and "Max" columns in case of simple probability distributions, such as triangular and uniform. Parameters of more complex distributions, such as modified Weibull's and lognormal distribution, are given in the column "Other parameters". Differentiation between public (market) and private (project) related risks are given in the column "Risk type".

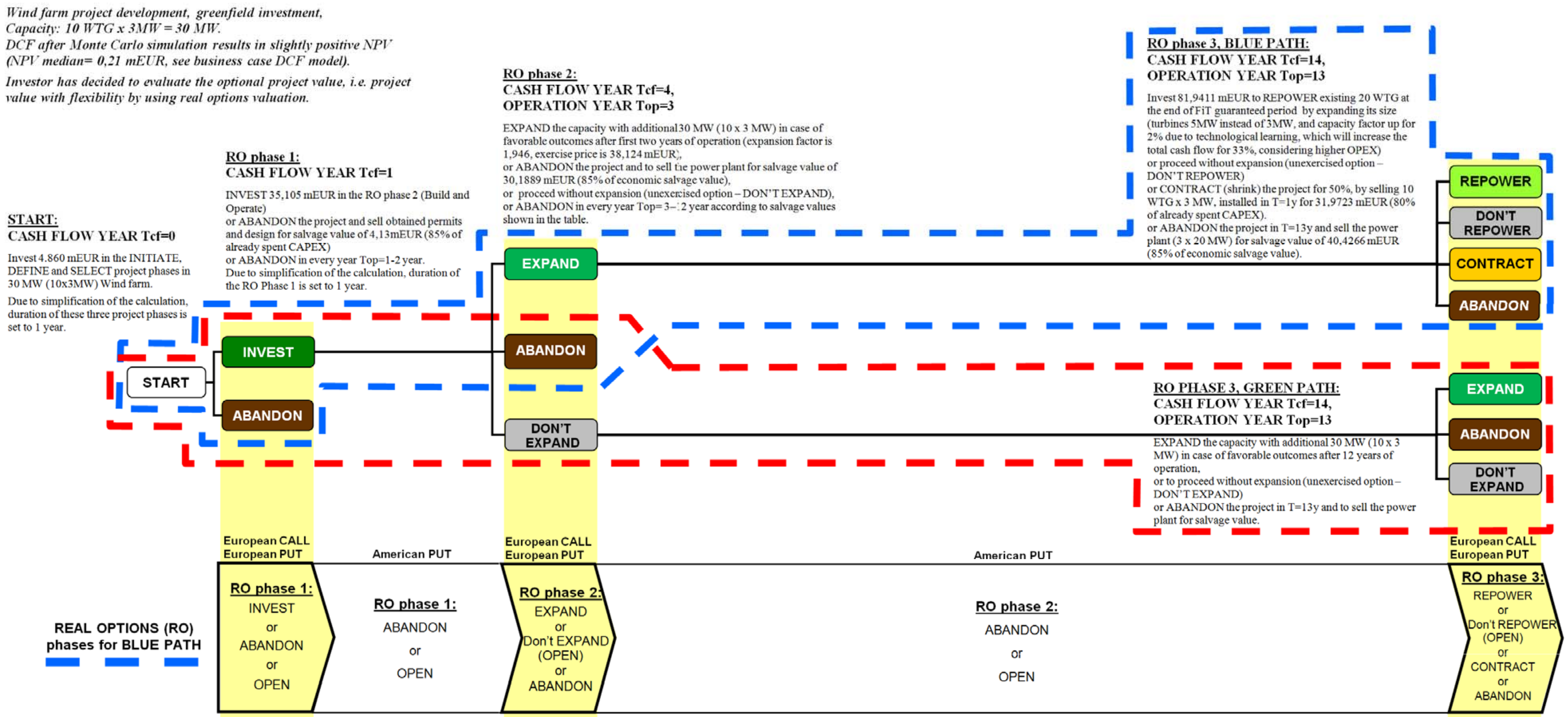
## Addendum 11: DCF analysis – Base case

| | Year of operation | 0 | 0 | 1 | 3 | 5 | 7 | 9 | 11 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Item** | **Year of cash flow** | **0** | **1** | **2** | **4** | **6** | **8** | **10** | **12** | **14** | **16** | **18** | **20** | **22** | **24** | **26** | **Total** |
| FiT | EUR/MWh | 92,0 | 92,0 | 93,8 | 97,6 | 101,6 | 105,7 | 109,9 | 114,4 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | |
| Market Electricity price | EUR/MWh | 50,0 | 51,0 | 52,0 | 54,1 | 56,3 | 58,6 | 60,9 | 63,4 | 66,0 | 68,6 | 71,4 | 74,3 | 77,3 | 80,4 | 83,7 | |
| FiT premium | EUR/MWh | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 0,0 | 53,0 | 55,2 | 57,4 | 0,0 | 0,0 | 0,0 | 0,0 | |
| Electricity generation | MWh | 0 | 0 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | |
| Gross Revenues, El.generation | EUR | 0 | 0 | 6.411.900 | 6.670.940 | 6.940.446 | 7.220.840 | 7.512.562 | 7.816.070 | 8.131.839 | 8.460.365 | 8.802.164 | 5.076.591 | 5.281.685 | 5.495.065 | 5.717.066 | 175.034.408 |
| Gross Revenues, other ($CO_2$, ...) | EUR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Gross Revenues | EUR | 0 | 0 | 6.411.900 | 6.670.940 | 6.940.446 | 7.220.840 | 7.512.562 | 7.816.070 | 8.131.839 | 8.460.365 | 8.802.164 | 5.076.591 | 5.281.685 | 5.495.065 | 5.717.066 | 175.034.408 |
| **Total Gross Revenues, disc.** | **EUR** | **0** | **0** | **5.497.170** | **4.903.340** | **4.373.658** | **3.901.195** | **3.479.770** | **3.103.869** | **1.663.935** | **1.380.069** | **1.144.630** | **526.274** | **436.492** | **362.026** | **300.265** | **59.949.575** |
| O&M Costs | EUR | 0 | 0 | -1.248.480 | -1.298.919 | -1.351.395 | -1.405.991 | -1.462.793 | -1.521.890 | -1.583.375 | -1.647.343 | -1.713.895 | -1.783.137 | -1.855.176 | -1.930.125 | -2.008.102 | -39.989.189 |
| Other costs | EUR | 0 | 0 | -62.424 | -64.946 | -67.570 | -70.300 | -73.140 | -76.095 | -79.169 | -82.367 | -85.695 | -89.157 | -92.759 | -96.506 | -100.405 | -1.999.459 |
| Total OPEX | EUR | 0 | 0 | -1.310.904 | -1.363.865 | -1.418.965 | -1.476.291 | -1.535.933 | -1.597.985 | -1.662.543 | -1.729.710 | -1.799.590 | -1.872.294 | -1.947.934 | -2.026.631 | -2.108.507 | -41.988.648 |
| **Total OPEX, disc.** | **EUR** | **0** | **0** | **-1.123.889** | **-1.002.481** | **-894.188** | **-797.594** | **-711.434** | **-634.582** | **-340.189** | **-282.153** | **-234.018** | **-194.095** | **-160.982** | **-133.519** | **-110.740** | **-12.722.005** |
| EBITDA | EUR | 0 | 0 | 5.100.996 | 5.307.076 | 5.521.482 | 5.744.549 | 5.976.629 | 6.218.085 | 6.469.296 | 6.730.655 | 7.002.574 | 3.204.297 | 3.333.751 | 3.468.434 | 3.608.559 | 133.045.760 |
| **EBITDA, disc.** | **EUR** | **0** | **0** | **4.373.281** | **3.900.859** | **3.479.470** | **3.103.601** | **2.768.336** | **2.469.287** | **1.323.746** | **1.097.916** | **910.612** | **332.179** | **275.510** | **228.508** | **189.524** | **47.227.569** |
| Depreciation | EUR | 0 | 0 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -1.598.616 | -39.965.400 |
| **Depreciation, disc.** | **EUR** | **0** | **0** | **-1.370.556** | **-1.175.030** | **-1.007.399** | **-863.682** | **-740.469** | **-634.832** | **-327.109** | **-260.769** | **-207.883** | **-165.723** | **-132.114** | **-105.320** | **-83.961** | **-13.508.244** |
| EBIT | EUR | 0 | 0 | 3.502.380 | 3.708.460 | 3.922.866 | 4.145.933 | 4.378.013 | 4.619.469 | 4.870.680 | 5.132.039 | 5.403.958 | 1.605.681 | 1.735.135 | 1.869.818 | 2.009.943 | 93.080.360 |
| **EBIT, disc.** | **EUR** | **0** | **0** | **3.002.726** | **2.725.829** | **2.472.071** | **2.239.919** | **2.027.867** | **1.834.455** | **996.638** | **837.147** | **702.728** | **166.456** | **143.396** | **123.188** | **105.564** | **33.719.326** |
| Taxes | EUR | 0 | 0 | -525.357 | -556.269 | -588.430 | -621.890 | -656.702 | -692.920 | -730.602 | -769.806 | -810.594 | -240.852 | -260.270 | -280.473 | -301.491 | -13.962.054 |
| **Taxes, disc.** | **EUR** | **0** | **0** | **-450.409** | **-408.874** | **-370.811** | **-335.988** | **-304.180** | **-275.168** | **-149.496** | **-125.572** | **-105.409** | **-24.968** | **-21.509** | **-18.478** | **-15.835** | **-5.057.899** |
| **Net Income after tax** | **EUR** | 0 | 0 | 2.977.023 | 3.152.191 | 3.334.436 | 3.524.043 | 3.721.311 | 3.926.549 | 4.140.078 | 4.362.233 | 4.593.364 | 1.364.829 | 1.474.864 | 1.589.345 | 1.708.451 | 79.118.306 |
| **Net income after tax, disc.** | **EUR** | **0** | **0** | **2.552.317** | **2.316.954** | **2.101.260** | **1.903.931** | **1.723.687** | **1.559.287** | **-149.496** | **711.575** | **597.319** | **141.487** | **121.886** | **104.709** | **89.729** | **27.664.789** |
| Initial Investment | EUR | -4.860.000 | -35.105.400 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -39.965.400 |
| Other investment | EUR | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| Total Investment | EUR | -4.860.000 | -35.105.400 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -39.965.400 |
| **Total Investment, disc.** | **EUR** | **-4.860.000** | **-33.755.192** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **0** | **-38.615.192** |
| Free Cash Flow (FCF) after tax | | -4.860.000 | -35.105.400 | 4.575.639 | 4.750.807 | 4.933.052 | 5.122.659 | 5.319.927 | 5.525.165 | 5.738.694 | 5.960.849 | 6.191.980 | 2.963.445 | 3.073.480 | 3.187.961 | 3.307.067 | 79.118.306 |
| **FCF after tax, disc (-> Static NPV)** | **EUR** | **-4.860.000** | **-33.755.192** | **3.922.873** | **3.491.985** | **3.108.659** | **2.767.613** | **2.464.156** | **2.194.119** | **1.174.250** | **972.344** | **805.203** | **307.211** | **254.000** | **210.030** | **173.690** | **3.554.478** |
| **Acc. FCF after tax, disc. (-> Acc.Static NPV)** | **EUR** | -4.860.000 | -38.615.192 | -34.692.320 | -27.499.207 | -21.095.826 | -15.395.054 | -10.319.441 | -5.800.121 | -2.555.410 | -514.536 | 1.175.495 | 2.215.459 | 2.748.796 | 3.189.793 | 3.554.478 | **OK** |
| | **EUR** | 0 | 0 | 4.575.639 | 4.750.807 | 4.933.052 | 5.122.659 | 5.319.927 | 5.525.165 | 5.738.694 | 5.960.849 | 6.191.980 | 2.963.445 | 3.073.480 | 3.187.961 | 3.307.067 | 119.083.706 |
| **Discount factor for PV** | **-** | 0,000 | 0,000 | 0,857 | 0,735 | 0,630 | 0,540 | 0,463 | 0,397 | 0,205 | 0,163 | 0,130 | 0,104 | 0,083 | 0,066 | 0,053 | |
| **costs, disc. (=PV=Underlying Asset Value)** | **EUR** | 0 | 0 | 3.922.873 | 3.491.985 | 3.108.659 | 2.767.613 | 2.464.156 | 2.194.119 | 1.174.250 | 972.344 | 805.203 | 307.211 | 254.000 | 210.030 | 173.690 | **42.169.670** |
| **Investment (=Implementation costs)** | **EUR** | -4.860.000 | -35.105.400 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -39.965.400 |
| **PV (0) for volatility** | **EUR** | 0 | 0 | 4.575.639 | 4.392.388 | 4.216.793 | 4.048.512 | 3.887.219 | 3.732.603 | 3.584.371 | 3.442.242 | 3.305.949 | 1.462.840 | 1.402.696 | 1.345.177 | 1.290.158 | **79.288.115** |
| **PV (1) for volatility** | **EUR** | 0 | 0 | 0 | 4.568.083 | 4.385.465 | 4.210.453 | 4.042.707 | 3.881.907 | 3.727.746 | 3.579.932 | 3.438.187 | 1.521.353 | 1.458.804 | 1.398.985 | 1.341.764 | **77.700.976** |
| **Static PV(0) for volatility** | **EUR** | 0 | 0 | 4.575.639 | 4.392.388 | 4.216.793 | 4.048.512 | 3.887.219 | 3.732.603 | 3.584.371 | 3.442.242 | 3.305.949 | 1.462.840 | 1.402.696 | 1.345.177 | 1.290.158 | |
| **Dynamic NPV (P50, median)** | **EUR** | -4.859.444 | -33.903.676 | 3.907.811 | 3.470.247 | 3.084.193 | 2.741.207 | 2.438.406 | 2.169.132 | 547.116 | 450.545 | 371.042 | 305.470 | 251.439 | 207.061 | 170.664 | |
| **Accumulated Dynamic NPV** | **EUR** | -4.859.444 | -38.763.120 | -34.855.309 | -27.702.988 | -21.347.757 | -15.699.344 | -10.675.975 | -6.206.833 | -3.613.511 | -2.666.422 | -1.886.444 | -1.244.331 | -715.650 | -280.365 | 78.211 | |
| **Variable X (during whole project)** | - | -0,0202 | | | | | | | | | | | | | | | |
| **Volatility (during whole project)** | %/y | 13,00% | | | | | | | | | | | | | | | |

## Addendum 12: RO Strategy decision tree with datasheet

**Path 1 (BLUE):** Start → Invest / Abandon / Open → Expand / Abandon / Open → Repower / Don't repower / Contract / Abandon

**Path 2 (RED):** Start → Invest / Abandon / Open → Don't expand / Abandon → Expand / Don't expand / Abandon




| T cash flow | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| T operation | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| ABANDON salvage[1,2] | NA | 4.1305 | 32.7570 | 31.4468 | 30.1889 | 59.9214 | 57.3559 | 54.9006 | 52.5509 | 50.3018 | 48.1499 | 46.0900 | 44.1190 | 42.2324 | 40.4266 |
| REPOWER factor[2] | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 1.7460 |
| REPOWER costs[2] | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 81.9411 |
| CONTRACT factor[2] | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 0.491 |
| CONTRACT saving[2] | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | 31.9723 |
| EXPAND factor[2] | NA | NA | NA | NA | 1.946 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| EXPAND costs[2] | NA | NA | NA | NA | 38.1241 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| BUILD factor[2] | NA | 1.0000 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |
| BUILD costs[2] | NA | 35.2829 | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA | NA |

t

1) **ABANDON SALVAGE VALUE** calculated as 85% of economic salvage value.
Economic salvage value $S = P(1-i)^y$, where $P$ are implementation costs, $i$ is depreciation rate, $y$ is age in years.

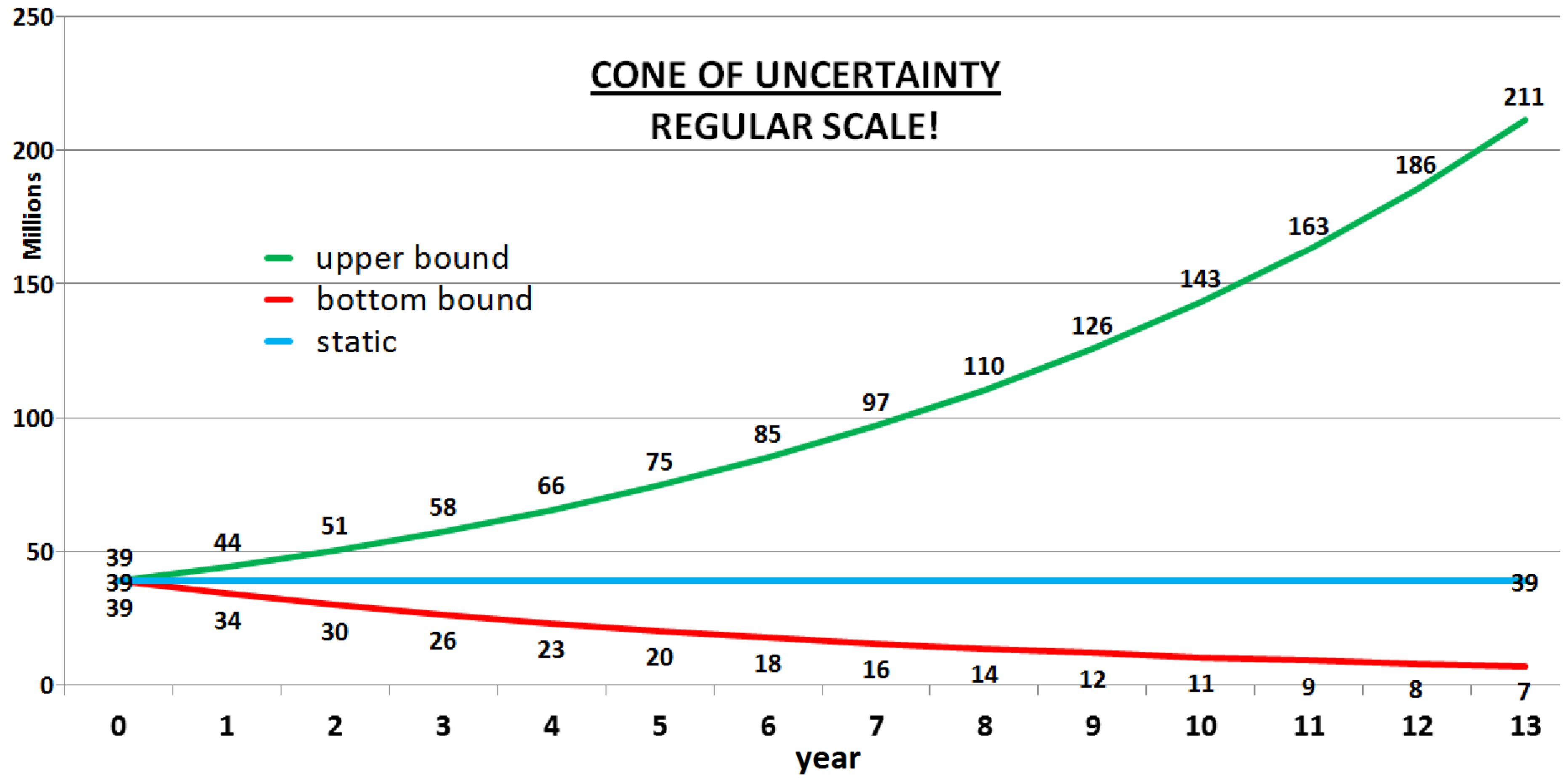
2) All costs and factors represent **median (P50) values** from Monte Carlo Simulation

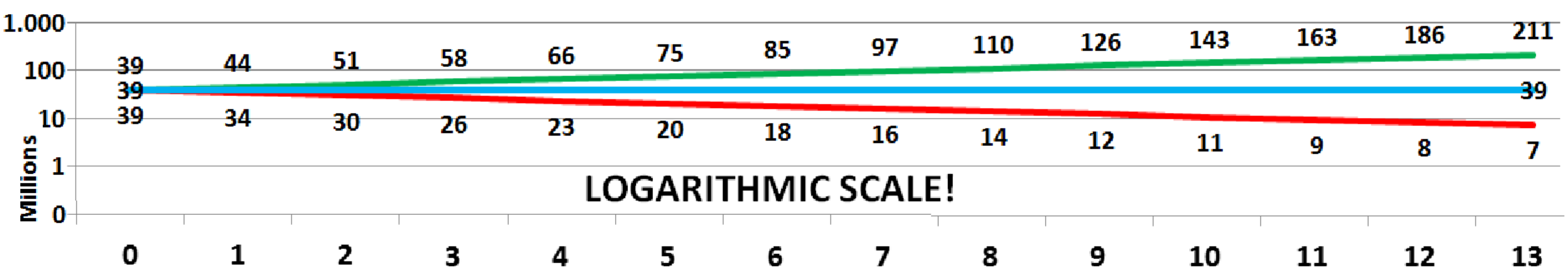

3) All costs, savings and salvage values are in mEUR

**Addendum 13: Underlying asset value binomial tree and cone of uncertainty**

Ivan:
PV Underlying Asset value, i.e. Value of the project (without implementation costs) without flexibility!

| | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | | | | | | | 240.614.129 |
| | | | | | | | | | | | | | | 211.282.168 | |
| | | | | | | | | | | | | | 185.525.906 | | 185.525.906 |
| | | | | | | | | | | | | 162.909.450 | | 162.909.450 | |
| | | | | | | | | | | | 143.050.044 | | 143.050.044 | | 143.050.044 |
| | | | | | | | | | | 125.611.590 | | 125.611.590 | | 125.611.590 | |
| | | | | | | | | | 110.298.963 | | 110.298.963 | | 110.298.963 | | 110.298.963 |
| | | | | | | | | 96.853.016 | | 96.853.016 | | 96.853.016 | | 96.853.016 | |
| | | | | | | | 85.046.191 | | 85.046.191 | | 85.046.191 | | 85.046.191 | | 85.046.191 |
| | | | | | | 74.678.671 | | 74.678.671 | | 74.678.671 | | 74.678.671 | | 74.678.671 | |
| | | | | $V*u^3$ | 65.575.000 | | 65.575.000 | | 65.575.000 | | 65.575.000 | | 65.575.000 | | 65.575.000 |
| | | | $V*u^2$ | 57.581.108 | | 57.581.108 | | 57.581.108 | | 57.581.108 | | 57.581.108 | | 57.581.108 | |
| | | V*u | 50.561.708 | | 50.561.708 | | 50.561.708 | | 50.561.708 | | 50.561.708 | | 50.561.708 | | 50.561.708 |
| Underlying Asset value | | 44.398.005 | | 44.398.005 | | 44.398.005 | | 44.398.005 | | 44.398.005 | | 44.398.005 | | 44.398.005 | |
| $PV_0$ | 38.985.685 | | 38.985.685 | | 38.985.685 | | 38.985.685 | | 38.985.685 | | 38.985.685 | | 38.985.685 | | 38.985.685 |
| | | 34.233.152 | | 34.233.152 | | 34.233.152 | | 34.233.152 | | 34.233.152 | | 34.233.152 | | 34.233.152 | |
| | | V*d | 30.059.974 | | 30.059.974 | | 30.059.974 | | 30.059.974 | | 30.059.974 | | 30.059.974 | | 30.059.974 |
| | | | $V*d^2$ | 26.395.526 | | 26.395.526 | | 26.395.526 | | 26.395.526 | | 26.395.526 | | 26.395.526 | |
| | | | | $V*d^3$ | 23.177.791 | | 23.177.791 | | 23.177.791 | | 23.177.791 | | 23.177.791 | | 23.177.791 |
| | | | | | | 20.352.312 | | 20.352.312 | | 20.352.312 | | 20.352.312 | | 20.352.312 | |
| | | | | | | | 17.871.272 | | 17.871.272 | | 17.871.272 | | 17.871.272 | | 17.871.272 |
| | | | | | | | | 15.692.683 | | 15.692.683 | | 15.692.683 | | 15.692.683 | |
| | | | | | | | | | 13.779.673 | | 13.779.673 | | 13.779.673 | | 13.779.673 |
| | | | | | | | | | | 12.099.868 | | 12.099.868 | | 12.099.868 | |
| | | | | | | | | | | | 10.624.839 | | 10.624.839 | | 10.624.839 |
| | | | | | | | | | | | | 9.329.622 | | 9.329.622 | |
| | | | | | | | | | | | | | 8.192.299 | | 8.192.299 |
| | | | | | | | | | | | | | | 7.193.620 | |
| | | | | | | | | | | | | | | | 6.316.685 |
| Year of operation | 0 | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 |
| Year of cash flow | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 |



# Addendum 14: Expansion, Repower and Contraction factor calculation

**BLUE PATH:**

Calculation of EXPANSION, REPOWERING and CONTRACTION FACTORS:

| | 0 (-2) | 0 (-1) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **Year of operation** | 0 (-2) | 0 (-1) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 |
| **Year of cash flow** | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 16 | 18 | 20 | 22 | 24 | 26 |

**DECISION: Expansion with additional 10 WTG in Top=3. year**

| Parameter | Unit | Most likely | Min | Max | Other parameters | Distribution | Risk type |
|---|---|---|---|---|---|---|---|
| **Expansion year** | year of oper. | 3 | 3 | 15 | | Uniform | Private |
| Wind turbine size, expand | MW | 3,00 | | | | | |
| **Number of generators_expand** | pcs | 10 | 5 | 20 | | Uniform | Private |
| Rated capacity, el, expand | MW | 30,00 | | | | | |
| **Capacity factor, expand** | %/y | 26,0% | | | Loc:21%, Sc:5,65%, Sh:2 | Weibull^3 | Private |
| Yearly El.generation, expand | MWh | 68.328 | | | | | |
| Specific Investment costs, T=3, expand | EUR/MW | -1.270.804 | -1.334.345 | -1.207.264 | | Uniform | Private |
| Total Investment in scenario based on the decision 1.1.1 | EUR | -38.124.130 | | | | | |
| Specific O&M cost, T=3, expand | EUR/MW*y | -41.184 | -43.244 | -39.125 | | Uniform | Private |
| O&M costs, expand | EUR/y | -1.235.533 | | | | | |
| Other costs (on top to O&M costs), expand | %/y | 5,0% | 4,0% | 6,0% | | Uniform | Private |

| | | |
|---|---|---|
| **Specific Investment costs, T=3, expand** | EUR/MW | -1.270.804 |
| **Specific O&M cost, T=3, expand** | EUR/MW*y | -41.184 |

**Milovanovic, Ivan:**
reduced due to learning rate ( %/ year) in T year

**Milovanovic, Ivan:**
reduced for learning rate ( %/ year) and increased for OPEX escalation rate, as of T year onwards

**DECISION: Expansion with additional 10 WTG in Top=3. year**

| | Unit | 0 (-2) | 0 (-1) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity generation, expand | MWh,el | | | 68.328 | 68.328 | 102.492 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 3.245.580 | |
| Revenues, expand | EUR | | | 6.411.900 | 6.540.138 | 10.006.410 | 13.608.718 | 13.880.892 | 14.158.510 | 14.441.681 | 14.730.514 | 15.025.124 | 15.325.627 | 15.632.139 | 15.944.782 | 16.263.678 | 16.920.730 | 17.604.328 | 10.153.181 | 10.563.370 | 10.990.130 | 11.434.131 | 333.781.310 | |
| O&M Costs, expand | EUR | | | -1.248.480 | -1.273.450 | -1.967.609 | -2.689.025 | -2.742.805 | -2.797.661 | -2.853.615 | -2.910.687 | -2.968.901 | -3.028.279 | -3.088.844 | -3.150.621 | -3.213.634 | -3.343.464 | -3.478.540 | -3.619.073 | -3.765.284 | -3.917.401 | -4.075.664 | -77.897.183 | |
| Other cost, expand | EUR | | | -62.424 | -63.672 | -98.380 | -134.451 | -137.140 | -139.883 | -142.681 | -145.534 | -148.445 | -151.414 | -154.442 | -157.531 | -160.682 | -167.173 | -173.927 | -180.954 | -188.264 | -195.870 | -203.783 | -3.894.859 | |
| EBITDA, expand | EUR | | | 5.100.996 | 5.203.015 | 7.940.421 | 10.785.242 | 11.000.947 | 11.220.966 | 11.445.385 | 11.674.293 | 11.907.779 | 12.145.934 | 12.388.853 | 12.636.630 | 12.889.362 | 13.410.093 | 13.951.860 | 6.353.154 | 6.609.822 | 6.876.859 | 7.154.684 | 251.989.268 | |
| Depreciation, expand | EUR | | | -1.598.616 | -1.598.616 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -78.089.530 | |
| EBIT, expand | EUR | | | 3.502.380 | 3.604.399 | 4.684.234 | 7.529.055 | 7.744.760 | 7.964.779 | 8.189.198 | 8.418.106 | 8.651.592 | 8.889.747 | 9.132.666 | 9.380.443 | 9.633.175 | 10.153.906 | 10.695.673 | 3.096.967 | 3.353.635 | 3.620.672 | 3.898.497 | 173.899.737 | |
| Tax, expand | EUR | | | -525.357 | -540.660 | -702.635 | -1.129.358 | -1.161.714 | -1.194.717 | -1.228.380 | -1.262.716 | -1.297.739 | -1.333.462 | -1.369.900 | -1.407.066 | -1.444.976 | -1.523.086 | -1.604.351 | -464.545 | -503.045 | -543.101 | -584.775 | -26.084.961 | |
| Net Income after tax, expand | EUR | | | 2.977.023 | 3.063.740 | 3.981.599 | 6.399.697 | 6.583.046 | 6.770.062 | 6.960.819 | 7.155.390 | 7.353.853 | 7.556.285 | 7.762.766 | 7.973.377 | 8.188.199 | 8.630.820 | 9.091.322 | 2.632.422 | 2.850.590 | 3.077.571 | 3.313.722 | 147.814.777 | |
| Total Investment, expand | EUR | -4.860.000 | -35.105.400 | 0 | 0 | -38.124.130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -78.089.530 | |
| FCF after tax, expand | EUR | -4.860.000 | -35.105.400 | 4.575.639 | 4.662.356 | -30.886.344 | 9.655.884 | 9.839.233 | 10.026.249 | 10.217.005 | 10.411.577 | 10.610.040 | 10.812.472 | 11.018.953 | 11.229.564 | 11.444.386 | 11.887.007 | 12.347.509 | 5.888.609 | 6.106.777 | 6.333.758 | 6.569.909 | 147.814.777 | |
| **FCF after tax, disc. (=PV) for EXPAND OPTION in T=3.yr** | EUR | -4.860.000 | -33.755.192 | 3.922.873 | 3.701.128 | -27.268.678 | 6.571.632 | 6.200.386 | 5.850.220 | 5.519.930 | 5.208.381 | 4.914.501 | 4.637.284 | 4.375.778 | 4.129.087 | 2.341.748 | 1.939.028 | 1.605.665 | 610.453 | 504.679 | 417.281 | 345.057 | **3.661.158** | **NPV, expand** |
| **Cum.FCF after tax, disc. (=PV) for EXPAND OPTION in T=3.yr** | EUR | -4.860.000 | -38.615.192 | -34.692.320 | -30.991.192 | -58.259.869 | -51.688.237 | -45.487.851 | -39.637.631 | -34.117.701 | -28.909.320 | -23.994.819 | -19.357.535 | -14.981.757 | -10.852.670 | -8.510.922 | -4.441.015 | -1.070.872 | 1.000.749 | 2.060.473 | 2.936.652 | 3.661.158 | | |
| **PV (w/o initial impl.costs), disc, expand** | EUR | 0 | 0 | 3.922.873 | 3.701.128 | 5.319.989 | 6.571.632 | 6.200.386 | 5.850.220 | 5.519.930 | 5.208.381 | 4.914.501 | 4.637.284 | 4.375.778 | 4.129.087 | 2.341.748 | 1.939.028 | 1.605.665 | 610.453 | 504.679 | 417.281 | 345.057 | | |

| | | | |
|---|---|---|---|
| | | **PV expansion factor in T=3yr** | |
| PV (w/o initial implementation costs), expand as of T=3.yr | **67.241.016** | **1,946** | 2,000 |
| PV (w/o initial implementation costs), basic, as of T=3.yr | 34.545.670 | | |
| PV of the Exercise price in T=3.yr | **-38.124.130** | **Excercise price for Expand option!** | |
| Tomato S | 74.865.017 | 32.695.347 | |
| Tomato X | 76.739.323 | 38.124.130 | |

**Milovanovic, Ivan:**
expansion and contraction factors must be calculated in details due to different discount rate applied (r1, r2

**P50 VALUES USED FOR OPTIMIZATION:**

| | |
|---|---|
| -3.057.721 | Expand NPV,P50 |
| 1,928 | Exp.factor,P50 |
| -38.135.466 | Exp.exercise price,P50 |

**DECISION: Repower all WTG in Top=13.yr**

| Parameter | Unit | Most likely | Min | Max | Other parameters | Distribution | Risk type |
|---|---|---|---|---|---|---|---|
| **Repowering year** | year of oper. | 13 | 5 | 20 | | Uniform | Private |
| Wind turbine size, repower | MWel | 5,00 | | | | | |
| **Number of generators_repower** | pcs | 20 | 5 | 20 | | Uniform | Private |
| Rated capacity, repower | MWel | 100,00 | | | | | |
| **Capacity factor, repower** | %/y | 26,0% | | | Loc:23, Sc:5,65%, Sh:2 | Weibull^3 | Private |
| Yearly El.generation, repower | MWh,el | 245.280 | | | | | |
| Specific Investment costs, T=13, repower | EUR/MWel | -819.412 | -860.382 | -778.441 | | Uniform | Private |
| Total Investment in scenario based on the decision 1.1.1 | EUR | -81.941.189 | | | | | |
| Specific O&M cost, T=13, repower | EUR/MWel | -42.514 | -44.640 | -40.388 | | Uniform | Private |
| O&M costs, repower | EUR/y | -4.251.412 | | | | | |
| Other costs (on top to O&M costs), repower | %/y | 5,0% | 4,0% | 6,0% | | Uniform | Private |

**Remarks:**
1 Repower costs ca. 75% of total costs (land, tower, other costs = ca. 25%, are not affected). Source: IRENA, Wind Power Cost Analysis, June 2012
2 Capacity factor (CF) in the Scenario 2 (Repower) is slightly increased (26% -> 28%) in comparison to the Base scenario, due to technological learning and higher efficiency

**Milovanovic, Ivan:**
reduced for learning rate ( %/ year) in T year as well as for part of the initial costs which are not subject to reinvestment for repowering (plot, some permits, part of the structures, ..., ca. 25% in total of the whole initial investment, depriciated), according to IRENA, 2012

| | | |
|---|---|---|
| **Specific Investment costs, T=13, repower** | EUR/MWel | -819.412 |
| **Specific O&M cost, T=13, repower** | EUR/MWel | -42.514 |

**Milovanovic, Ivan:**
reduced for learning rate ( %/ year) and increased for OPEX escalation rate, as of T year onwards

**DECISION: Repower all WTG in Top=13.yr**

| | Unit | 0 (-2) | 0 (-1) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity generation, repower | MWh,el | | | 68.328 | 68.328 | 102.492 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 171.696 | 245.280 | 245.280 | 245.280 | 245.280 | 245.280 | 245.280 | 4.584.108 | |
| Revenues, repower | EUR | | | 6.411.900 | 6.540.138 | 10.006.410 | 13.608.718 | 13.880.892 | 14.158.510 | 14.441.681 | 14.730.514 | 15.025.124 | 15.325.627 | 15.632.139 | 15.944.782 | 20.433.851 | 30.370.541 | 31.597.511 | 18.223.659 | 18.959.895 | 19.725.874 | 20.522.800 | 466.570.639 | |
| O&M Costs, repower | EUR | | | -1.248.480 | -1.273.450 | -1.967.609 | -2.689.025 | -2.742.805 | -2.797.661 | -2.853.615 | -2.910.687 | -2.968.901 | -3.028.279 | -3.088.844 | -3.150.621 | -3.926.754 | -5.836.278 | -6.072.064 | -6.317.375 | -6.572.597 | -6.838.130 | -7.114.390 | -111.388.577 | |
| Other cost, repower | EUR | | | -62.424 | -63.672 | -98.380 | -134.451 | -137.140 | -139.883 | -142.681 | -145.534 | -148.445 | -151.414 | -154.442 | -157.531 | -196.338 | -291.814 | -303.603 | -315.869 | -328.630 | -341.906 | -355.720 | -5.569.429 | |
| EBITDA, repower | EUR | | | 5.100.996 | 5.203.015 | 7.940.421 | 10.785.242 | 11.000.947 | 11.220.966 | 11.445.385 | 11.674.293 | 11.907.779 | 12.145.934 | 12.388.853 | 12.636.630 | 16.310.760 | 24.242.450 | 25.221.845 | 11.590.415 | 12.058.668 | 12.545.838 | 13.052.690 | 349.612.633 | |
| Depreciation, repower | EUR | | | -1.598.616 | -1.598.616 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -7.117.215 | -7.117.215 | -7.117.215 | -7.117.215 | -7.117.215 | -7.117.215 | -7.117.215 | -128.282.897 | -160.030.719 |
| EBIT, repower | EUR | | | 3.502.380 | 3.604.399 | 4.684.234 | 7.529.055 | 7.744.760 | 7.964.779 | 8.189.198 | 8.418.106 | 8.651.592 | 8.889.747 | 9.132.666 | 9.380.443 | 9.193.545 | 17.125.234 | 18.104.629 | 4.473.200 | 4.941.453 | 5.428.623 | 5.935.475 | 221.329.736 | |
| Tax, repower | EUR | | | -525.357 | -540.660 | -702.635 | -1.129.358 | -1.161.714 | -1.194.717 | -1.228.380 | -1.262.716 | -1.297.739 | -1.333.462 | -1.369.900 | -1.407.066 | -1.379.032 | -2.568.785 | -2.715.694 | -670.980 | -741.218 | -814.293 | -890.321 | -33.199.460 | |
| Net Income after tax, repower | EUR | | | 2.977.023 | 3.063.740 | 3.981.599 | 6.399.697 | 6.583.046 | 6.770.062 | 6.960.819 | 7.155.390 | 7.353.853 | 7.556.285 | 7.762.766 | 7.973.377 | 7.814.513 | 14.556.449 | 15.388.935 | 3.802.220 | 4.200.235 | 4.614.330 | 5.045.154 | 188.130.276 | |
| Total Investment, repower | EUR | -4.860.000 | -35.105.400 | 0 | 0 | -38.124.130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | -81.941.189 | 0 | 0 | 0 | 0 | 0 | 0 | -160.030.719 | |
| FCF after tax, repower | EUR | -4.860.000 | -35.105.400 | 4.575.639 | 4.662.356 | -30.886.344 | 9.655.884 | 9.839.233 | 10.026.249 | 10.217.005 | 10.411.577 | 10.610.040 | 10.812.472 | 11.018.953 | 11.229.564 | -67.009.460 | 21.673.664 | 22.506.150 | 10.919.435 | 11.317.450 | 11.731.545 | 12.162.369 | 196.347.854 | |
| **FCF after tax, disc. (=PV) for REPOWER OPTION in T=13.yr** | EUR | -4.860.000 | -33.755.192 | 3.922.873 | 3.701.128 | -27.268.678 | 6.571.632 | 6.200.386 | 5.850.220 | 5.519.930 | 5.208.381 | 4.914.501 | 4.637.284 | 4.375.778 | 4.129.087 | -37.829.611 | 3.535.444 | 2.926.691 | 1.131.983 | 935.302 | 772.899 | 638.777 | **-26.393.947** | **NPV, repower** |
| **Cum. FCF after tax, disc. (=PV) for REPOWER OPTION in T=13.yr** | EUR | -4.860.000 | -38.615.192 | -34.692.320 | -30.991.192 | -58.259.869 | -51.688.237 | -45.487.851 | -39.637.631 | -34.117.701 | -28.909.320 | -23.994.819 | -19.357.535 | -14.981.757 | -10.852.670 | -48.682.281 | -41.260.956 | -35.117.596 | -31.322.714 | -29.358.475 | -27.735.358 | -26.393.947 | | |
| **PV (w/o impl.costs), disc, repower** | EUR | 0 | 0 | 3.922.873 | 3.701.128 | 5.319.989 | 6.571.632 | 6.200.386 | 5.850.220 | 5.519.930 | 5.208.381 | 4.914.501 | 4.637.284 | 4.375.778 | 4.129.087 | 3.055.327 | 3.535.444 | 2.926.691 | 1.131.983 | 935.302 | 772.899 | 638.777 | | |
| Rep_0 | | | | 4.575.639 | 4.316.996 | 6.205.235 | 7.665.152 | 7.232.130 | 6.823.697 | 6.438.446 | 6.075.055 | 5.732.274 | 5.408.928 | 5.103.907 | 4.816.167 | [illegible] | 7.379.038 | 6.569.331 | 2.732.578 | 2.428.139 | 2.157.906 | 1.917.997 | | **PV repower factor in T=13yr** |
| Rep_1 | | | | 0 | 4.662.356 | 6.701.654 | 8.278.364 | 7.810.700 | 7.369.592 | 6.953.522 | 6.561.060 | 6.190.856 | 5.841.642 | 5.512.220 | 5.201.461 | 6.403.962 | 7.969.361 | 7.094.877 | 2.951.184 | 2.622.390 | 2.330.539 | 2.071.437 | **25.343.662** | **1,746** 1,795 |
| | | | 1,4956 | 4.575.639 | 4.316.996 | -34.625.977 | 7.665.152 | 7.232.130 | 6.823.697 | 6.438.446 | 6.075.055 | 5.732.274 | 5.408.928 | 5.103.907 | 4.816.167 | -50.903.318 | 7.379.038 | 6.569.331 | 2.732.578 | 2.428.139 | 2.157.906 | 1.917.997 | 14.513.828 | |

| | | |
|---|---|---|
| PV of the Exercise price in T=13.yr | **-81.941.189** | **Excercise price for Repower option** |
| Tomato S | 85.694.851 | |
| Tomato X | 158.680.511 | |

**Milovanovic, Ivan:**
expansion and contraction factors must be calculated in details due to different discount rate applied (r1, r2 and rf)

**P50 VALUES USED FOR OPTIMIZATION:**

| | |
|---|---|
| -40.274.933 | Repower NPV,P50 |
| 1,77 | Repower factor,P50 |
| -81.933.197 | Repower exercise price,P50 |

**DECISION: Contract (shrink) half of the WTG in Top=13.yr**

| Parameter | Unit | Most likely | Min | Max | Other parameters | Distribution | Risk type |
|---|---|---|---|---|---|---|---|
| **Contraction year** | year of oper. | 13 | 5 | 20 | | Uniform | |
| Reduction factor of el.generation | - | 0,50 | 0,1 | 0,9 | | | |
| Number of operating generators after contraction | pcs | 10 | 10 | 20 | | Uniform | Private |
| Operating rated capacity after contraction | MWel | 30,00 | | | | | |
| **Capacity factor after contraction** | %/y | 26,0% | | | Loc:21%, Sc:5,65%, Sh:2 | Weibull^3 | Private |
| Yearly El.generation, repower | MWh,el | 68.328 | | | | | |
| Specific Investment costs, T=13 | EUR/MWel | 0 | | | | | |
| Total De-Investment in scenario based on the decision 1.1.1.3 | EUR | 31.972.320 | 30.373.704 | 33.570.936 | | | |
| Specific O&M cost, T=13,contract | EUR/MWel | -42.514 | -44.640 | -40.388 | | | |
| O&M costs after contraction | EUR/y | -1.275.424 | | | | | |
| Other costs (on top to O&M costs), contract | %/y | 5,0% | 4,0% | 6,0% | | Uniform | Private |

| | | |
|---|---|---|
| **Total De-Investment in scenario based on the decision 1.1.1.3** | EUR | 31.972.320 |
| **Specific O&M cost, T=13** | EUR/MWel | -42.514 |

**Milovanovic, Ivan:**
reduced for learning rate ( %/ year) and increased for OPEX escalation rate, as of T year onwards

**DECISION: Contract (shrink) half of the WTG in Top=13.yr**

| | Unit | 0 (-2) | 0 (-1) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | Total | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Electricity generation, contract | MWh,el | | | 68.328 | 68.328 | 102.492 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 136.656 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 68.328 | 2.357.316 | |
| Revenues, contract | EUR | | | 6.411.900 | 6.540.138 | 10.006.410 | 13.608.718 | 13.880.892 | 14.158.510 | 14.441.681 | 14.730.514 | 15.025.124 | 15.325.627 | 15.632.139 | 15.944.782 | 8.131.839 | 8.460.365 | 8.802.164 | 5.076.591 | 5.281.685 | 5.495.065 | 5.717.066 | 244.743.873 | |
| O&M costs, contract | EUR | | | -1.248.480 | -1.273.450 | -1.967.609 | -2.689.025 | -2.742.805 | -2.797.661 | -2.853.615 | -2.910.687 | -2.968.901 | -3.028.279 | -3.088.844 | -3.150.621 | -1.682.894 | -1.750.883 | -1.821.619 | -1.895.212 | -1.971.779 | -2.051.439 | -2.134.317 | -55.425.425 | |
| Other costs, contract | EUR | | | -62.424 | -63.672 | -98.380 | -134.451 | -137.140 | -139.883 | -142.681 | -145.534 | -148.445 | -151.414 | -154.442 | -157.531 | -84.145 | -87.544 | -91.081 | -94.761 | -98.589 | -102.572 | -106.716 | -2.771.271 | |
| EBITDA, contract | EUR | | | 5.100.996 | 5.203.015 | 7.940.421 | 10.785.242 | 11.000.947 | 11.220.966 | 11.445.385 | 11.674.293 | 11.907.779 | 12.145.934 | 12.388.853 | 12.636.630 | 6.364.800 | 6.621.938 | 6.889.464 | 3.086.618 | 3.211.317 | 3.341.054 | 3.476.033 | 186.547.177 | |
| Depreciation, contract | EUR | | | -1.598.616 | -1.598.616 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -3.256.187 | -891.157 | -1.628.093 | -1.628.093 | -1.628.093 | -1.628.093 | -1.628.093 | -1.628.093 | -56.187.380 | |
| EBIT, contract | EUR | | | 3.502.380 | 3.604.399 | 4.684.234 | 7.529.055 | 7.744.760 | 7.964.779 | 8.189.198 | 8.418.106 | 8.651.592 | 8.889.747 | 9.132.666 | 9.380.443 | 5.473.642 | 4.993.844 | 5.261.370 | 1.458.524 | 1.583.223 | 1.712.961 | 1.847.939 | 130.359.797 | |
| Tax, contract | EUR | | | -525.357 | -540.660 | -702.635 | -1.129.358 | -1.161.714 | -1.194.717 | -1.228.380 | -1.262.716 | -1.297.739 | -1.333.462 | -1.369.900 | -1.407.066 | -821.046 | -749.077 | -789.206 | -218.779 | -237.484 | -256.944 | -277.191 | -19.553.970 | |
| Net Income after tax, contract | EUR | | | 2.977.023 | 3.063.740 | 3.981.599 | 6.399.697 | 6.583.046 | 6.770.062 | 6.960.819 | 7.155.390 | 7.353.853 | 7.556.285 | 7.762.766 | 7.973.377 | 4.652.596 | 4.244.767 | 4.472.165 | 1.239.746 | 1.345.740 | 1.456.017 | 1.570.748 | 110.805.828 | |
| Total (De)Investment, contract | EUR | -4.860.000 | -35.105.400 | 0 | 0 | -38.124.130 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 31.972.320 | 0 | 0 | 0 | 0 | 0 | 0 | -46.117.210 | |
| FCF after tax, contract | EUR | -4.860.000 | -35.105.400 | 4.575.639 | 4.662.356 | -30.886.344 | 9.655.884 | 9.839.233 | 10.026.249 | 10.217.005 | 10.411.577 | 10.610.040 | 10.812.472 | 11.018.953 | 11.229.564 | 37.516.073 | 5.872.861 | 6.100.258 | 2.867.839 | 2.973.833 | 3.084.110 | 3.198.842 | 160.841.397 | |
| **FCF after tax, disc. (=PV) for CONTRACT OPTION in T=13. year** | EUR | -4.860.000 | -33.755.192 | 3.922.873 | 3.701.128 | -27.268.678 | 6.571.632 | 6.200.386 | 5.850.220 | 5.519.930 | 5.208.381 | 4.914.501 | 4.637.284 | 4.375.778 | 4.129.087 | 21.986.374 | 957.991 | 793.275 | 297.300 | 245.765 | 203.188 | 168.006 | **17.124.161** | **NPV, contract** |
| **Cum.FCF after tax, disc. (=PV) for CONTRACT OPTION in T=13. year** | EUR | -4.860.000 | -38.615.192 | -34.692.320 | -30.991.192 | -58.259.869 | -51.688.237 | -45.487.851 | -39.637.631 | -34.117.701 | -28.909.320 | -23.994.819 | -19.357.535 | -14.981.757 | -10.852.670 | 11.133.704 | 13.144.481 | 14.809.501 | 15.828.680 | 16.344.748 | 16.771.397 | 17.124.161 | | |
| **PV (w/o impl.costs), disc, contract** | EUR | 0 | 0 | 3.922.873 | 3.701.128 | 5.319.989 | 6.571.632 | 6.200.386 | 5.850.220 | 5.519.930 | 5.208.381 | 4.914.501 | 4.637.284 | 4.375.778 | 4.129.087 | 1.134.362 | 957.991 | 793.275 | 297.300 | 245.765 | 203.188 | 168.006 | | |
| | | | S01 | S02 | S03 | S04 | S05 | S06 | S07 | S08 | S09 | S10 | S11 | S12 | S13 | S14 | | | | | | | | |
| Salvage value, after invest in 1st phase | 4,00% | 39.965.400 | 4.860.000 | 38.366.784 | 36.832.113 | 35.358.828 | 33.944.475 | 32.586.696 | 31.283.228 | 30.031.899 | 28.830.623 | 27.677.398 | 26.570.302 | 25.507.490 | 24.487.191 | 23.507.703 | | | | | | | | |
| Salvage, after expand in 3rd Top | 4,55% | 38.124.130 | NA | NA | NA | NA | 36.391.215 | 34.737.069 | 33.158.111 | 31.650.925 | 30.212.246 | 28.838.962 | 27.528.100 | 26.276.823 | 25.082.422 | 23.942.312 | | | | | | | | |
| Salvage, total (reduced) | | NA | 4.131.000 | 32.611.766 | 31.307.296 | 30.055.004 | 59.785.337 | 57.225.200 | 54.775.139 | 52.430.400 | 50.186.439 | 48.038.906 | 45.983.642 | 44.016.666 | 42.134.171 | 40.332.513 | | | | | | | | |
| Salvage, total (reduced), P50 | | NA | 4.130.502 | 32.757.031 | 31.446.750 | 30.188.880 | 59.921.443 | 57.355.941 | 54.900.632 | 52.550.859 | 50.301.773 | 48.149.902 | 46.090.002 | 44.119.034 | 42.232.419 | 40.426.565 | | | | | | | | |
| **operation period Top (years):** | | 0 (-2) | 0 (-1) | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | | |
| **cash flow period Tcf (years):** | | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | | |

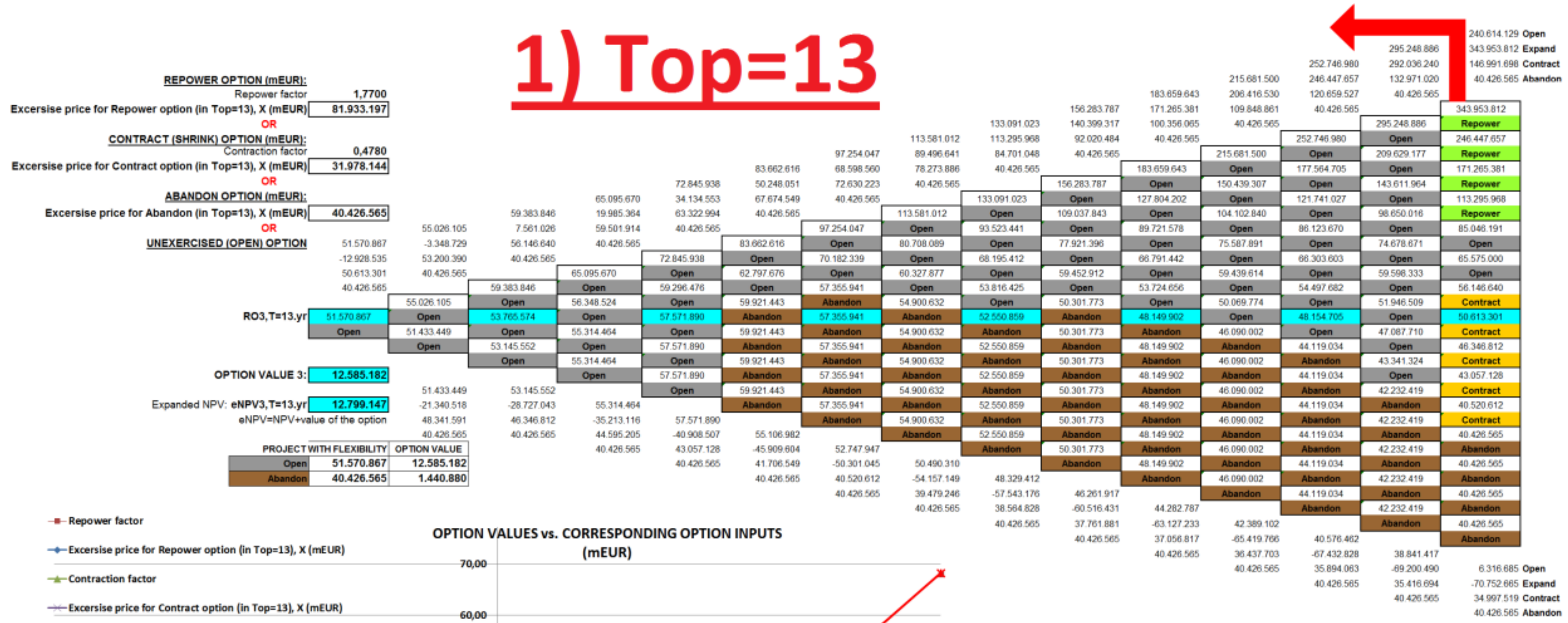
| | | | |
|---|---|---|---|
| | | **PV contraction factor in T=13yr** | |
| PV (w/o implementation costs), contract as of T=13.yr | **7.124.819** | **0,491** | 0,500 |
| PV (w/o implementation costs), expand as of T=13.yr | 14.513.828 | | |
| PV of the Exercise price in T=13.yr | **31.972.320** | **Excercise price for Contract option!** | |
| Tomato S | 67.476.008 | | |
| Tomato X | 44.767.003 | | |

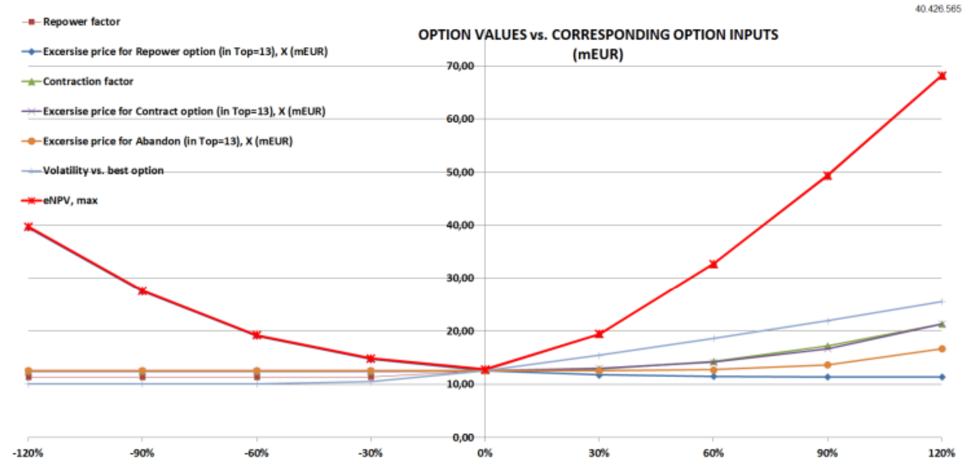
**Milovanovic, Ivan:**
expansion and contraction factors must be calculated in details due to different discount rate applied (r1, r2 and rf)

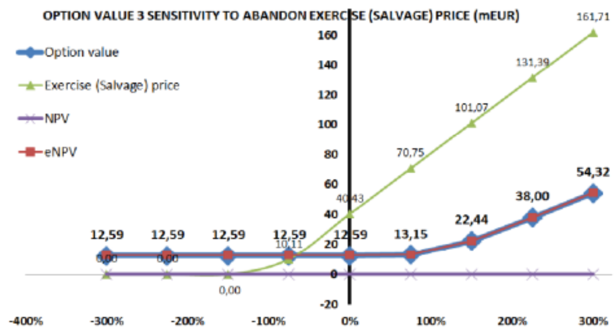
**P50 VALUES USED FOR OPTIMIZATION:**

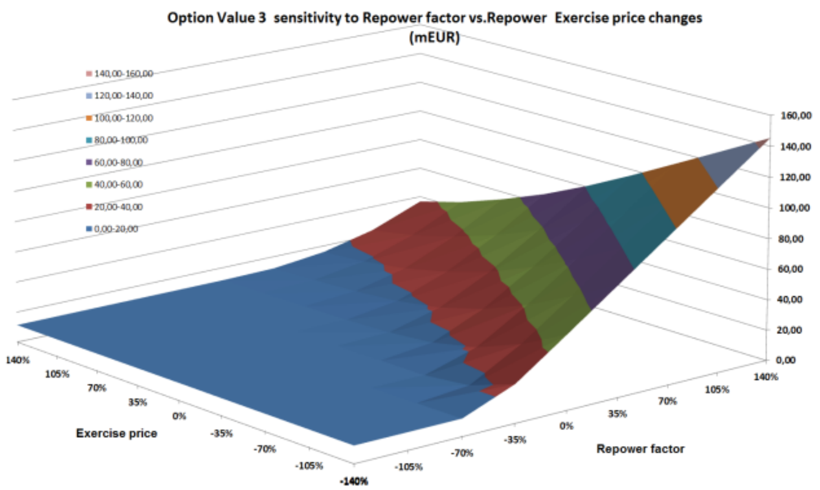
| | |
|---|---|
| 11.976.911 | Contract NPV,P50 |
| 0,478 | Contract factor,P50 |
| 31.978.144 | Contract exercise price,P50 |

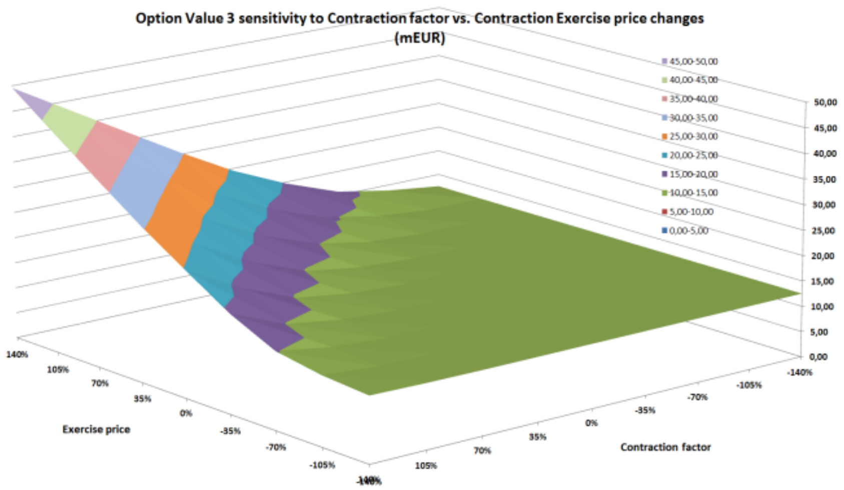
**Addendum 15: ROV at $T_{op}$=13 binomial tree with sensitivity charts**



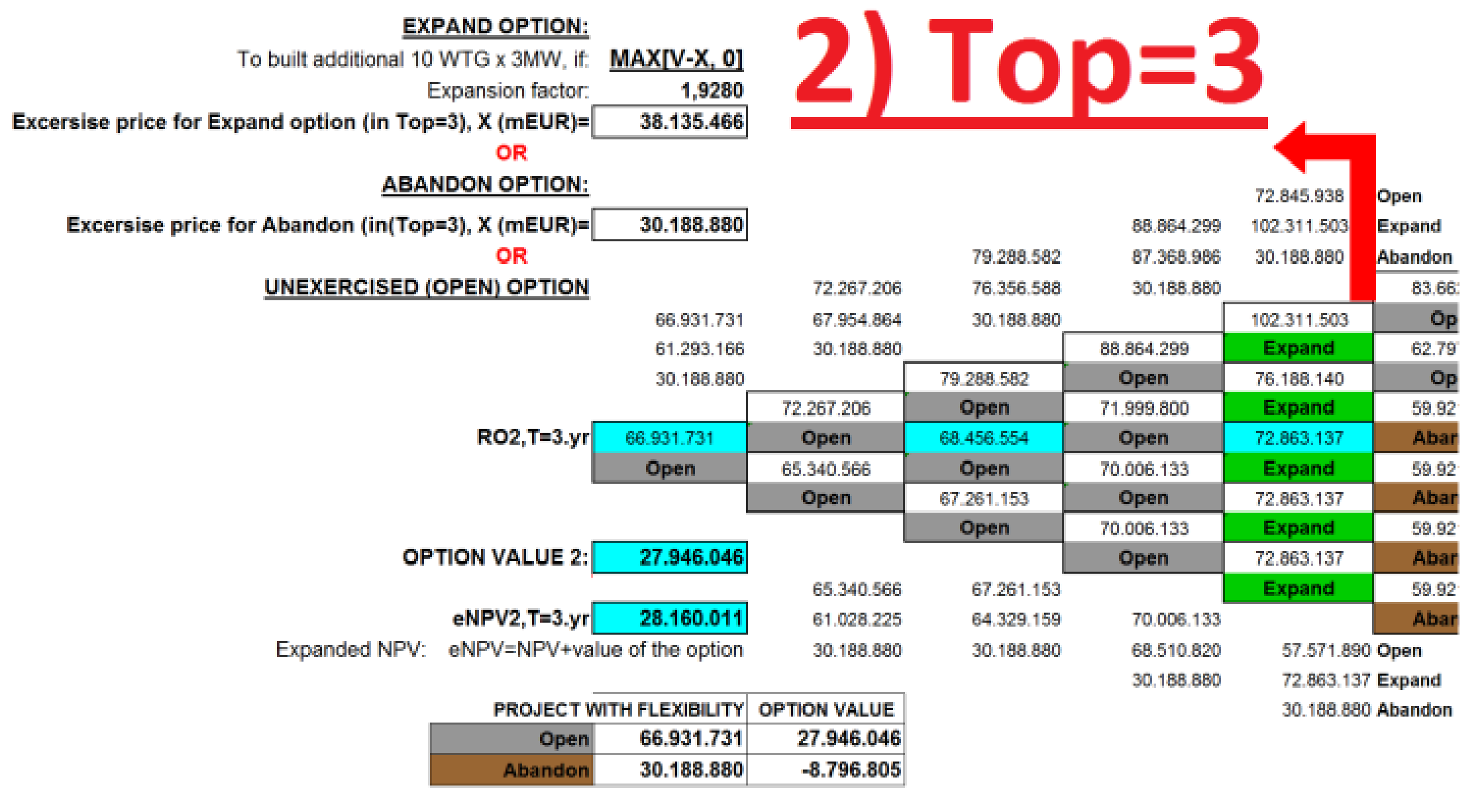



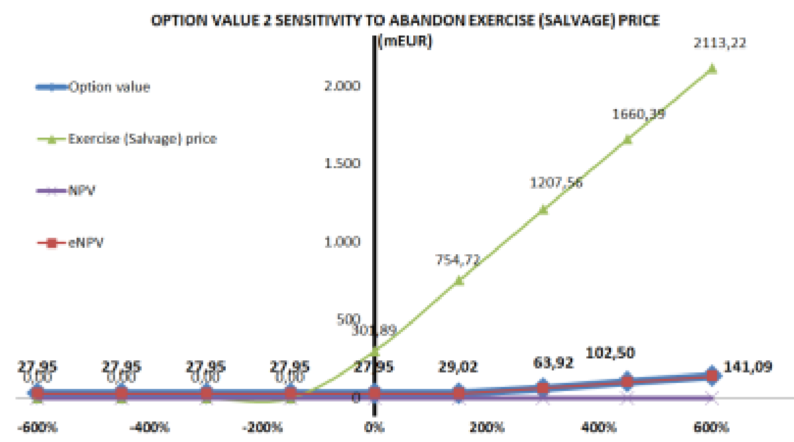



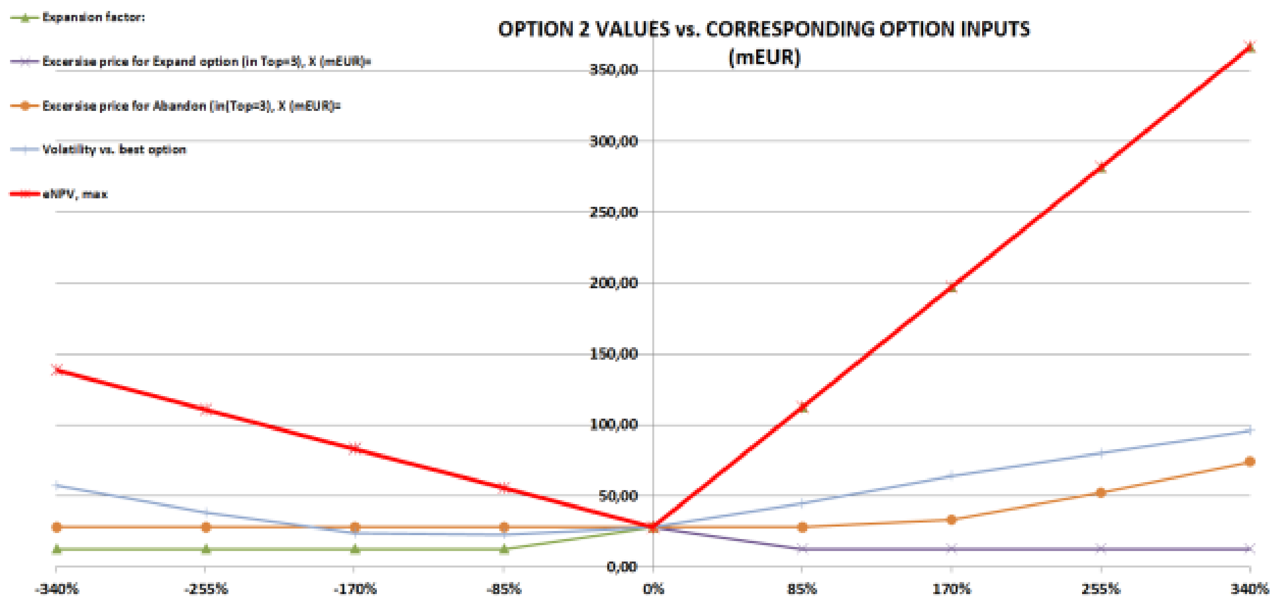



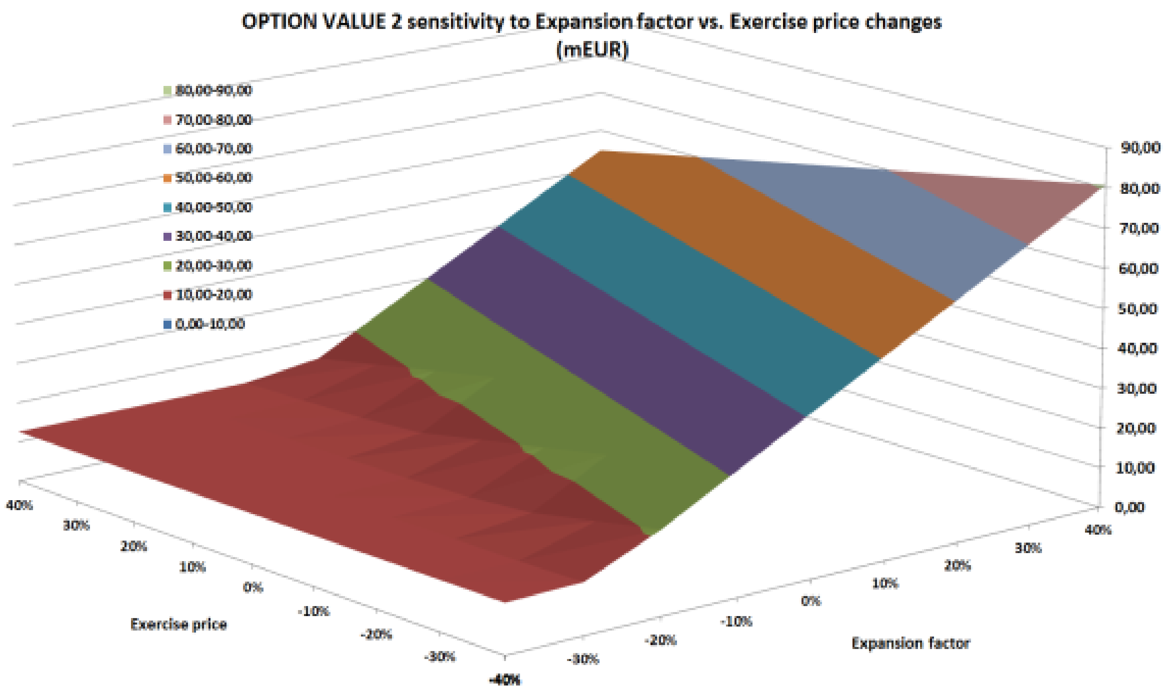



## Addendum 16: ROV at $T_{op}$=3 binomial tree with sensitivity charts

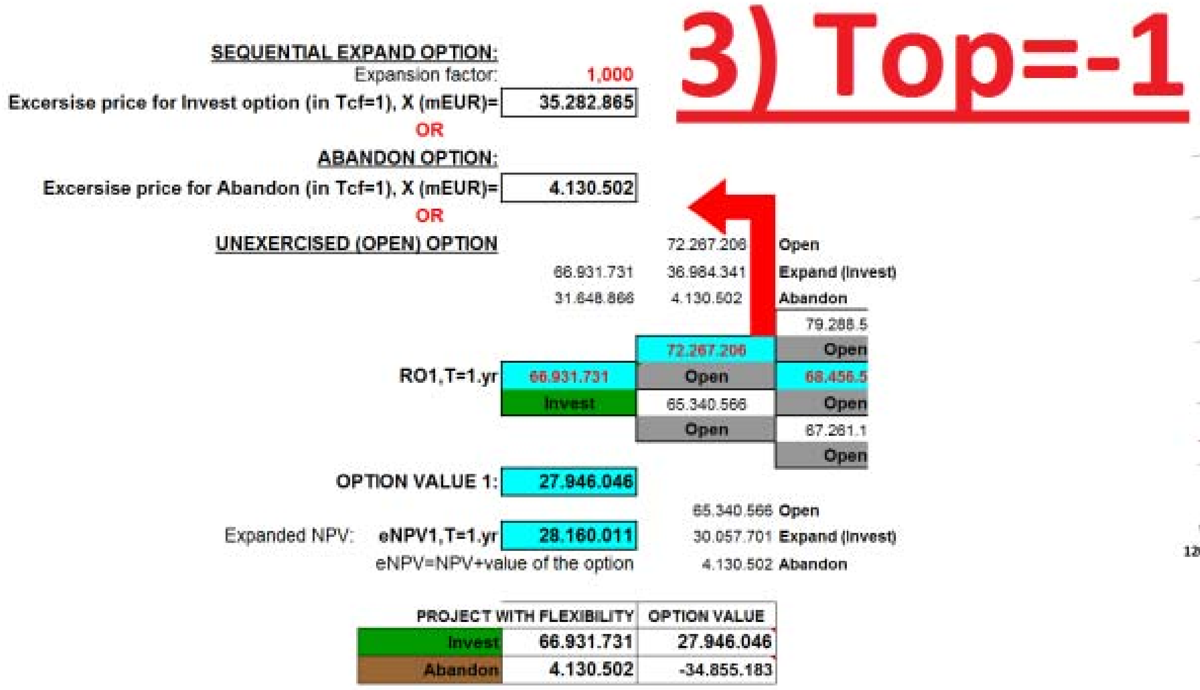


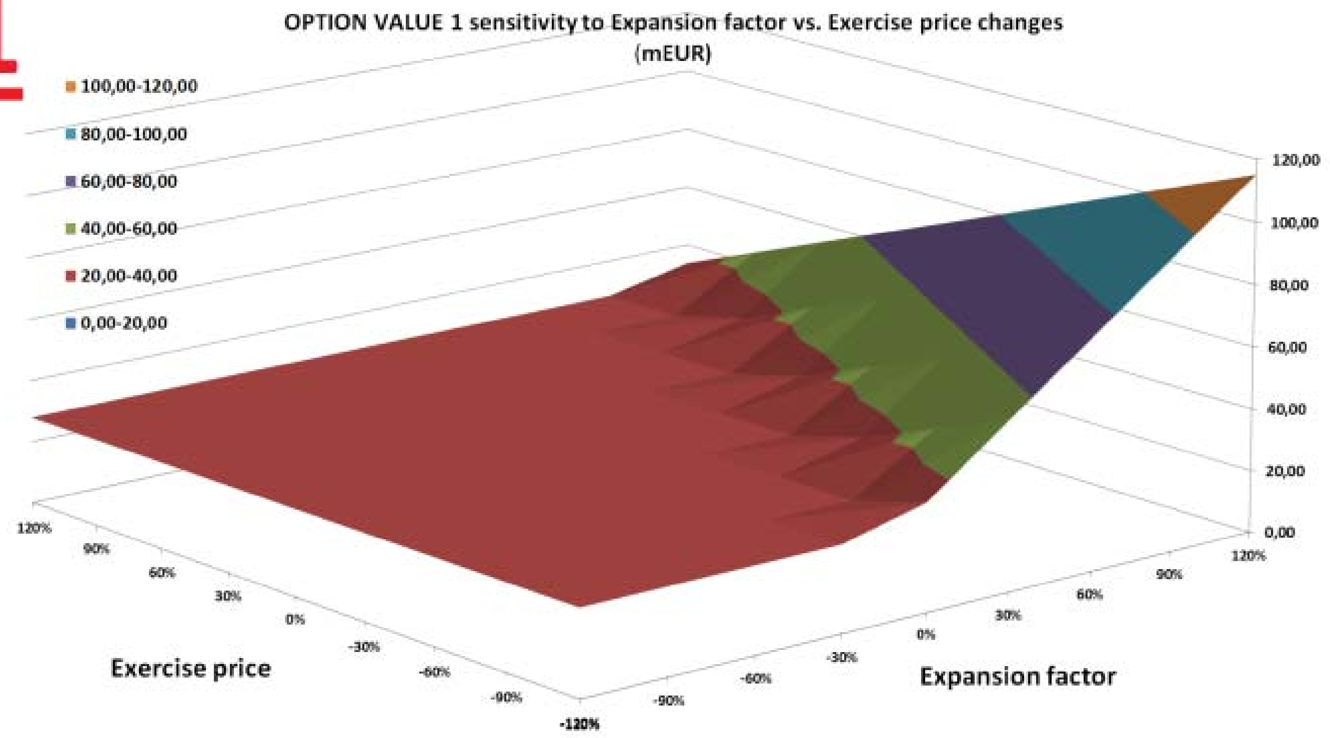



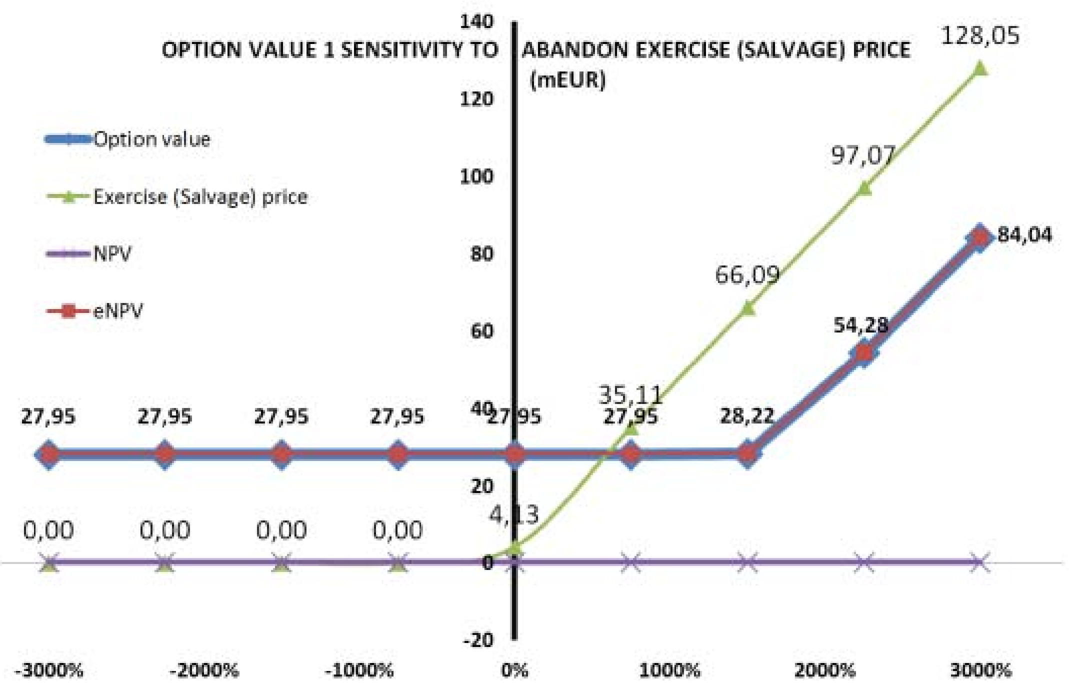



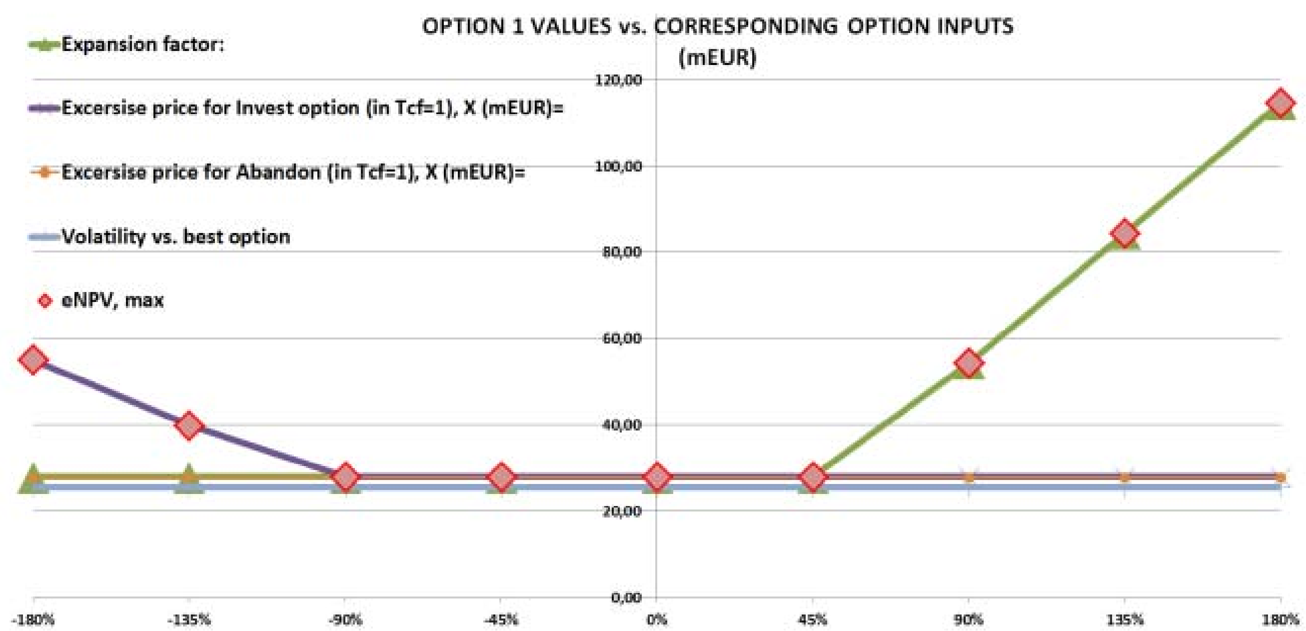



## Addendum 17: ROV at $T_{op}$=-1 ($T_{cf}$ = 1) binomial tree with sensitivity charts

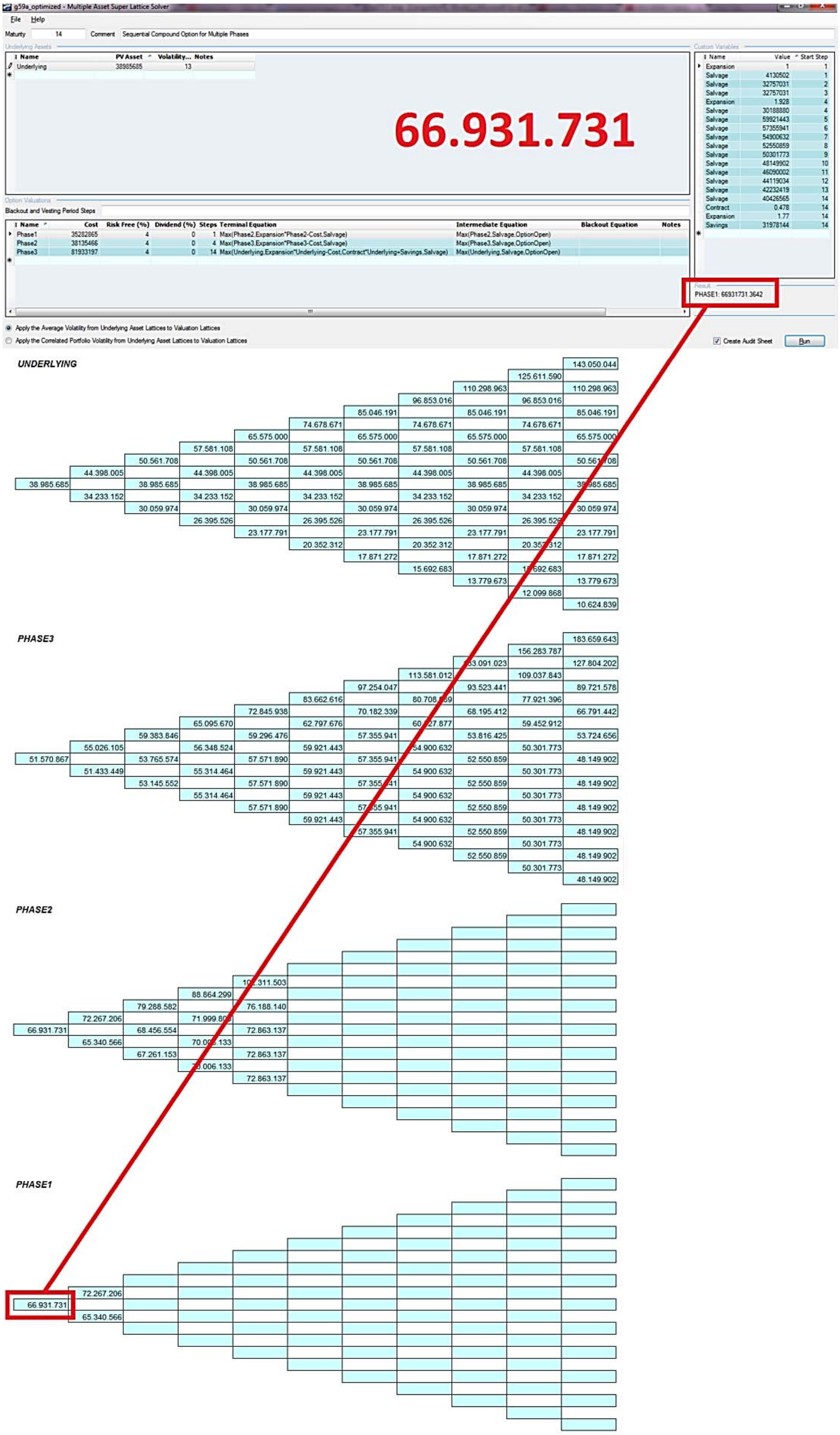


**Addendum 18: SLS output – proof of the ROV results obtained by the author's MS Excel based software solution**



## Addendum 19: RO model optimization, including the four moments datasheet

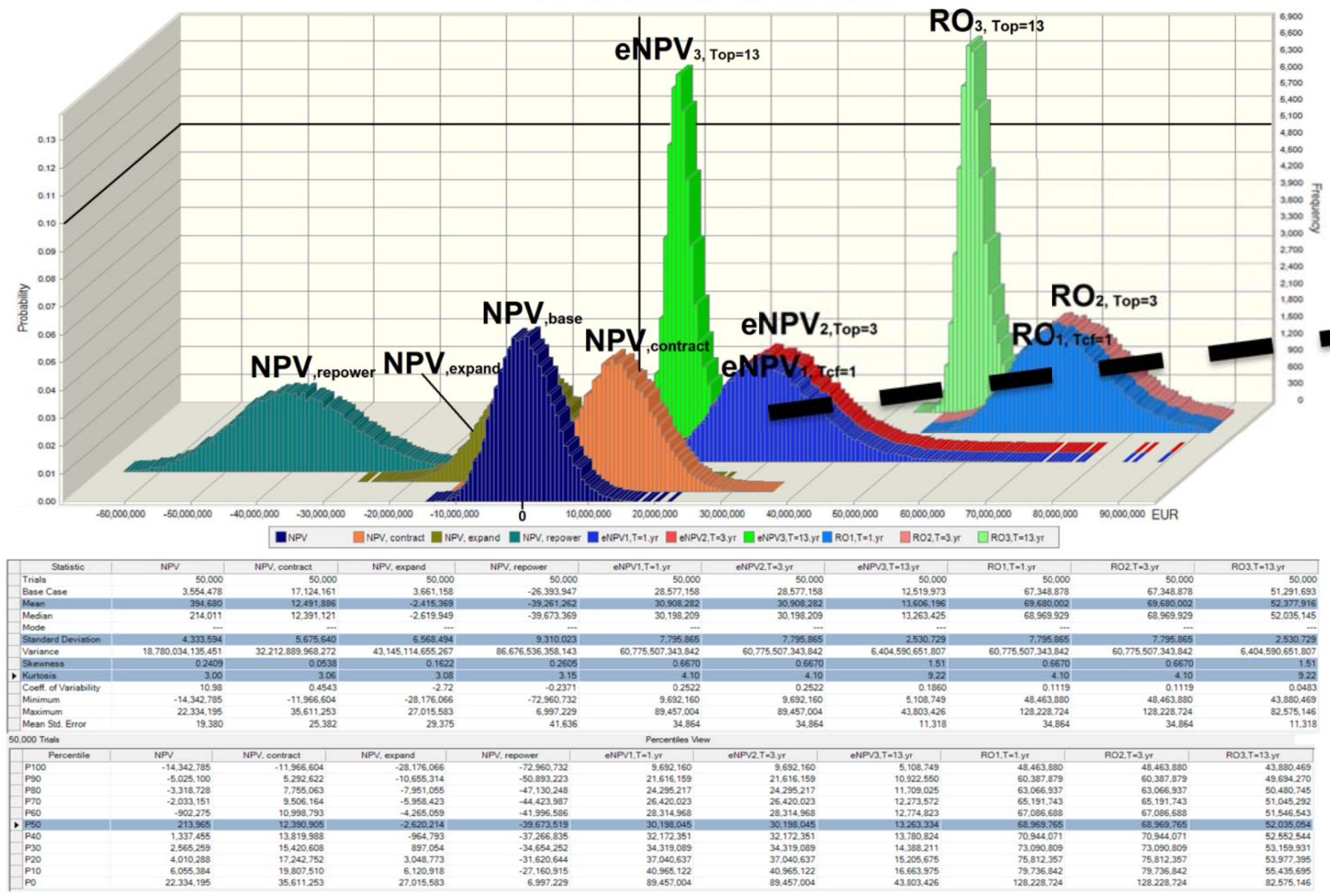
**COMPARISON: BEFORE vs. AFTER OPTIMIZATION**

| Forecast parameter | NPV, base case | eNPV1, Not Opt. | eNPV1,Optimized | |
|---|---|---|---|---|
| P50, Median | 0.2140 | 29.7707 | 28.1390 | [mEUR] |
| 1st moment (MEAN) | 0.3947 | 30.4386 | 28.1573 | [mEUR] |
| 2nd moment (STANDARD DEVIATION=RISK) | 4.3336 | 7.6732 | **1.0119** | [mEUR] |
| 3rd moment (SKEWNESS) | 0.2409 | 0.6270 | **-0.0360** | [-] |
| 4th moment (KURTOSIS) | 3.0000 | 3.9700 | **2.5000** | [-] |

**both charts have the same scale**

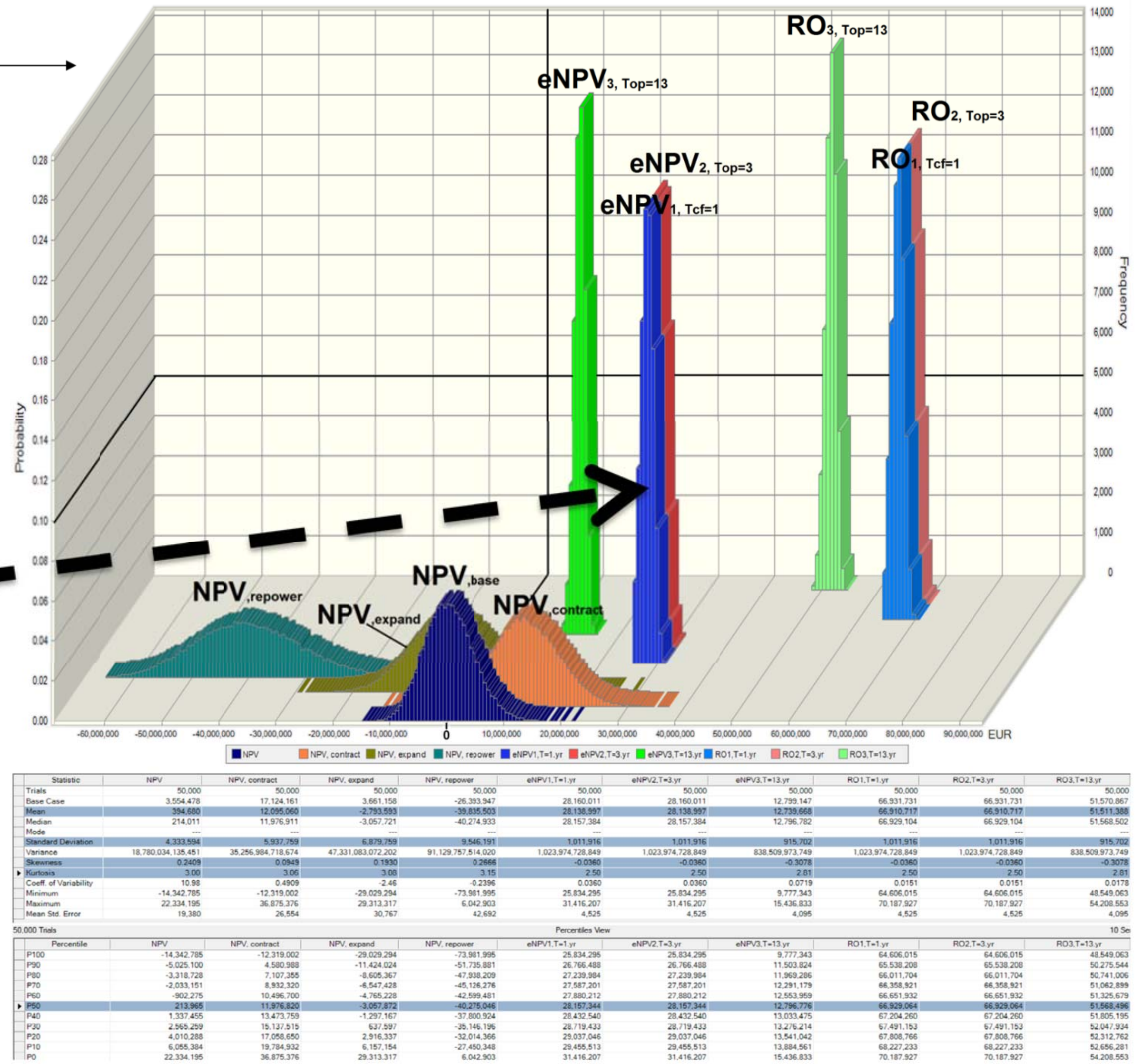
**BEFORE OPTIMIZATION**

**NPVs vs. eNPVs vs. ROs**

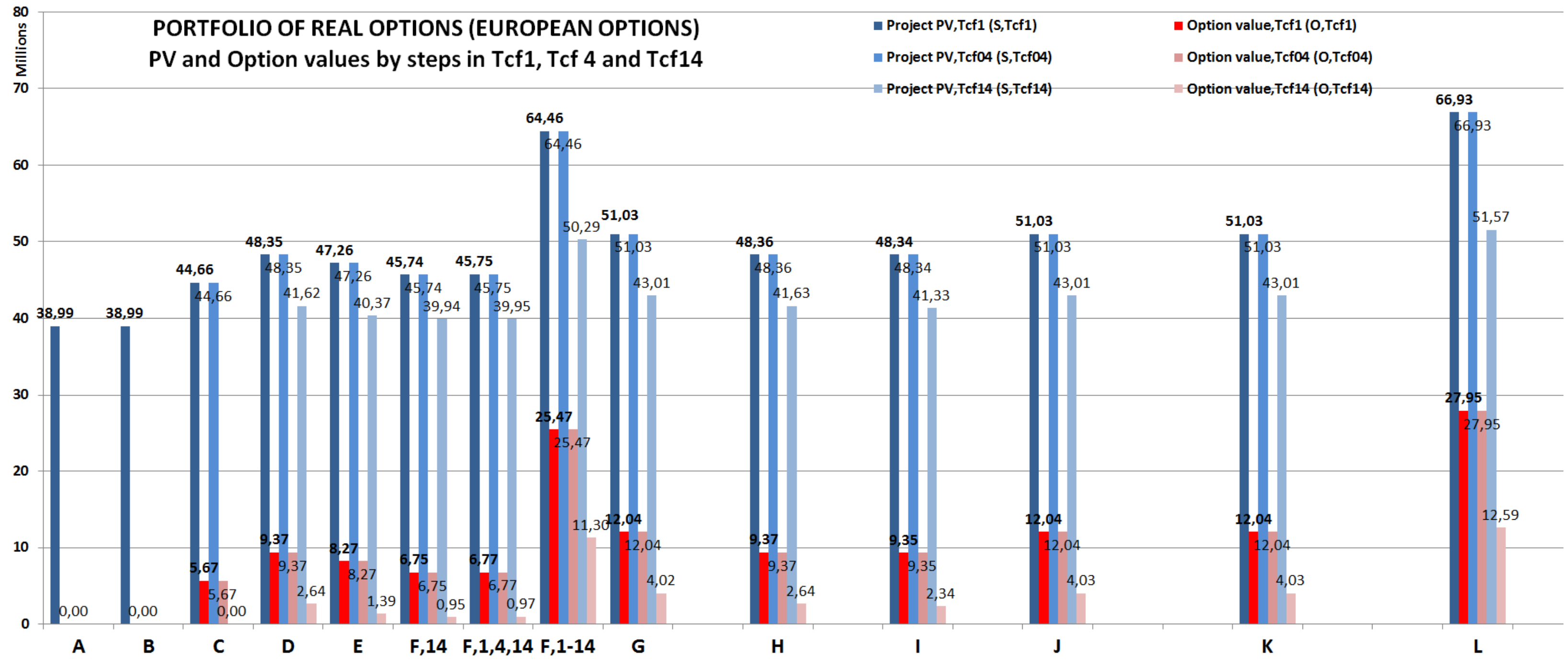



**AFTER OPTIMIZATION**

**NPVs vs. eNPVs vs. ROs**



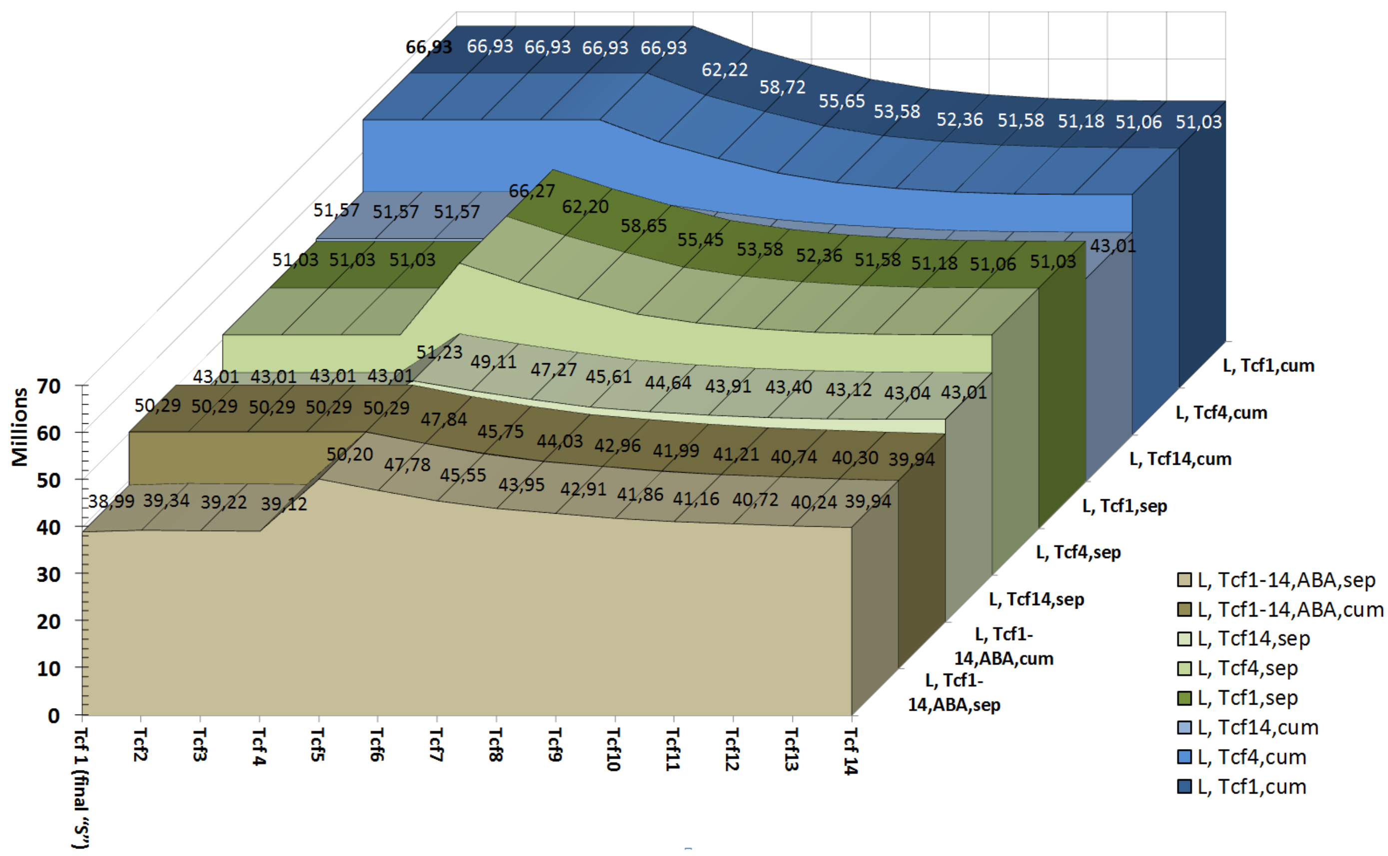
## Addendum 20: RO interactions

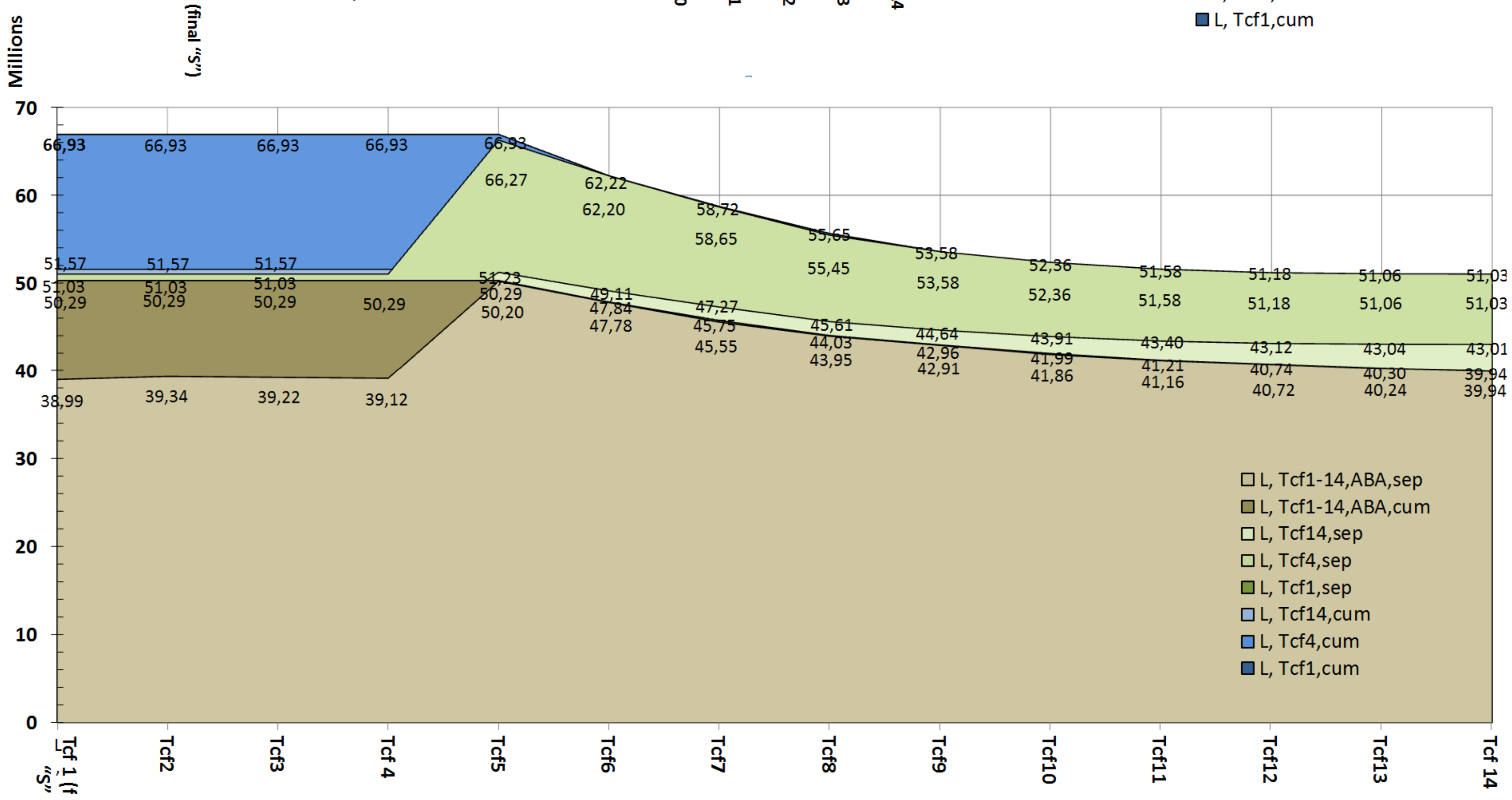



**Key:**

| | |
|---|---|
| A | Base case |
| B | Invest in Tcf1 only |
| C | Invest in Tcf1, Expand in Tcf4 |
| D | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14 |
| E | Invest in Tcf1, Expand in Tcf4, Repower in Tcf14 |
| F | Invest in Tcf1, Expand in Tcf4, Abandon in Tcf14 |
| G | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14 |
| H | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Abandon in Tcf14 |
| I | Invest in Tcf1, Expand in Tcf4, Repower in Tcf14, Abandon in Tcf14 |
| J | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon in Tcf14 |
| K | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon in Tcf1,4,14 |
| L | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon in Tcf1-14 |
| M,sep | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon separately in Tcf1-14 |
| M,cum | Invest in Tcf1, Expand in Tcf4, Contract in Tcf14, Repower in Tcf14, Abandon cumulatively in Tcf1-14 |

| | REAL OPTIONS INTERACTIONS | | | |
|---|---|---|---|---|
| | Option value | Combined value | Sum of separate | Interaction value |
| B | 0 | 0 | 0 | 0 |
| C | 5.672.682 | 5.672.682 | 5.672.682 | 0 |
| D | 9.367.078 | 9.367.078 | 9.367.078 | 0 |
| E | 8.273.388 | 8.273.388 | 8.273.388 | 0 |
| F14 | 6.752.145 | 6.752.145 | 6.752.145 | 0 |
| F1,4,14 | 6.767.772 | 6.767.772 | 6.767.772 | 0 |
| F1-14 | 25.474.408 | 25.474.408 | 25.474.408 | 0 |
| G (=D&E) | 12.040.360 | 12.040.360 | 17.640.466 | -5.600.106 |
| H (=D&F14) | 9.370.045 | 9.370.045 | 16.119.223 | -6.749.178 |
| I (=E&F14) | 9.352.852 | 9.352.852 | 15.025.533 | -5.672.681 |
| J (=D&E&F14) | 12.043.327 | 12.043.327 | 24.392.611 | -12.349.284 |
| K (=D&E&F1,4,14) | 12.043.327 | 12.043.327 | 24.392.611 | -12.349.284 |
| L (=D&E&F1-14) | 27.946.046 | 27.946.046 | 43.114.874 | -15.168.828 |



## Addendum 21: RO in the 3D "Tomato garden" model

TOMATO GARDEN: PORTFOLIO OF REAL OPTIONS STRATEGY (T. Luehrman, HBR Sep-Oct 1998)

| | | | CONTRACT BRANCH | | | REPOWER BRANCH | | | ABANDON BRANCH | | | REPOWER & CONTRACT&ABANDON in Tcf 14 | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Variable | Description | A (Base case) | B,con (Invest) | C,con (Expand) | D (Contract) | B,rep (Invest) | C,rep (Expand) | E (Repower) | B,aba (Invest) | C,aba (Expand) | F (Abandon) | B,aba (Invest) | C,aba (Expand) | $G(R\&C\&A_{14})$) |
| S | Underlying asset value (EUR) | 38.985.685 | 48.398.514 | 48.398.514 | 41.993.399 | 48.063.195 | 48.063.195 | 41.822.375 | 46.085.865 | 46.085.865 | 40.804.340 | 51.073.786 | 51.073.786 | 43.367.831 |
| X | Exercise price (EUR) | 38.615.192 | 35.282.865 | 38.135.466 | 31.978.144 | 35.282.865 | 38.135.466 | 81.933.197 | 35.282.865 | 38.135.466 | 40.426.565 | 35.282.865 | 38.135.466 | |
| t | Time to expiration (years) | 0 | 1 | 4 | 14 | 1 | 4 | 14 | 1 | 4 | 14 | 1 | 4 | 14 |
| σ | Standard deviation (per year) | 13% | 13% | 13% | 13% | 13% | 13% | 13% | 13% | 13% | 13% | 13% | 13% | 13% |
| RFR | Risk free rate of return (% per year) | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% | 4% |
| | | | | | | | | | | | | | | |
| NPVq | Value-to-cost metric | 1,01 | 1,37 | 1,27 | 1,31 | 1,36 | 1,26 | 0,51 | 1,31 | 1,21 | 1,01 | 1,45 | 1,34 | #DIV/0! |
| σ√t | Volatility metric | 0,00 | 0,13 | 0,26 | 0,49 | 0,13 | 0,26 | 0,49 | 0,13 | 0,26 | 0,49 | 0,13 | 0,26 | 0,49 |
| | Option value (EUR) | 0 | 9.412.829 | 9.412.829 | 3.007.714 | 9.077.510 | 9.077.510 | 2.836.690 | 7.100.180 | 7.100.180 | 1.818.655 | 12.088.101 | 12.088.101 | 4.382.146 |
| S-X | Conventional NPV (EUR) | 370.493 | 13.115.649 | 10.263.048 | 10.015.255 | 12.780.330 | 9.927.729 | -40.110.822 | 10.803.000 | 7.950.399 | 377.775 | 15.790.921 | 12.938.320 | |
| | **Region (1-6)** | **1** | **1** | **2** | **3** | **1** | **2** | **4** | **1** | **3** | **3** | | | |
| | **Excersise decision** | **Now** | **Now** | **Maybe now** | **Probably later** | **Now** | **Maybe now** | **Maybe later** | **Now** | **Probably later** | **Probably later** | | | |