Modelling of input data uncertainty based on random set theory for evaluation of the financial feasibility for hydropower projects

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DISSERTATION

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Kurzfassung

Die Auslegung von Wasserkraftanlagen stellt einen komplexen Planungsablauf dar, mit dem Ziel das vorhandene Wasserkraftpotential möglichst vollständig zu nutzen und künftige, wirtschaftliche Erträge der Kraftanlage zu maximieren. Um dies zu erreichen und gleichzeitig die Genehmigungsfähigkeit eines komplexen Wasserkraftprojektes zu gewährleisten, besteht hierbei die zwingende Notwendigkeit eine Vielzahl für die Konzepterstellung relevanter Einflussfaktoren zu erfassen und in der Projektplanungsphase hinreichend zu berücksichtigen.

In frühen Planungsstadien kann ein Großteil der für die Detailplanung entscheidenden, technischen und wirtschaftlichen Parameter meist nicht exakt bestimmt werden, wodurch maßgebende Designparameter der Wasserkraftanlage, wie Durchfluss und Fallhöhe, einen umfangreichen Optimierungsprozess durchlaufen müssen.

Ein Nachteil gebräuchlicher, deterministischer Berechnungsansätze besteht in der zumeist unzureichenden Objektivität bei der Bestimmung der Eingangsparameter, sowie der Tatsache, dass die Erfassung der Parameter in ihrer gesamten Streubreite und sämtlichen, maßgeblichen Parameterkombinationen nicht sichergestellt werden kann.

Probabilistische Verfahren verwenden Eingangsparameter in ihrer statistischen Verteilung bzw. in Form von Bandbreiten, mit dem Ziel, Unsicherheiten, die sich aus dem in der Planungsphase unausweichlichen Informationsdefizit ergeben, durch Anwendung einer alternativen Berechnungsmethode mathematisch zu erfassen und in die Berechnung einzubeziehen.

Die untersuchte Vorgehensweise trägt dazu bei, aus einem Informationsdefizit resultierende Unschärfen bei der wirtschaftlichen Beurteilung komplexer Infrastrukturprojekte objektiv bzw. mathematisch zu erfassen und in den Planungsprozess einzubeziehen. Es erfolgt eine Beurteilung und beispielhafte Überprüfung, inwiefern die Random Set Methode bei Bestimmung der für den Optimierungsprozess von Wasserkraftanlagen relevanten Eingangsgrößen Anwendung finden kann und in wieweit sich hieraus Verbesserungen hinsichtlich Genauigkeit und Aussagekraft der Berechnungsergebnisse ergeben.

Abstract

The design of hydropower projects requires a comprehensive planning process in order to achieve the objective to maximise exploitation of the existing hydropower potential as well as future revenues of the plant. For this purpose and to satisfy approval requirements for a complex hydropower development, it is imperative at planning stage, that the conceptual development contemplates a wide range of influencing design factors and ensures appropriate consideration of all related aspects.

Since the majority of technical and economical parameters that are required for detailed and final design cannot be precisely determined at early planning stages, crucial design parameters such as design discharge and hydraulic head have to be examined through an extensive optimisation process.

One disadvantage inherent to commonly used deterministic analysis is the lack of objectivity for the selection of input parameters. Moreover, it cannot be ensured that the entire existing parameter ranges and all possible parameter combinations are covered.

Probabilistic methods utilise discrete probability distributions or parameter input ranges to cover the entire range of uncertainties resulting from an information deficit during the planning phase and integrate them into the optimisation by means of an alternative calculation method.

The investigated method assists with the mathematical assessment and integration of uncertainties into the rational economic appraisal of complex infrastructure projects. The assessment includes an exemplary verification to what extent the Random Set Theory can be utilised for the determination of input parameters that are relevant for the optimisation of hydropower projects and evaluates possible improvements with respect to accuracy and suitability of the calculated results.

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Abbreviations and list of Symbols

Abbreviations and symbols that are used in the study are listed below in alphabetical order. Furthermore all important terms, abbreviations and symbols are explained at their first appearance in the document. Comprehensive definitions of expressions are presented in the glossary of terms.

For easier reference and unambiguous identification a distinction has been made according to the context where abbreviations and symbols are used.

Hydropower Engineering

Abbreviations:

EIA	Environmental impact assessment
E&M	Electrical and mechanical installations
HPP	Hydropower Plant
LRWL	Lowest regulated water level
NOL	Normal operating level
O&M	Operation and Maintenance

Symbols:

C_P	generating station cost
C_T	cost of turbine-generator unit and controls
E(t)	electric energy in KWh
$\overline{E}_A$	average annual energy production
E_F	firm energy
E_S	secondary energy
g	ground acceleration (9.81 m/s^2)
H	head of water or specific hydraulic energy
H_{Gross}	gross hydraulic head (m)
H_{Net}	net hydraulic head (m)
$H_L(t)$	head loss in water conduits
H_R	rated hydraulic head (m)

ICOLD	International Commission on Large Dams
k	site factor
KW	installed capacity in KW
MW	installed capacity in MW
P(t)	electric power in KW
P_{Net}	net input power
P_{theo}	see P_{Net}
P_T	mechanical output power
P_{Transf}	output power
Q_d	design discharge (m^3/s)
Q(t)	plant discharge (m^3/s)
ρ_w	density of water (999,73 kg/m^3at T=10ºC)
η_{tot}	total efficiency factor (turbine, generator, transformer and head losses)
$\eta_{tot,PGU}$	efficiency factor for power generation unit (turbine, generator, transformer)
η_{Plant}	plant efficiency
η_G	generator efficiency
η_T	turbine efficiency
η_{Tr}	transformer efficiency

Probabilistic and mathematical theory

Abbreviations:

CDF	Cumulative Distribution Function
DST	Dempster-Shafer Theory
RSM	Random Set Method
RST	Random Set Theory
RS-FEM	Random-Set-Finite-Element-Method

Symbols:

A_i	focal element
Bel	belief function

E	generic subset
f	function
F^*	upper cumulative probability distribution function
F_*	lower cumulative probability distribution function
i	index number
j	index number
k	index number
l	lower value of a closed interval
m	basic probability assignment
n	number of information sources
Pl	plausibility function
Pro	probability function
u	upper value of a closed interval
x	basic variable
X	non-empty set
$\Im$	support of random set

Financial and economic terms

Abbreviations:

ADSCR	Annual Debt Service Cover Ratio
B/C	Benefit Cost Ratio
COD	Commercial Operation Date
CPI	Consumer Price Index
DCF	Discounted Cash Flow
GDP	Gross Domestic Product
ICB	International Competitive Bidding
IDC	Interest During Construction
IRR	Internal Return Rate
LDs	Liquidated damages

LIBOR	London Interbank Offered Rate
LLCR	Loan Life Cover Ratio
LOI	Letter of Intend
MIRR	Modified IRR
NPV	Net Present Value
PLCR	Project Life Cover Ratio
PPA	Power Purchase Agreement
PPP	Public Private Partnership
RFP	Request for Proposals
SPV	Special Purpose Vehicle
VAT	Value Added Tax

Symbols:

CF_t	cash flow at the end of period n
I_0	initial outlay
k	rate of return
t	period

1 INTRODUCTION

1.1 Problem definition and objective of the study

The decision to develop a particular hydropower project is based on economic grounds, which are formed by several factors including physical characteristics, environmental and social acceptability of the site in addition to project specific technological and engineering solutions. For the determination of a hydropower project's economic merit a variety of factors such as predicted future power market and energy market conditions as well as possible tariff scenarios present equally important parameters.

Appropriate and dependable economic decisions on large water projects are of major significance to the public, which is emphasised by the following quotation from the publication 'Water Policies for the Future, The Final Report to the President and to the Congress of the United States by the National Water Commission' (National Water Commission 1973):

> *"Once they are completed, major water control structures can be altered only with difficulty, or not at all. There are only a few suitable dam sites, and once they are appropriated, the possibilities for economic multiple-purpose development are very limited. Once an irrigation project is developed, it cannot be moved because unfavourable soil or climatic factors are discovered. There is a sobering finality in the construction of a river basin development; and it behoves us to be sure we are right before we go ahead."*

During the process of assessing a project's technical and economical feasibility one of the main challenges for the planer is the fact that especially at early planning stages only very limited and in many cases rather unreliable project information is available. Consequently a considerable number of design parameters usually need to be approximated using engineering judgement, technical literature or experiences collected from comparable previous projects. In cases where sufficient data cannot be made available modern statistical correlation techniques may be used to supplement observed records and incomplete data. Although the deterministic approach, which is based on using estimated values and a limited variation of different parameter combinations, is widely accepted and commonly established amongst engineers, this method does not necessarily provide satisfactory results to an acceptable level of accuracy.

This study investigates if and to what extent the Random Set Theory (RST) is suitable as a reliable, scientific methodology that can be utilised for handling of imprecise input parameters in the context of hydropower optimisation.

Primary applications of RST are the identification, analysis and management of project risks as well as its utilisation for the support of the investment decision making.

Random Set Theory has been used successfully (Tonon et al. 1996) to account for uncertainties in rock engineering and tunnel lining design where statistics of imprecise data arise in rock mass characterisation. The uncertainties related to the imprecise parameters are used in a RST based calculation to determine upper and lower bounds of the reliability of a tunnel lining. Within this field the RST can provide an appropriate mathematical model of uncertainty when the information about mechanical properties of a rock mass is not complete or when the result of each observation is not point valued but set valued, so that it is not possible to assume the existence of a unique probability measure.

Based on the investigations by Tonon further studies within the field of geotechnical engineering by Pöttler, Schweiger and Peschl (Pöttler et al. 2005) have extended RST to be combined with the finite element method, called Random-Set-Finite-Element-Method (RS-FEM). The investigations concluded that the RS-FEM provides a convenient tool to account for the scatter in material and model parameters and thus increases the value of numerical analysis significantly. Since conventional design analysis based on deterministic parameters cannot reflect the behaviour in situ, the RS-FEM is rated as an efficient tool for reliability analysis within geotechnical applications during early design phases being highly complementary to the so called observational method.

The objectives of the following study can be briefly summarised as follows:

- Provision of a formalised approach to address and incorporate inherent uncertainties related to input parameters into the process of hydropower optimisation.
- Critical review and suggestions for further enhancement of methods and tools that are commonly used for the optimisation of hydropower parameters during design stage of a hydropower development.
- The recommended methodology must be suitable for being used within the context of practical engineering applications.
- The proposed model shall support the designer with carrying out his work in a rational, transparent and thus defensible manner when facing a situation of scant and imprecise information.
- The study highlights restrictions and limitations of the Random Set Method (RSM) within the context of hydropower optimisation and provides recommendations regarding the practical utilisation for hydropower engineering applications.
- The study describes and demonstrates the suitability of the RSM as an instrument that can be utilised in the context of project risk assessment and as a support for the investment decision making.

1.2 Outline and structuring of the document

Common procedures and engineering methods utilised by consultants and engineers in the context of hydropower optimisation are illustrated in chapter 2. The standard methods are introduced taking account of technical hydropower engineering aspects as well as parameters that are used as indicators for determination of a power project's financial feasibility. This section of the study includes a depiction of the most significant input parameters involved in the hydropower optimisation procedure and illustrates difficulties related to uncertain and imprecise data. The focus is placed on parameters that may alternatively be treated by means of a probabilistic approach. A case study based on a run-of-river type of hydropower development illustrates the described methodology in detail and highlights deficiencies related to the deterministic approach.

Chapter 3 outlines the definition of uncertainty and provides a general description of existing probabilistic methods with particular emphasis on the random set theory and its engineering applications.

The concept of employing a probabilistic approach to evaluate the financial feasibility of a hydropower project is introduced and discussed in chapter 4. Relevant aspects of the proposed methodology are described and evaluated in detail, with the purpose of developing a suitable procedure that can be applied to the real project.

The practical application of the described method and its suitability for the anticipated purpose are appraised in chapter 5 through the feasibility study for a hydropower development, investigating a 1100 MW run-of-river plant. The project, which is located at the Angara River in Siberia/Russia, represents a typical example for the difficulties that may arise during the design phase due to limited availability of information and imprecise input data. The case study compares the results and possible consequences for the HPP design by judging the findings based on conventional engineering methods in contrast to conclusions that can be drawn from a probabilistic approach.

Chapter 6 summarises the conclusions that can be drawn from the comparison of the alternative engineering methods. Possible advantages as well as limitations regarding the use of probabilistic methods within the described context are discussed and recommendations for future research are presented in this section of the study.

A glossary of terms is included in chapter 7. The study concludes with a summary of the used literature and a collection of references presented in chapter 8.

1.3 Limitations of the study

The analytical processes described are limited to the determination of the economic merit of a specific project within a sequence of projects, which fit into a specific development plan. The economic evaluation of such elements is termed micro-economic analysis because the scope of the investigation is limited to the establishment of the merit of a single sectoral element only. Consequently the study does not consider the impact a particular development proposal has on the local, regional or national economy as a whole nor on the financial position of the developer and of the country. These matters involve a much more extensive investigation, for example, into the economic and financial circumstances surrounding the project and the developer (Goldsmith 1993).

Nowadays, hydropower developments are for the most part designed as multi purpose projects. In addition to power production and the requirement to meet an identified electricity demand other goals such as water storage, irrigation, water supply and flood control need to be taken into consideration during the design process. These project specific additional benefits are difficult to quantify in monetary terms and will not be taken into account within the scope of this study. The focus of the following investigations is limited to subjects related to power production only.

All economic calculations are based on the assumption of a perfect financial market. The term is explained in the context of the economic project appraisal in chapter 2.2. A perfect financial market does not exist under real conditions but this applies to all methods employed in the context of financial project analysis. Since the calculations presented in the study are of comparative character the assumption of a perfect market does not have an influence on the conclusions that can be drawn from the comparison between conventional and probabilistic engineering methods.

The assessment of socio-economic and environmental impacts forms an integral part of a project’s feasibility study. However, since these aspects cannot be generalised a detailed and project specific case by case investigation is usually required in order to adequately judge the necessary mitigation measures. In this study financial impacts resulting from activities such as preparation of the reservoir area, resettlement, compensation measures etc. are taken into account as lump sum expenditures although the determination of these costs in fact requires a detailed and project specific cost estimation.

With regard to the subsequent case study, which is based on the feasibility study for an existing Hydropower Project several project relevant aspects could not be assessed in detail due to lacking information and imprecise data. A detailed description of the assumptions and approximations that had to be made during the engineering process as a result of these restrictions is given in chapter 2.

2 HYDROPOWER OPTIMISATION

2.1 Common approach and methodology

The development of an electric power supply system as well as its operation will have its primary objective in meeting the existing and future energy demand with seasonal and daily variations at the lowest possible cost. In a pure hydropower based system, power production capability is subject to stochastic variations in annual precipitation and variable availability of water to the power plants during a year.

The planning activities for a hydropower development always involve choices among physically feasible alternatives. Alternative concepts, which have been seriously considered, need to be expressed in monetary terms before a choice can be made. Unless alternative options for a hydropower development can be expressed in monetary units, the items involved in such comparisons remain incommensurable.

> *"Predominant characteristics of well maintained hydropower plants are their high availability and reliability as well as their ability to respond rapidly to load changes in the system. The relatively simple hydropower apparatus is operationally very flexible resulting in quick start-up and shutdown capability. Hydropower plants are also characterised by very low forced outage rates, low operation and maintenance costs and negligible fuel costs. Hydropower development can be considered a mature technology although marginal improvements are still being made with respect to efficiencies of electrical and mechanical equipment"* (Haga 1992).

Each hydropower project will have to be designed to meet a specific system demand within existing physical and other restrictions. Expected demand both with respect to total capacity and the pattern of demand reflecting the daily and seasonal variations is thus the basis for establishing the value of a project in a power supply system.

Daily load variations in high and low load seasons are usually described by means of demand curves. The load is the chronological sequence of instantaneous power levels over a period of time that the power system has to meet. For the purpose of planning, it is convenient to transfer the demand curve to a load duration diagram, where the load as a percentage of peak load is plotted against time. The area below the curve represents the total amount of energy required in a given year.

An important element of hydropower developments is their potential ability to store water. Available storage capacity raises the value of hydropower considerably, because it allows targeting the use of hydropower during periods when it is at its highest value.

2.1.1 Power and Energy calculation

Verification of the future power and energy production potential of an investigated hydropower project site is usually supported by a simulation model of the hydropower development to simulate the operation of the scheme.

In most regions of the world river flows exhibit a large variability both in the short term, seasonally and from year to year. This variability is mainly due to climatic variability, and has to be taken into consideration at planning stage as well as during operation. The production and economic benefits of a hydropower system always need to be estimated under consideration of varying hydrological conditions. In contrast to thermal power generation units, which can usually assume unlimited availability of fuel resources, the inflow for a hydropower project is never constant and varies through the year as well as for consecutive years. Furthermore the exact future inflow is also not known for certain.

For the simulation it has to be assumed that hydrological conditions for the project do not change over time and inflow during the operation period will be statistically similar to the flow rates within the observed period. "*This includes that future inflows of the hydropower development will have the same statistical properties, such as mean value and pattern of variation as during the earlier, historical observation periods*" (Killingveit, Saeltun 1995).

In order to obtain appropriate forecasts it is compulsory that all relevant features of the specific project in question are adequately incorporated into the model, data on inflows are correctly observed and a sufficient amount of data can be made available. The observed series must also be representative for the project.

Once a model has been constructed, the operation of the project needs to be simulated over a number of years, with varying hydrological conditions. For obvious reasons reliability and accuracy of the simulation output will highly depend on the amount and quality of the available observations (e.g. flow measurements).

"*In Norway, simulation for at least a 30 year period is recommended for planning of hydropower projects*" (Killingveit, Saeltun 1995).

If necessary, short or fragmentary records may be filled in and extended by correlation techniques utilising records from neighbouring areas. By means of modern statistical correlation techniques it is also possible to extend the observed records over an acceptable period of time.

The following parameters need to be obtained from the simulation of the project's operation since they represent essential input for the subsequent financial project analysis:

- Installed capacity
- Annual average energy production $\overline{E}_A$
- In case that the existing tariff structure provides differentiated remuneration, the production of firm and secondary energy, E_F and E_S, also needs to be determined.

The project's potential production capacity as described in the following section represents one of the key input parameters for the subsequent economic project appraisal.

The output of the power plant is calculated for each time step and added up in order to calculate the annual output for the entire simulation period using the following equations:

Electric Power P(t) in KW:

$$P(t) = \frac{g \cdot \rho_W \cdot \eta_{tot,\,PGU} \cdot Q(t) \cdot (H_{Gross}(t) - H_L)}{1000} \qquad (1)$$

g:	ground acceleration
ρ_W:	density of water
$\eta_{tot,PGU}$:	total efficiency factor for turbine, generator and transformer, function of Q(t) as per unit (e.g. 0.91)
Q(t):	plant discharge
H_{Gross}:	gross head
$H_L(t)$:	head loss in water conduits such as tunnels, penstock, trash rack etc.

Equation (1) is widely used for hydropower design and also described in scientific textbooks by Giesecke/Mosonyi (Giesecke et al. 2005 /// 2009) as well as Killingveit/Saeltun (Killingveit, Saeltun 1995).

The main parameters of relevance in this context are depicted in figure 1 below:

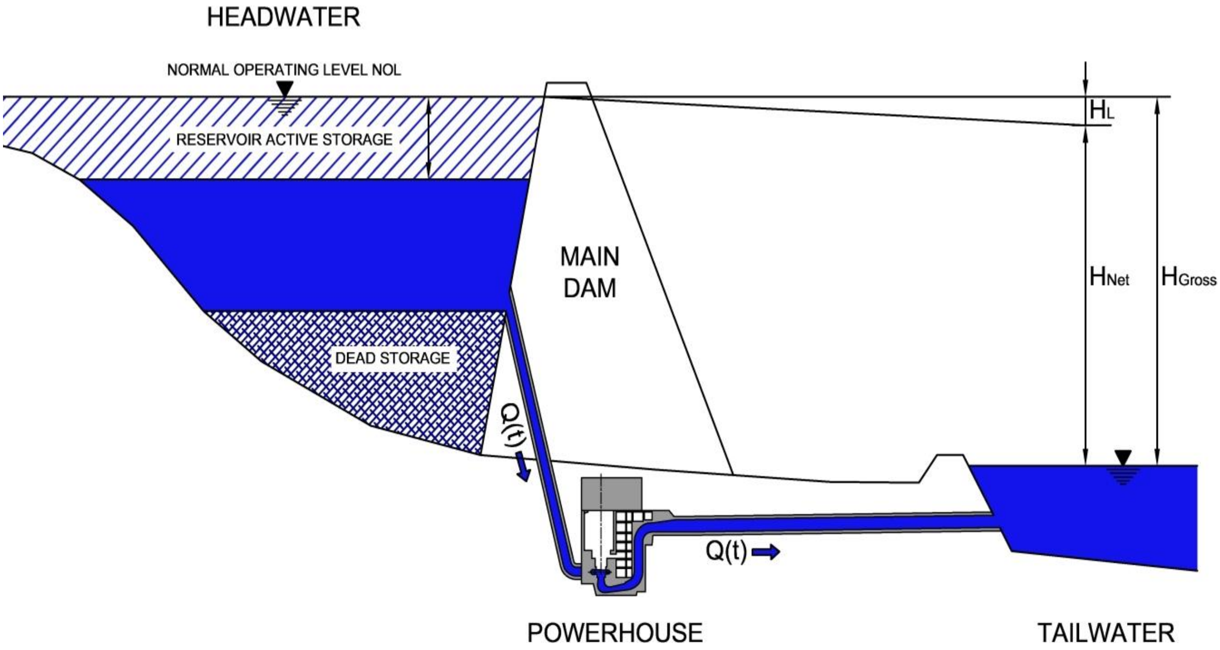

Figure 1: Illustration of significant parameters for power and energy calculation.

The average annual energy production $\overline{E}_A$, which forms a fundamental design parameter of the hydroelectric plant, can be computed using equation (1) for all time steps over a long period of years, and then computing the average (Killingveit, Saeltun 1995).

Electric Energy E(t) in KWh:

$$E(t) = \int_0^t P(t)dt = P(t) \cdot \Delta t \tag{2}$$

Δt: time step

Average annual energy production:

$$\overline{E}_A = \frac{\sum_{i=1}^{N}\sum_{j=1}^{M} E(i,j)}{N \cdot M} \tag{3}$$

N: number of years

M: number of time steps within each year (52 weeks, 365 days etc.)

Due to the large variability in hydrological conditions from one year to another, it is usually necessary to compute the average energy production based on a considerable number of years of hydrological observations. As illustrated before it is advisable and common practise in most countries to utilise data covering an extended observation period for such computations (e.g. at least 30 years or more if possible).

2.1.2 Flow duration curve and design discharge

Since a hydropower plant is normally designed for a lifetime exceeding 50 years (Länderarbeitsgemeinschaft Wasser 2005), a correspondingly large variability in future flow conditions must be expected. Continuous flow data series are generated on the basis of stream flow measurements.

In order to obtain the best possible estimate for the average power production and to ensure adequate representation of the daily, monthly and annual variability of the river discharge, it is desirable to base the calculations on a large number of flow measurements. These records also form the basis for flood computations if precipitation data and precipitation-runoff models are not being used.

The variability of natural river runoff is illustrated in the following flow hydrograph showing flow measurements of the Russian river Angara taken in the vicinity of the proposed project site over a period of 45 years.

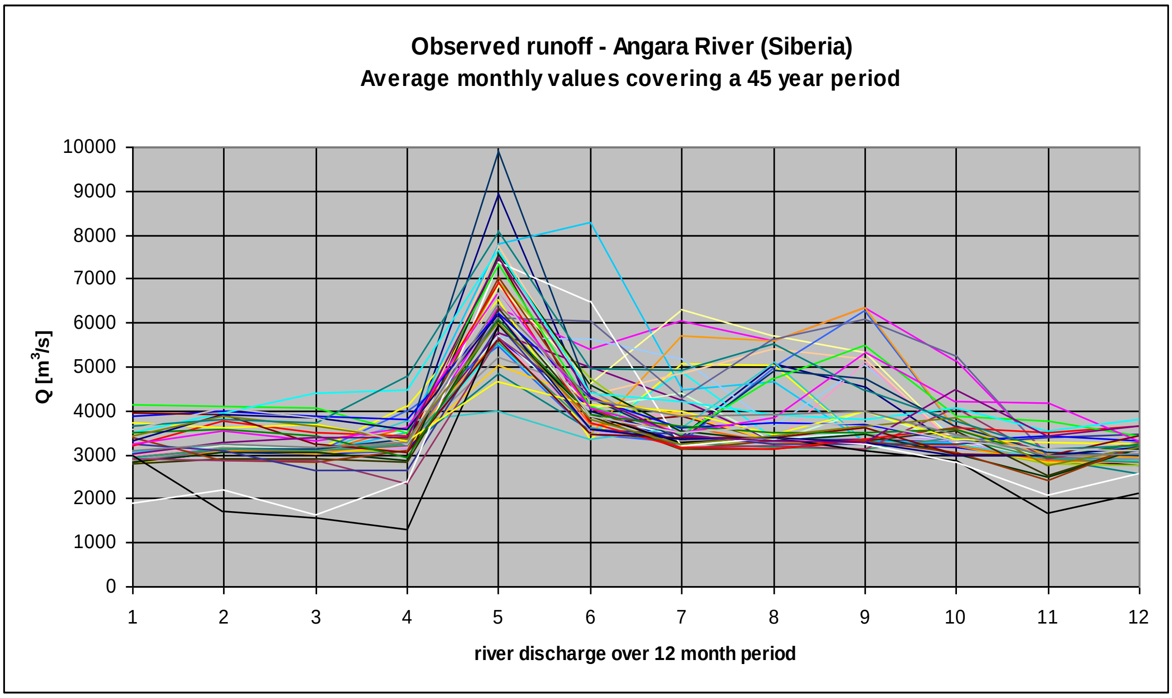

Figure 2: Observed runoff at the Angara River in Siberia covering a 45 year period

For hydropower simulation and optimisation models it has to be assumed that hydrological conditions in the future will be statistically similar to those in the past. For obvious reasons the optimum design and operation of a hydropower system can be greatly improved if reliable inflow forecasts can be made available as a basis for the planning works.

The operation of hydropower plants differs from the operation of thermal power plants since the water availability is a stochastic variable, leading to a certain degree of uncertainty concerning the determination of future production capacity.

The selected design discharge Q_d for a projected hydropower development will primarily depend on the following factors:

- Discharge characteristics of the river (uniform or varying runoff data)
- Existing power generation and transmission infrastructure as well as the plant's envisaged role within the power generating system (supply of base load or peak load, power supply to the grid on the day-ahead market/capacity market versus supply to industrial consumers based on power purchase agreements)
- Possibility of creating a storage reservoir and its maximum active storage volume
- Result of overall benefit cost analysis of the investigated options
- Objectives related to water utilisation such as navigation and irrigation
- Environmental considerations (existing ground water level, max. allowable variation of the reservoirs water level, stipulated min. residual discharge etc.)

Hydropower plants can be differentiated and categorised according to their capacity to store water. In this context the Capacity to Inflow Ratio – CIR is used to describe the storage capacity or size of the reservoir related to the mean annual inflow. "*The CIR consequently illustrates the level of flow regulation respectively the level of water utilisation in a river*" (Lysne 2003).

The higher the CIR the less water will bypass the power plant through the spillways (e.g. during floods) and consequently be lost for power production.

Based on the mean monthly runoff values measured at the Angara River during a 45 year observation period figure 3 illustrates typical flow duration curves and indicates possible conclusions with regard to optimisation of a hydropower plant's design discharge. Curve Q1 in the diagram represents the Angara River's runoff data of figure 2 in form of a flow duration curve. The river discharges are systematically arranged according to their respective exceedance probabilities. The area below the curve represents the annual volume of water that is used for power generation.

Discharge values above the plants design discharge must not be taken into account for power generation since these volumes are spilled during floods.

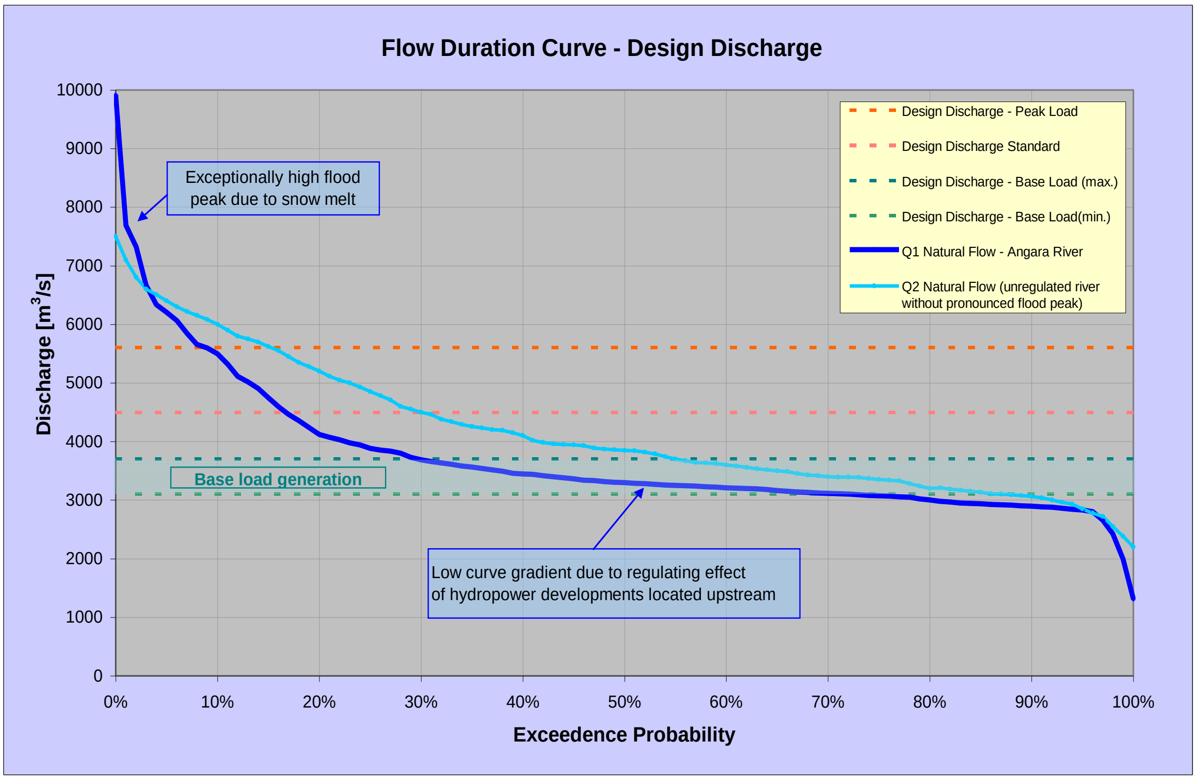

Figure 3: Flow duration curves versus HPP design optimisation

A run-of-river plant without storage reservoir is characterised by a low CIR value. This type of hydropower development does not make extensive use of the water resources of the river and the HPP's design discharge is likely to be chosen for generation of base load only. The development concept involves a comparably low capital investment in conjunction with a high availability of the plant, but the rivers potential for energy generation is not exploited efficiently.

The design of the HPP is likely to be based on a high CIR, provided that the annual river runoff shows a pronounced flood peak, such as illustrated in the above diagram by curve Q1 (flow data from the Angara River taken as an example) and if the remuneration for peak capacity is sufficiently attractive. Under these circumstances the necessary higher capital investment for the plant, resulting from the higher design discharge Q_d, is justified by the additional revenues that can be generated. A reservoir of sufficient capacity will become inevitable in order to make efficient use of the varying water resources.

Should a run-of-river-plant in conjunction with a daily peaking reservoir be anticipated, the plants design discharge is likely to be elevated to a level as illustrated for the 'standard case' above.

The previous descriptions are confirmed by Haga as a result of his investigations regarding the coordination of hydropower and thermal power (Haga 1992), where he concludes that “*In a pure hydropower system, the different development schemes would be allocated load within the load duration curve according to their specific characteristics. A typical run- of-river plant would obviously serve the base load part of the demand while plants with sufficient reservoirs would cover both seasonal and daily intermediate and peak load situations.*”

Since particular project characteristic factors need to be taken into account for the design of each individual hydropower development, it is always mandatory to carry out a case specific optimisation analysis. Therefore the above recommendations for hydropower development cannot be automatically generalised for all projects and must be understood as an indicative general guideline only.

2.1.3 Unused discharges

Due to restrictions which are determined by individual project requirements it is usually not feasible to take the entire available river discharge into account for power generation purposes.

If applicable, appropriate deductions have to be made to account for losses resulting from operation of the plants structures, such as navigation lock, fish pass etc. In addition, losses related to objectives like irrigation, the requirement of a minimum residual flow and environmental restrictions must be considered for calculation of the projects power generating potential.

2.1.4 Usable storage, active storage volume

The projects power generating potential does not simply depend on the overall size of the storage reservoir. The limiting factor in this context is the reservoirs active storage volume, as illustrated in figure 1. Provided that no other restrictions are applicable, the water volume above the reservoirs dead storage (limited by the lowest regulated water level LRWL) up to the normal operating level (NOL) will be exploitable for power generation.

2.1.5 Gross head

Based on the river bed topography downstream of the power plant the rating curve method allows the engineer to specify tailwater elevations corresponding to specific flows, forming a rating curve relating flow and tailwater elevation. The difference between normal operating level and the tailwater elevation represents the gross head, which forms one of the key parameters for calculation of the output of the power plant as illustrated in equation (1).

2.1.6 Energy losses

Hydropower turbines represent the plants most cost intensive key equipment for power generation and form an integral part of the powerhouse. "*The turbines are installed to convert the hydraulic energy of the water into mechanical energy, which involves losses that arise partly in the machines itself and partly in the water conduits to and from the machines*" (Kjolle 2001).

Inevitably the flow through turbines is always exposed to energy losses caused by flow friction, change of flow direction etc. For calculation of a HPPs power and energy production the turbine losses, which are accounted for by the turbine efficiency η_T have to be taken into consideration. On account of these unavoidable losses the turbine efficiency is always lower than the hydraulic efficiency. Equally important in this context are losses related to inlet, trash rack, penstock and outlet of the powerhouse.

Within the field of turbine efficiency extensive research and optimisation (incl. model and performance tests) have been carried out by turbine manufacturers as well as scientific research institutes. The turbine efficiency η_T is commonly defined as the ratio between mechanical output power P_T and the net input power, whereby the net input power is defined as the gross hydraulic power of the unit minus losses in the conduits to and from the hydropower turbine.

Turbine efficiency:

$$\eta_T = \frac{mechanical\ output\ power}{net\ input\ power} = \frac{P_T}{P_{Net}} \tag{4}$$

The above definition is described in technical literature published by recognised hydropower experts such as Vinogg/Elstad (Vinogg, Elstad 2003) and Giesecke/Mosonyi (Giesecke et al. 2005 /// 2009).

The output is the mechanical power P_T delivered by the turbine shaft. The input power is the hydraulic power available to the turbine, which is the net specific hydraulic energy $g \cdot H_{Net}$ (Joule/kg) of the water times the mass flow of the water $\rho \cdot Q$ (kg/s), where ρ (kg/m^3) is the density of water. Giesecke and Mosonyi (Giesecke et al. 2005 /// 2009) prefer to use the term theoretically possible power P_{theo}, instead of net input power for the same equation.

Net input power:

$$P_{Net} = g \cdot H_{Net} \cdot \rho_w \cdot Q \tag{5}$$

Turbine efficiency:

$$\eta_T = \frac{P_T}{P_{theo}} = \frac{P_T}{g \cdot H_{Net} \cdot \rho_w \cdot Q} \tag{6}$$

The input power to a hydropower turbine is not efficiently utilised to a maximum at all operating conditions since each machine achieves its optimum efficiency at only one combination of flow discharge, water head and rotational speed.

Subject to existing requirements the turbines are operated with different flow rates Q according to the variable grid load, alternating heads and varying discharges. Therefore the hydraulic design of the turbines is not primarily based on full power operation but on the best efficiency point within the whole range of expected flow and net head (Vinogg, Elstad 2003).

In order to ensure that the variation of loss coefficients remains within an acceptable magnitude, the actual operating conditions of the HPP should not deviate extensively from the original design assumptions. The maximum efficiency point, which is represented by the most suitable operating conditions, is reaching values of approximately η_T for larger and best reaction turbines.

Typical turbine efficiency curves in relation to their relative discharge are shown in figure 4 below (Vinogg, Elstad 2003):

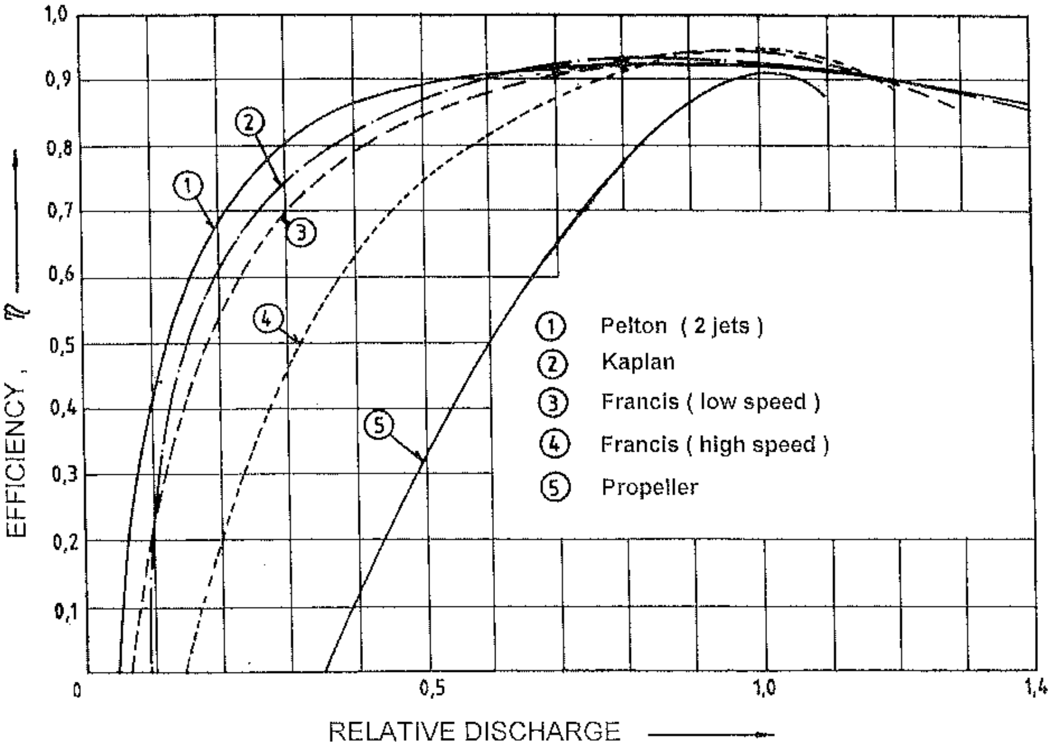

Figure 4: Turbine efficiency versus relative discharge for different types of turbines

A general overview with regard to the suitability of different turbine types depending on the hydraulic head and the discharge per unit is depicted below in figure 5 (diagram by VA-Tech Hydro, Escher Wyss/Ossberger):

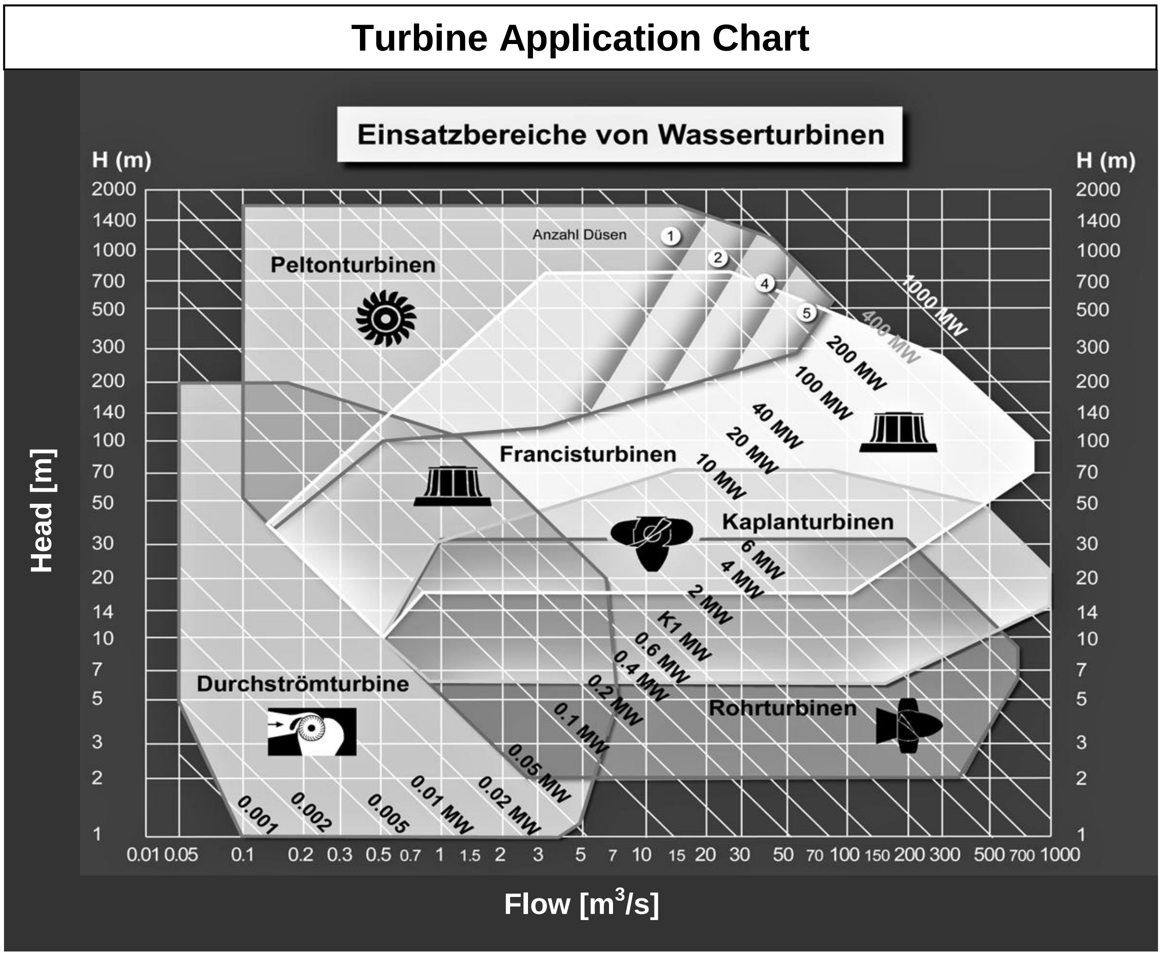

Figure 5: Different types of turbines with respect to hydraulic head and discharge

The plant efficiency η_{Plant} of a hydropower plant is defined as the ratio between the mechanical power output from the machine shaft and the gross hydraulic power of the power plant (Kjolle 2001). The parameter is usually expressed by means of the following formula (Vinogg, Elstad 2003):

Plant efficiency:

$$\eta_{Plant} = \frac{P_{Transf}}{g \cdot H_{Gross} \cdot \rho_w \cdot Q} \qquad (7)$$

Since the losses included in the plant efficiency depend on the design of the water conduits to and from the turbine as well as the operating conditions, the parameter η_{Plant} is variable and not proportional to the discharge or power output. The shape of the plant efficiency curve consequently differs from the shape of the turbine efficiency curve (Vinogg, Elstad 2003).

The plant efficiency η_{Plant} accounts for the following losses:

- Head losses in the water passages to and away from the turbine which reduce the gross head to the turbine net head
- Generator losses that reduce the mechanical output from the turbine to a smaller electrical output on the generator terminals
- Transformer losses that reduce the generator output to what comes out in the transmission line.

In line with studies by Giesecke and Mosonyi (Giesecke et al. 2005 /// 2009), Vinogg/Elstad (Vinogg, Elstad 2003) and according to recommendations received from turbine manufactures such as Andritz Hydro GmbH and Voith Hydro, the following efficiency factors will be taken into account for all subsequent power and energy calculations respectively. These figures are based on well maintained state of the art low head run-of-river plants equipped with Kaplan types of turbine:

Turbine efficiency:	$\eta_{T\,=}\,0.93$
Generator efficiency	$\eta_{G\,=}\,0.98$
Transformer efficiency	$\eta_{Tr\,=}\,0.993$

As a result of the above all further power and energy calculations within the following sections of the study are based on a total efficiency factor for the power generation units $\eta_{tot,PGU}$ of 0.91 to account for turbine, generator and transformer losses.

For the selected example the equation to calculate the output of the power plant can then be modified to the following formula.

Electric Power P(t) in KW:

$$P(t) = \frac{g \cdot \rho_w \cdot 0.91 \cdot}{1000 \cdot 3600} \cdot Q(t) \cdot (H_{Gross}(t) - H_L) = 8.9 \cdot Q(t) \cdot (H_{Gross}(t) - H_L) \qquad (8)$$

Hydraulic losses related to the water conduits to and from the turbines require a project specific case by case study since these figures cannot be generalised.

Provided that the powerhouse comprises a sufficient number of turbines, the availability of all installed units can usually be assumed with 1.0 for energy calculation, as long as it is possible to schedule planned maintenance activities during the periods of low flow months. Consequently no further deductions need to be considered when calculating the average annual energy production for the simulation period.

2.2 Economic project appraisal

2.2.1 Benefit and Cost streams – Financial Analysis

The focus in this chapter is on the assessment of whether future benefits of a hydropower project are worth the investment required. Furthermore, if a certain choice of investment or financing decision is more beneficial than other existing alternatives, the advantages must be quantified by a certain standard.

Only values which can be expressed in monetary terms are included in a financial project assessment. “*In the case of hydropower, the direct benefit from the project is the electric power and energy generated. These benefits can be quantified in monetary terms through the price the public is willing to pay for this commodity*” (Ravn 1992).

In case that the hydropower development operates as a merchant power plant the electricity will be sold in the competitive wholesale power market. The revenues generated by the sale of capacity and energy may also be fixed for a certain period of time by establishing power purchase contracts with industrial consumers or public utilities. These two alternative forms of remuneration do have a significant impact on the amount of risk and uncertainty related to the revenue generation of the power plant, which is described in detail in chapter 5 of the study.

In order to allow for adequate evaluation and comparison of alternative investment opportunities the necessary calculations are based on the assumption of a perfect market.

Economists define a perfectly competitive market for a product or service as having the following characteristics (Seitz, Ellison 2004):

- There are no restrictions keeping producers from entering or exiting the market. There are no taxes, transaction costs, or other restrictions keeping buyers of funds and sellers of funds from entering and exiting the market.
- No one producer or buyer is large enough to affect price through any action. No one buyer of funds or seller of funds is large enough to affect the price (interest rate) through any action.
- All producers manufacture identical products.
- All producers have identical costs.
- Everyone is completely informed about what everyone else is doing. Identical information is available to everyone without cost, resulting in identical beliefs.
- Wealth maximisation represents the motivation of all market participants.

2.2.2 Discounted Cash Flow Method

All capital investments possess a time value and attract interest. When money is used for a capital investment it is diverted from other productive uses. The cost of capital is consequently an opportunity cost and a capital investment can only be justified if its return on money is at least as high as the return generated through alternative opportunities of comparable risk. In order to ensure that adequate recognition is given to the time value of money, economic and financial evaluations are usually based on the discounted cash flow technique.

A cash flow analysis is carried out to confirm the merit of a new project in financial terms by identifying the revenue requirements necessary to cope with the additional outlay for the project. The cash flow presents the incidence of costs and benefits over the period of analysis of a given project. Inputs to the cash flow are positive for benefits (or revenues) or negative for costs.

The significant importance, which the cash flow analysis represents for the financial project evaluation is emphasised by Goldsmith through the statement *"…the cash flow is a common tool for measuring the financial performance of an enterprise and has become one of the essential instruments for project analysis*" (Goldsmith 1993).

This proclamation is confirmed by Yescombe who points out that "*The standard measurements of return on equity for investors in a project are calculated on a cash flow basis*" (Yescombe 2006).

Goldsmith clarifies further that the analysis is always comparative and aims to determine

- the project profitability, with benefits exceeding costs over the timeframe of the analysis.
- which of two alternative projects has been, or is likely to be, the less costly and hence the more profitable over the given timeframe.

"*By definition, the cash flow must include all expenditure incurred on a project during its development up to implementation, during its construction and during its operation until the end of the study period*" (Goldsmith 1993).

In case of a complex hydropower development expenditures also have to cover the pre-investment phase and must include costs for activities such as geological and geotechnical field investigations, hydrological flow measurements and data evaluation, the preparation of an environmental impact assessment and comparisons of alternative project sites to name but a few.

The primary elements that need to be included in the cash flow model for a hydropower development can be summarised as follows:

on the cost side

- Capitalised pre-investment expenses prior to financial close (e.g. field investigations, development costs and fees, Project Company costs etc.)
- Capital investments (e.g. EPC Contract price, start-up costs, insurance etc.)
- Financing costs incl. interests for loan capital, interest during construction, fees etc.
- Re-investment and project related general expenditure
- Operating, maintenance and project related administrative costs

on the benefit side

- Income accruing to the project directly out of the revenue the project is expected to earn
- While indirect benefits from electrification can be significant, only directly assessable and quantifiable benefits are included in the numerical analysis.
  Intangible benefits, avoided costs and socio-economic issues are not considered in the cash flow analysis unless they can be distinctly expressed in monetary terms.

Although the production of power may not represent the only benefit derived from a hydropower facility, methodologies developed to ensure the due consideration of other benefits, such as irrigation, water supply, flood control etc. are not described in further detail. Unless indicated otherwise the financial analysis described in this chapter is based on the assumption that all costs and benefits are measured in monetary units and have been adjusted for tax implications.

In this context it has to be highlighted that the costs and benefits entered into the financial analysis can only be estimated with a very limited level of precision during pre-investment stages. Since these input parameters are to be valid throughout the asset lives, in particular the economic life of the project, it is advisable to test the sensitivity of the financial analysis to changes in the input parameters. This practice can assist the decision making process whether to proceed with the project or not.

The opportunity cost, which determines the discount rate that has to be selected for the financial analysis is also subject to change and varies according to economic circumstances. Over a long period of time the parameter can consequently only be used as an approximate guide on the merit of an investment. Hydropower projects, which were previously rated as non-economically viable 10 to 15 years ago may be regarded nowadays as desirable investment opportunities due to increased costs for fuel and energy.

An example showing a typical cash flow related to a hydropower development and the corresponding costs and benefits is depicted in figure 6 below.

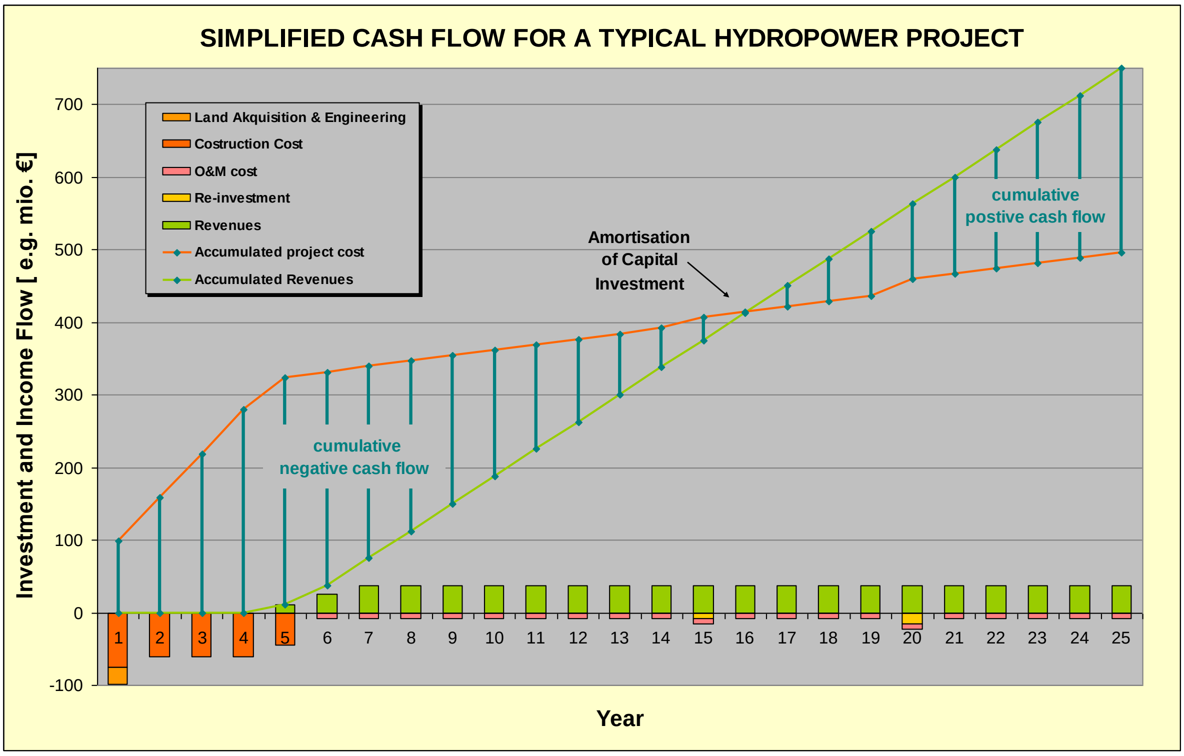

Figure 6: Typical cash flow distribution for a hydro electric power project

In comparison to other forms of energy generation, the cash flow of a typical hydropower development can be differentiated through the following characteristics:

- Hydropower schemes are capital intensive and require a high initial investment but usually possess a longer economic life compared to thermal power plants.
- Planning activities for a hydropower development require an extensive pre-investment phase to study the feasibility of the project and to complete basic investigations.
- Long construction periods without revenues are leading to negative cash flows.
- Operation, maintenance and management costs are negligible compared to the overall capital investment.
- In contrast to thermal power generation, the hydropower development is characterised by the absence of fuel costs.

The characteristics summarised above need to be taken into consideration throughout the project appraisal for the evaluation on whether future benefits generated by the project are worth the investment required. The desirability of a project is assessed by means of certain investment selection criteria as summarised and described in the following chapter.

Seitz and Ellison (Seitz, Ellison 2004) underline the importance of the DCM for investment decisions with the statement:
"*These discounted cash flow methods, as they are commonly called, are recognized as the best methods for evaluating a capital investment because they base the investment decision on whether or not the investment will increase the owners' wealth. As long as the objective of the firm is the maximization of the owner's wealth, investments that are not in competition with each other and will not change the company's risk should be accepted if they meet the acceptability criteria of the discounted cash flow evaluation methods*". In the context of hydropower development this opinion is strengthened by the investigations of Ravn, which conclude that "*Hydropower projects are normally appraised by their direct benefits and the monetary value they can earn on invested capital. […] The time value of money is accepted in all modern societies*" (Ravn 1992).

Yescombe correspondingly summarises "*…to measure the return to investors from cash flows occurring at different times it is necessary to reduce these to a common basis through discounted cash flow calculations. Two interrelated measures are commonly used: the net present value of a cash flow (NPV), and the internal rate of return (IRR*), *both which are measures of a future cash flow adjusted for the time value of money*" (Yescombe 2006). In this context Yescombe correctly advises that "*these measures have to be used with care, and they may also be misleading […]. In summary, an IRR or NPV calculation reflects the return on a cash investment, not the return on any amount that the investors have at risk but which has not yet been drawn in cash.*" In agreement with the above also Goldsmith highlights "*…it can be misleading to place undue reliance on the numerical result of a DCF analysis, especially as the parameters on which the analysis is based are often selected somewhat arbitrarily, in particular the discount rate and the asset lives*" (Goldsmith 1993).

The discounted cash flow model converts the cash flow for a project to a single present value by discounting it from year to year. Discounted cash flow methods are widely used for project analysis and project appraisal due to their simplicity as well as easy computerisation by means of financial calculators and spread-sheet software. In order to justify and confirm an investment decision supplementary information and further decision criteria are usually required.

The calculated indices of merit for a selected scheme may be influenced to a certain extent by the peculiarities inherent to the discounting process of a typical hydropower development. A thorough interpretation of the calculated parameters is therefore crucial for responsible decision making and the final investment decision also depends on the development policy, which the project owner (e.g. public utility) and other project participants (e.g. investor and project developer) wish to pursue. Difficulties that may arise in this context for the project appraisal will be further discussed in detail in the following chapter of the study.

2.2.3 Feasibility Indicators – Indices of merit for a selected scheme

A commonly used standard to judge investment and financing decisions is wealth maximisation (Seitz, Ellison 2004). According to Seitz/Ellison "*An action increases wealth if the benefits gained exceed the benefits expended. […] In single-period business decisions, wealth is created if cash inflow exceeds cash outflow by more than we would have earned by investing our money somewhere else during that period*".

The project life of hydropower developments always exceeds a single period and consequently the time value of money needs to be accounted for. In a comparative project analysis indices of merit are obtained for a selected scheme and compared to economic indicators to demonstrate whether the proposed development is worth pursuing.

In the context of wealth maximisation Seitz and Ellison describe the above as follows:
"*In multi-period decisions, the **present value** of an expected future cash flow is the amount that must be invested elsewhere, at the same risk, to generate the same expected cash flow. The **net present value** of an investment or course of action is the present value of all cash inflows, minus the present value of all cash outflows. Thus, the net present value is the economic profit or wealth created by a multi-period investment*" (Seitz, Ellison 2004)."

A detailed description and critical evaluation covering the most important economic indicators of relevance in this context is included below.

Although parameters such as net present value (NPV), internal return rate (IRR) and further secondary investment criteria are suitable instruments that may indicate the financial feasibility and attractiveness of an investment opportunity, the project can still encounter cash flow difficulties during the early years, which may lead to serious financing problems. For hydropower developments this risk is of particular significance since these projects are usually capital intensive and characterised by long construction periods without revenues.

The net present value (NPV) methodology has developed into a widely established tool for supporting investment decisions, which is considered theoretically reliable and normatively suggested by many corporate finance textbooks. Commonly recognised investment criteria and their related parameters as referred to in the following chapter are described in detail by Rachlin (Rachlin 2001), Ross (Ross et al. 2006), Rollwage (Rollwage 2006) and Dörsam (Dörsam 2007). A comprehensive review on the subject including a description of apparent deficiencies of the individual methods and suggestions for possible improvements has been compiled by Rolfes (Rolfes 2003).

2.2.3.1 Net Present Value

The NPV is the value today of a sum of money due in the future, taking account of the cost of money, known as the discount rate (Yescombe 2006). This definition by Yescombe corresponds to the previous descriptions of the subject and can be expressed by means of the following formula:

$$NPV = \sum_{t=1}^{n} \frac{CF_t}{(1+k)^t} - I_0 \tag{9}$$

n:	project life
t:	period (year)
k:	rate of return that can be earned from alternative investments
I_0:	initial outlay
CF_t:	cash flow at the end of period n
CF_n / $(1+k)^n$:	present value of amount CF_n

"*CF_n is the amount that could be invested elsewhere today at rate of return k in order to have amount CF_n at the end of period n. The arbitrage pricing principle then requires that the value of an investment is the sum of the present values of all future cash flows. The difference between the value of the future cash flows and the initial outlay needed to achieve those cash flows is the increase (or decrease) in wealth for the investor acquiring that investment. A company investing on behalf of the stockholders would create shareholder wealth increases equal to the NPV*" (Seitz, Ellison 2004).

The net present value is recognised as a robust measure of investment desirability and can thus be regarded as a key guideline for capital investment decisions.

The following investment decision criteria are applicable with regard to the NPV:

- A positive NPV (NPV>0) indicates a desirable capital investment. Since the total of discounted benefits exceeds the sum of the discounted costs the project is profitable and adds monetary value to the firm, thus increasing the wealth of the owners.
- A NPV of zero (NPV=0) denotes that the project repays the original investment plus the required rate of return (reflecting opportunity cost). The investor should be indifferent in the decision whether to accept or reject the project since this investment neither gains nor loses monetary value.

- If the NPV is below zero (NPV<0) the investment should be rejected since it does not yield any benefits.
- If several acceptable investment alternatives of similar risk are to be compared, the option yielding the highest NPV should be selected.

  Provided that income streams of the discounted cash flow model represent conventional cash flows (costs occurring earlier and profits later without changing more than once from negative to positive values) it can be summarised that

  - Higher/lower project income amounts result in a higher/lower net present value.
  - An earlier profit generation by the project results in a higher NPV, if profits are generated later the NPV is lower.
  - Variations of the discount rate change the project's NPV. A higher/lower discount rate decreases/increases the NPV of the project.

2.2.3.2 Internal Rate of Return

The IRR measures the return on the investment over its life. It is the discount rate at which the NPV of the cash flow is zero (Yescombe 2006).

The IRR is calculated by means of an iterative process and can be used to determine the attractiveness, in particular the profitability, of an investment opportunity. Since the internal rate of return is defined as the discount rate that results in a net present value of zero, the IRR calculation may not be suitable for projects where the cash flow varies between negative and positive values. In such cases the calculation of the IRR requires additional verification since it may deliver more than one result.

For projects where cumulative cash flows are expected to change only once from negative to positive values the IRR can be defined by using equation (9), as the value for k that leads to a NPV of zero.

The investment decision criteria based on IRR calculation can be summarised as follows:

- The project can be accepted if the IRR is higher than the opportunity cost of capital.
- In most cases the developer will establish a minimum attractive rate of return, which defines whether a project or alternative investment opportunities are rated as acceptable.
- If several acceptable investment alternatives of similar risk and cash flow distribution are to be compared the option with the highest IRR should be selected. The comparison must be based on the use of equal discount rates.

NPV and IRR will generally yield the same accept/reject investment decision as long as the project shows conventional cash flows (cash flow signs do not change more than once) and the indices are not employed to compare mutually exclusive projects where the scale of initial investments or the timing of cash flows are substantially different.

The two parameters can provide conflicting signals if they are calculated for the assessment of mutually exclusive investments. Net present value and internal rate of return may also indicate different rankings of projects due to differences in the magnitude and timing of cash flow.

While the NPV calculation is based on the assumption that project cash flows are reinvested at the cost of capital, the standard IRR calculation assumes that cash taken out of the project is reinvested at the internal return rate until the end of the calculation period.

According to Ross (Ross et al. 2006), Seitz (Seitz, Ellison 2004), Yescombe (Yescombe 2006) and the majority of corporate finance textbooks NPV and IRR can be considered as the most commonly used primary investment criteria.

It is not recommended to place undue reliance on the numerical result of the DCF analysis and particular care must be exercised with the interpretation of results. The following chapter summarises the possible perils related to the utilisation of NPV and IRR as the sole investment decision criteria.

2.2.4 DCF method - Common pitfalls with regard to result interpretation

NPV as well as IRR calculations reflect the return on a cash investment by measuring the value of a future cash flow adjusted for the time value of money. The return to investors from cash flows occurring at different times is evaluated by reducing them to a common basis through discounted cash flow calculations.

2.2.4.1 Considerations for result interpretation related to IRR

Standard IRR calculation assumes that cash taken out of the project is reinvested at the IRR rate until the end of the calculation period. However, the assumption that this cash can be reinvested at the same rate is not necessarily correct and may lead to an overvaluation of early cash flows. In the assessment of projects that are characterised by long cash flow periods, which can be considered a distinctive attribute of hydropower developments, the IRR may be exaggerated by using a high reinvestment rate (Yescombe 2006).

In order to account for this type of distortion it is possible to use the modified IRR (MIRR) as an alternative feasibility indicator. The calculation of the MIRR assumes a lower reinvestment rate representing the investor’s cost of capital instead of the IRR rate for cash taken out of the project. The MIRR also provides an approach to addressing the issue of nonconventional cash flows. However, since such aspects are not to be considered for the purpose of the described hydropower case study, the utilisation of a MIRR won't be necessary for the calculations described in chapter 2.4.

If a discounted cash flow model is used for the analysis of electricity supply projects the discount rate always represents a critical parameter. If the discount rate is set too high, the benefits generated by a given scheme will be undervalued, if the rate is too low, the benefits will be exaggerated. Fine tuning is therefore an indispensable measure for arriving at a realistic discount rate. Sensitivity tests with alternative rates above and below the target rate are essential in order to adequately assess the impact of the discount rate on the result of the analysis.

2.2.4.2 Recommendations for result interpretation related to NPV

The NPV does not yield information about the ratio of benefits to costs. Selecting an appropriate discount rate for net present value calculations is equally difficult as for the IRR and the parameters on which the DCF analysis is based are often selected rather arbitrarily. In real-life applications, decision makers frequently use the NPV rule, but apply a subjectively determined hurdle rate, as opposed to the 'correct' opportunity cost of capital.

For a comparison of two different projects, their relative sizes must also be taken into account. Although a higher initial investment may lead to a higher NPV for the overall project it is not guaranteed that the incremental investment also leads to an equally attractive return as the smaller project.

Goldsmith considers the "…*diminishing effect of future expenditure and benefits on the present value on which the investment decision is taken*" as the principal disadvantage of discounting processes (Goldsmith 1993). The discounted cash flow method is characterised by a progressively diminishing impact of costs and benefits over time, which discriminates against solutions with high initial costs even though these costs may be regained later through larger benefits.

According to Goldsmith "*A hydro-thermal comparison is thus generally biased in favour of thermal*". This effect leads to the conclusion that "*The comparative merit of a hydro scheme can therefore be materially reduced by its relatively unfavourable cost pattern*".

Since the following case study is solely based on comparing the economic merit of different design variations of the same hydropower development, the described deficiency of the DCF method does not affect the results.

However, in a perfectly competitive economy, positive NPV projects should not exist. Therefore, positive NPV projects must be based on some market imperfection and it is advisable to try to identify the imperfection and think about how realistic the NPV projections are.

It is recommended by Goldsmith that „*The background of the data entering into the analysis need to be carefully scrutinised and their sensitivity to predictable changes tested where a critical decision depends on the analytical results. An alternative method of appraisal may also offer assurance that the result obtained is well founded, particularly in borderline situations where a project may have shown to be of questionable merit and where social and policy considerations may also play a role*"(Goldsmith 1993).

The NPV can be regarded as the correct feasibility indicator for a project investment under the following conditions:

- Cash flows and the appropriate discount rate are known with certainty.
- The project is characterised by conventional cash flows and the assessment does not comprise mutually exclusive investments.
- Increasing wealth or shareholder value is the only basis of the decision rule.
- Capital constraints do not exist.

In practice, these conditions are unlikely to be met and therefore the use of additional tools and secondary investment criteria is recommended in order to provide supplementary information to complement the primary decision criteria.

2.2.5 Secondary investment criteria

2.2.5.1 Benefit cost ratio

The B/C ratio is the present worth of accumulated project benefits divided by the present worth of accumulated project costs, the accumulation extending over the life of the project (Gulliver, Arndt 1991).

The project is likely to be of economic merit if the present worth of the lifetime benefits exceeds the present worth of the lifetime costs by an acceptable margin.

Arithmetically the B/C ratio can be expressed by the following equation:

$$\frac{B}{C} = \sum_{t=1}^{n} \frac{\sum_{t=1}^{n} B_t}{\sum_{t=1}^{n} C_t} \tag{10}$$

n: project life

t: period (year)

B_t present worth of year t benefits

C_t: present worth of year t costs

B/C: Project benefit-cost ratio

However, it must be emphasised that the dimensionless index obtained from the above equation represents just one additional economic indicator and does not reveal the magnitudes of actual costs and benefits. Without further support this parameter alone is certainly not sufficient to allow for an adequate judgement of the projects financial feasibility.

The above statement is strengthened by the conclusions of Goldsmith who clarifies that with regard to the B/C ratio *"…it is not possible to deduce any economic meaning from the ratio other than to say that benefits exceed costs by a given percentage*" (Goldsmith 1993).

2.2.5.2 Payback period and discounted payback period

The payback period of a project is the time required to fully pay for the project, when cumulated cash flows equal (break even point) or exceed the initial costs. The end of the payback period is marked by the year of operation in which the net present value becomes positive (refer to the graphical illustration provided by figure 6).

The investment is considered acceptable if the payback time is less than a specified cut-off period. The payback period as an investment decision criterion has its focus on liquidity rather than long-term cash flows since cash flows beyond the payback period are ignored. The methodology can also be used as an indicator of risk but does not account for the time value of money, the size of the project and does not provide explicit criteria for decision-making.

Private investors do usually have a significant interest in receiving benefits early and therefore the payback period has a more pronounced importance for them than for governmental institutions.

2.2.5.3 Return on Investment ROI

The ROI is defined as the benefit (return) or net income of an investment divided by the total investment cost. The result is expressed as a percentage or a ratio.

A high ROI means that investment returns compare favourably to investment costs. If a project investment does not have a positive ROI, or if there are other opportunities with a higher ROI, the investment should be rejected.

The ROI plainly shows how project returns compare to project costs, but does not represent an appropriate indicator to compare investments, which are characterised by different size and project life. The ROI is also not a suitable parameter to indicate the risk of an investment.

2.2.5.4 Profitability index PI

The profitability index is calculated as the present value of future cash flows divided by the initial investment.

This method can be useful when resources are limited and usually (but not always) leads to the same decision as NVP calculations.

2.2.6 Uncertainty and risk considerations in view of the investment decision

Criteria for investment decisions are critical subjects and calculated feasibility indicators may provide conflicting signals.

Moreover, financing considerations will have to include:

- Risks inherent to the project or the market in which it operates (e.g., commercial project viability, design and engineering risks, completion risks i.e., risk of construction time or construction cost overrun, environmental risks, operating and revenue risks etc.),
- Macro-economic risks (i.e., inflation, interest rate and currency exchange rates etc.),
- Risks that are beyond the control of the developer or contractor such as political risks and force majeure.

The Hydropower Engineering Handbook (Gulliver, Arndt 1991) claims that "*Economic analyses for construction of power production facilities are infamous for their lack of precision.*"

The authors appropriately conclude that "*It would therefore be worthwhile for engineers involved in an economic analysis to have a formal means of expressing the potential inaccuracies of their estimates. […] Feasibility indicators computed in an economic or financial analysis –net present value, benefit/cost ratio, and internal rate of return- all have uncertainties associated with them, and it is useful to evaluate them.*"

The relevance of the above conclusion has been collectively recognised by engineers, project developers and their financial advisers.

This study attempts to achieve the above objective through a methodology that manages uncertain and imprecise input parameters by using an approach, which is based on mathematical theories of uncertainty, specifically the random set theory.

2.2.7 Debt Cover Ratio

Due to the early development stage of the project under investigation in this study the particular financing structure for the project has not yet been defined. Consequently the financial model does not take account of debt cover ratios although they unquestionably represent fundamental indicators for the financial feasibility of an investment project.

The level of debt that can be raised for a project mainly depends on its projected ability to pay interest and repay loan principal installments as they fall due. Debt cover ratios assess the project's ability to service debt with a comfortable margin of safety.

The annual debt service cover ratio ADSCR assesses the Project Company's ability to service its debt from its annual cash flow. It is calculated as the annual operating cash flow (i.e., operating revenues after deduction of operating and maintenance expenses) of the project divided by the debt service of the project over the year (i.e., interest payments and principal repayments).

The minimum ADSCR requirement is a project specific parameter and therefore varies between individual projects. Approximate levels for standard projects are indicated by Yescombe (Yescombe 2006) as follows:

- *1.2 for an infrastructure project with a Project Agreement with no usage risk (e.g., a public hospital or prison)*
- *1.3 for a power or process plant project with an Offtake Contract*
- *1.4 for an infrastructure project with usage risk (e.g., a toll road or mass transit project)*
- *1.5 for a natural resources project*
- *2.0 for a merchant power plant project with no Offtake Contract or price hedging*

The calculation of the project's loan life cover ratio LLCR is based on a similar calculation but has its focus on the term of the loan. It is defined as the projected operating cash flow (commencing with the start of operation until the date when the loan is repaid) divided by the debt outstanding on the calculation date.

Additional information regarding the ADSCR, LLCR and their importance for project evaluation as well as a description of additional parameters of relevance in this context such as project life cover ratio and reserve cover ratio can be found in the studies of Yescombe (Yescombe 2006).

Since the necessary details regarding the anticipated project financing still have to be finalised, the financial model does not analyse debt cover ratios for the described case study.

2.3 Input parameters for hydropower optimisation

2.3.1 Capital cost elements

In order to evaluate whether a project is worth pursuing and for planning of the subsequent budget it is important to balance the cost installation against magnitude of energy output in conjunction with the predicted future value of the energy generated by the plant. For determination of the project's economic merit, the appraisal of its financial implications and arrangement of the project financing, detailed cost estimates are required.

Compared to other sources of energy such as thermal power generation, hydropower plants are generally capital intensive. In addition to the considerable pre-investment costs, hydropower plants are characterised by their high direct investment costs in conjunction with comparably long construction periods where accompanying interest costs contribute significantly to the overall capital investment. These characteristics are also confirmed by the studies of Haga who investigated and described the coordination of hydropower and thermal power (Haga 1992).

Cost estimates for hydro schemes, which are usually prepared by the developer or by engineers appointed to assist him, are specific for each project and each potential site. During early planning stages when extensive site investigations are usually not available cost estimates must be prepared in form of reasonable approximations, which require revision and adjustment at a later stage if the final design includes elements that impact the costs of certain components.

As a result the determination of capital costs has to remain flexible until all works and project related activities are completed.

2.3.1.1 Powerhouse costs (civil works and equipment)

During the initial investigation process of a project (master plan/reconnaissance study, pre-feasibility and feasibility study etc.), detailed and reliable cost estimates are usually not available.

At these project stages it is common practise to use engineering judgement and empirical formulae to estimate costs of hydropower production based on location and physical characteristics of a potential site.

In 1979 (Gordon, Penman 1979), Gordon and Penman analysed costs of hydro plant development depending on the hydraulic characteristics of a site and developed empirical formulae to estimate the cost of electro-mechanical equipment (turbine, speed control and generator).

Based on the statistical analysis of data representing existing HPPs in North America the following generating equipment cost formulae deliver results for hydro power plants of up to 5 MW at existing dams that provide acceptable accuracy at early planning stages when only relative costs are required:

$C_T = 40{,}000 \cdot (kW / H_R)^{0.53}$ for units below 1.5 MW capacity and equipment efficiency of 80%

or alternatively

$C_T = 9{,}000 \cdot kW^{0.7} \cdot H_R^{-0.35}$ for units below 5 MW capacity based on experience from North American projects

C_T: Cost of turbine-generator unit and controls (US $, prices 1978)

KW: Installed capacity in KW

H_R: Rated hydraulic head in m

As illustrated by Gordon and Penman, the two equations provide similar costs and do not differ by more than 15% over a range of 500 to 1.500 kW and over a head of 5 to 15m.

Equipment costs can consequently be approximated as a function of the hydropower plant's capacity and hydraulic head. Based on the fact that project costs per unit of installed capacity decrease with increase of capacity, and that powerhouse costs tend to decrease with increasing head, a methodology was developed to check the estimates of first order of magnitude costs for hydro projects based on statistical analysis of existing hydro project cost data.

In a further study (Gordon 1981), Gordon developed mathematical formulae to estimate the generating station cost C_P of hydro plants for installed capacities of 5 to 1.000 MW and heads of between 10 and 300 m:

$$C_P = 2.1 \cdot 10^6 \cdot MW^{0.92} \cdot H_R^{-0.32 \cdot MW^{0.058}} \quad (11)$$

C_P: Generating station cost (US $, prices 1978)

MW: Installed capacity in megawatts

H_R: Rated hydraulic head in m

The costs C_P for the powerhouse include all civil works, necessary mechanical and electrical equipment, direct and indirect costs, engineering and owner's administration associated with the construction of a surface powerhouse and adjacent step-up substation. Interests during construction are not included. The empirical formulae were developed and are regarded as suitable for first cost approximations and quick feasibility assessments (e.g. to rank a number of sites in order of their economic priority). The data used by Gordon represents the average of conditions at historical projects with large variations in hydro project costs. As a consequence the resulting costs figures must be critically examined and therefore can not necessarily provide a reliable cost estimate. Furthermore the utilised database originating from 1978 is not up to date and the obtained costs require further adjustment to account for specific local conditions of a potential project site and for the inflation rate if the project duration exceeds one year, which is the case for most hydropower projects.

Terms which are not accounted for in the Gordon formula are listed below:

- Remoteness of the project (influencing costs for access roads, grid connection, requirement for a construction camp etc.)
- Climate and weather conditions at the site location (e.g., length of the construction season)
- Project type (run-of-river project, storage with large dams, power plant added to existing dam etc.)
- Design standards applicable for the project
- Effect of inflation

In order to validate the accuracy of costs estimated for a project by taking into account the differences in location, which include difference in labour costs, cost of materials and the cost of engineering and administration, different site location factors were introduced by Gordon (Gordon 1983, Gordon 2003) to further enhance the existing formulae.

The variation in the above conditions can be described by introducing a site factor k and adjustment of the Gordon formula for estimation of powerhouse costs as follows:

$$C_P = k \cdot MW^{0.92} \cdot H_R^{-0.32 \cdot MW^{0.058}} \tag{12}$$

C_P: Generating station cost (US $, prices 1978)

MW: Installed capacity in megawatts

H_R: Rated hydraulic head in m

k: Coefficient to account for project specific conditions based on engineering judgement and subject to escalation

2.3.1.2 Dam costs

The selection of the exact dam location and elaboration of the most appropriate design is a complex procedure that requires a systematic approach and thorough consideration of numerous project specific factors.

The main criteria for selection of the dam design can be summarised as follows:

- Topographical conditions (shape of the valley at the dam site etc.)
- Climatic conditions
- Overall concept and requirements for the river diversion during construction
- Geological and hydro-geological conditions
- Requirements for ground improvement (e.g. grout curtain, jet grouting etc.)
- Availability of suitable construction materials (quality, quantity and cost)
- Seismic conditions and safety considerations
- Construction time
- General layout of the hydroelectric plant including the dams adjacent structures such as powerhouse and spillway, which may also be integrated into the dam
- Design standards applicable for the project

Once a preliminary dam design has been developed it is possible to generate cost curves that can be utilised for optimisation of the reservoirs normal operating level (NOL).

The costs for construction of the dam can then be approximated as a function of the HPPs hydraulic head.

2.3.1.3 Other capital investment costs related to civil construction

a) Civil Structures

Besides the powerhouse and the dam every hydroelectric power plant consists of further structural elements such as a spillway, switchyard, navigation lock, fish pass etc., which are required for its safe and efficient operation.

The decision of which structural elements are required and the elaboration of their most suitable design are subject to project specific criteria. Thus costs for these elements cannot be generalised but need to be assessed by means of project specific case by case investigations.

b) Temporary structures and infrastructure

Expenditures for temporary structures such as cofferdams for river diversion, temporary access roads and retaining structures, site installation, work camp etc. also contribute to the projects capital costs. Although the calculation of these costs needs to be based on individual project requirements it is accepted practise for planning purposes to estimate these expenses as a percentage of the overall civil costs during pre-feasibility and feasibility stage.

c) Environmental mitigation

The construction of a dam and its corresponding reservoir may have severe impacts on the environment within the affected area resulting in potential negative effects on humans, fauna and flora, climate, soil, air and water quality. Socio-economic factors related to impending resettlement requirements and possible effects on cultural heritage also need to be taken into account.

The purpose of environmental mitigation is to avoid or minimise potential negative impacts related to the project implementation.

Costs related to necessary environmental mitigation measures are estimated for each individual project during the course of an environmental impact assessment (EIA), which is nowadays in most countries a compulsory requirement for approval of a hydropower project.

d) Energy transmission

Since most hydropower projects are located in fairly remote areas an adequate budget must be considered to cover expenses for grid connection. One of the most common difficulties in this context is the fact that during early planning stages of a hydropower project a definite decision between alternative options for the grid connection is still pending. Once the exact location of the connection point has been finalised a cost estimation of satisfactory accuracy can be prepared without major difficulties using standard cost estimating methods.

e) Land acquisition

Information regarding expenses arising from the requirement for land acquisition must be obtained from government authorities or local authorities in charge and from private land owners if necessary. The total amount of these costs must be sufficiently accurate at feasibility stage to allow for appropriate consideration of this cost item in the financial project analysis.

2.3.1.4 Costs for engineering and supervision

Compared to other project expenses this cost item has a limited impact on the overall capital investment. At feasibility stage it is therefore legitimate to approximate the costs for engineering, supervision and construction management with 3.0 to 5.0% of the total construction costs, depending on the complexity of the project and related planning activities.

2.3.1.5 Operation, maintenance and replacement costs (OM&R)

Operating costs must cover the entire lifetime of the HPP and need to be estimated at planning stages in order to establish the merit of the economic project proposal. They comprise the total annual expenditure incurred during the operation of a project and can be divided into fixed and variable costs.

While fixed operating costs are purely related to type and size of project, variable operating costs depend on the power plants actual output.

Operating costs include maintenance and refurbishment expenses but exclude capital expenditure for plant replacement.

As experienced in the majority of existing hydropower projects and also described by Haga (Haga 1992) the variable costs for those plants tend to be negligible compared to the fixed costs. As an approximation, the total annual expenditure for operation and maintenance can be expected to be in the range of 1.0-1.5% of the capital value of the plant. These figures are also confirmed by Ravn (Ravn 1992).

For the preliminary estimation of annual operating costs suitable figures can usually be taken from statistical records or from other comparable projects that are already in operation. At later planning stages, which require dependable figures of higher accuracy a schedule of annual manpower and material requirements should be prepared. This estimate must include a reasonable contingency margin to cover unforeseen expenditures and allow for periodic plant overhaul as well as repair or refurbishment of critical components.

Replacement costs occur due to replacements of parts of the plant as a whole or of sections of the plant that have exceeded their life expectancy. These expenditures are items of capital expenditure, which are accounted for separately in the financial project analysis as re-investments in the plant.

2.3.1.6 Insurance, administration and legal costs

Expenses for insurance as well as administrative and legal costs are not calculated in detail but are included in the financial model as a lump sum.

2.3.1.7 Financing costs (debt service)

Discount and interest rates reflecting the opportunity costs of capital are presented in the financial analysis. These opportunity costs are meant to represent the cost of money under the particular circumstances the project is being developed.

2.3.2 Energy Production

The Electric Power P(t) and the installed capacity of the power plant as well as its annual average energy production $\overline{E}_A$ can be calculated as depicted earlier in chapter 2.1.1.

The most important design parameters in this context, which present the focus for the hydropower optimisation are the plant discharge Q(t) and the hydraulic head H_{Net}.

2.3.3 Revenues

Project revenues are usually generated through payments for energy and capacity during the life of the project. Future tariff scenarios applicable for the calculation of project revenues can be based on projections derived from market studies, utility projections, projections of regulatory agencies or current rates subject to estimated inflation rates. Alternatively the relevant figures may be taken from power purchase agreements the project developer has been able to sign with potential industrial consumers by the time of the study.

Since the accuracy of future tariff projections is difficult to predict, the financial project analysis is usually based on higher and lower rates in order to create best and worst case scenarios. This methodology allows for assessing the sensitivity of the project's profitability with respect to variation of rates.

2.3.4 Construction Program and Payment Schedule

The construction program and its related payment schedule directly impact the project's cash flow model. Likewise the findings resulting from the financial analysis may equally effect the selection of the employed construction methods due to the necessity to further optimise the overall program.

2.3.5 Economic life of the Project and salvage value

Power plants of any type consist of several large components that can be described as assets, which play an important role for the financial analysis of the project. Asset lives are used for economic calculations to denote the length of safe and reliable service that can be expected from the plants main components before reaching the end of their useful life having no more than scrap value. Scrap values denote the recoverable sums at the end of the asset life, which may be entered into the cash flow at the end of the period of analysis, if applicable. Residual values represent the undepreciated part of the original cost of an asset and must also be taken into account if the anticipated asset lives exceed the period of analysis and the facility in question presents some tangible value at the end of the study period.

Asset lives selected for the analysis are notional physical lives based on statistical data and experience with completed projects. The asset lives have a reasonable expectancy of being achieved or exceeded, depending on maintenance, actual site conditions, amount of sediment transport and other limiting factors. Due to the complexity of composite hydropower developments and the consequently widely differing asset lives it is recommended to distinguish at least three different groups of project assets comprising civil engineering, electro-mechanical equipment and transmission (Goldsmith 1993).

Guidelines have been developed to indicate typical ranges of asset lives for hydroelectric plants (Länderarbeitsgemeinschaft Wasser 2005) that can be used for the analysis as follows:

• Civil structures	50-80 years
• Hydro-mechanical components	30-50 years
• Electro-mechanical components	25-35 years
• Transmission equipment, overhead lines and cables	25-40 years

The accuracy of the above ranges is confirmed in a recent article by ICOLD chairman Martin Wieland (Wieland 2010).

In order to obtain a meaningful comparison between different power generation schemes (including hydro and thermal power), it is mandatory to take account of equal time periods where satisfactory service can be expected and to aggregate all positive and negative costs occurred. Special calculating methods have been developed to compare projects characterised by different lead times and a different notional life.

The financial model for the preliminary study described in the following chapter is based on a project life of 30 years. Thus re-investments during the period of analysis will not become necessary. Following the recommendations of the publication ‘Leitlinien zur Durchführung dynamischer Kostenvergleichsrechnungen’, released by the German work group LAWA[1] (Länderarbeitsgemeinschaft Wasser 2005), no residual value has been considered for the financial analysis since this practise may lead to inappropriate results. Realistic residual values are extremely difficult to estimate and if the cash flow is discounted to establish its present value the effect of costs and benefits arising in later years becomes greatly reduced.

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[1] LAWA is a German work group on water and related issues concerning the Federal States and the Federal Government representing the Federal Ministry of Environment.

2.4 Exemplary case study using customary methods for hydropower optimisation

2.4.1 Project Introduction

The following case study is based on the feasibility study of a run-of-river hydropower project in Siberia/Russia. The project has been selected because it aptly illustrates possible difficulties related to imprecise input data and model parameters, which may be faced by planning and design engineers during the course of the project evaluation.

For this specific project some of the most visible topics that are leading to uncertainties during the planning process due to the utilisation of imprecise input data can be summarised as follows:

a) Applicable design standards

Since the project development takes place within an international environment, which involves parties and interests from different nationalities and professional backgrounds, it is difficult to clearly identify applicable design standards for planning and implementation of the project. Although the project site of the described hydropower development is situated within Russia and local authorities unquestionably request a design according to Russian standards this may not suffice for all parties involved in the project. In case that potential international investors face difficulties with understanding local design criteria and regulations or raise doubts regarding the suitability of these regulations to satisfy specific project requirements, they may insist that an optional design is being developed by the consultant according to internationally recognised criteria. Alternatively the local design may be verified using international standards or has to be complemented using structural or mechanical elements that are not considered imperative if local requirements are being followed.

The above scenario and resulting conflicts may have a serious impact on the planning activities as well as the design of the plant. The main consequences are uncertainties regarding costs and the overall construction time required, which represent important factors to be taken into account for the financial project appraisal.

b) Selection of final design and working methods

For the consultant as well as civil contractors who are showing interest in project participation it remains difficult to select appropriate construction methods as long as critical decisions regarding the design of the hydropower plant are pending. These uncertainties complicate the cost estimation and are likely to have a negative impact on the financial proposals submitted by civil contractors since more and higher risks are involved. Adequate allowances have to be made in the financial model to cover these risks by incorporating an additional budget or by using alternative scenarios.

c) Cost of labour, equipment and construction materials

Although Russian authorities require the submission of a detailed bill of quantities as well as thoroughly prepared cost estimations for project approval, the accuracy and reliability of such estimations remains inadequate. Most of the uncertainties which are inherent to the planning at this stage of the project development result from the fact that confirmed decisions with regard to major cost items are still pending. The definite selection of the turbine supplier for example, which represents a considerable cost factor for the project, is difficult to finalise without consent of the investor who may still need to be identified. Similarly, construction methods and corresponding costs will highly depend on the contractor selected to carry out the civil construction works.

To account for the lack of confirmed cost parameters it is common practice that consultants include financial allowances to cover the price risk or they design alternative scenarios that represent best, mean and worst cases.

d) Construction program

The detailed construction program mainly depends on the selected design elements and corresponding construction methods. However, other factors such as the amount of available resources, delivery schedules, stipulated approval procedures and other constraints may also have a major impact on the projects construction program. A preliminary construction schedule can be finalised once all critical decisions related to this context have been made.

The length of the construction period is a crucial element for the financial model and can severely impact the profitability of the project due to the following reasons:

- The length of the construction period determines the start of plant operation, beginning with the commissioning of the scheme and extending to the notional end of its life. The start of plant operation consequently defines the commencement of revenue generation. In order to maximise the profitability of the plant a minimisation of the required construction time must be one of the key targets of the planning works.
- Construction costs can usually be optimised if the length of the construction period is kept a short as possible.
- Interests during construction can be minimised by reducing the construction time required.

The above findings are strengthened by Goldsmith with the following conclusion:

"*The investment phase must be clearly kept as brief as possible, not only for minimising construction costs and keeping interest charges and cost escalation during construction in check but also for effective project execution*" (Goldsmith 1993).

Uncertainties about the length of the construction period will have an immediate impact on the financial model. The lack of precise and reliable input data may lead to inaccurate financial project assessments, which can severely affect conclusions for the profitability of the project.

e) Power market

Power Market Studies are necessary to describe the long term market and the competitive situation starting with the time of commissioning of a new hydropower development. The study must convincingly provide potential investors with the information they need to make an investment decision. In order to achieve this requirement, the study must provide transparent and defensible assumptions on future demand (i.e. potential customers) and future pricing.

Two main difficulties associated with describing the market for the investigated hydropower development have been observed:

- Power market reforms have been initiated in Russia and the study must predict future pricing in a market that does not yet exist.
- A significant increase in demand is predicted for Siberia, primarily due to several large industrial users, which is difficult to verify and estimate.

During the last decade of the 20th century the Russian energy system was characterised by the complete absence of competition in the wholesale market without the choice of supplier for consumers. The electricity sector was highly regulated and controlled by a number of state bodies playing different roles. Electricity prices were regulated without correlation between the cost of generation and the end-price paid by the customer. A significant level of subsidy existed for all customer groups in form of lower-than-cost tariffs or lower-than-cost recovery of infrastructure required for generation, transmission and distribution of electricity. A reform plan for the Russian power sector was announced by the Russian Government in June 2001 to ensure that supply continued to meet growing demand by creating conditions that were supposed to encourage investment in new capacity and to foster greater efficiency of both production and consumption. The implementation of the reforms is still ongoing, with the objective that tariffs will eventually rise to fully cost-reflective levels, ending cross subsidies and allowing free markets to operate where possible.

Furthermore, very moderate electricity prices have led to inefficient consumption of electricity in Russia. Although electricity consumption per capita is low by western standards the Russian residential sector consumes much more electricity than the residential sectors of other countries with the same GDP. Incentives are planned for more efficient use of electricity and as a consequence demand responses can be expected as a result of real price signals. This demand response refers to changes in the quantity demanded by consumers confronted with variations of the market price.

It has to be emphasised that the model which is used as a basis for the market study does not consider this elasticity of demand. In order to correctly evaluate the influence of price increases on the electricity demand in Russia the model would have to include the price elasticity of demand.

The new Russian wholesale market will also include capacity trading, which is expected to ensure reliable and sustainable electricity supplies. Separate payments for electricity and capacity shall be introduced. When selling capacity, suppliers are obliged to maintain their generation equipment in proper working condition in order to be always ready to produce electric power. Capacity payments depend on the fulfilment of the suppliers' obligations. These mechanisms are aimed at increasing reliability of the energy system in conditions of growing electricity demand.

f) Tariff projections

Since September 2006 new rules for the wholesale electricity and capacity market have been introduced within Russia, which change the whole system of relations between buyers and sellers of electric power and capacity. Further steps towards a free market for trading electric power have been taken.

A time frame for changing from a wholesale market at regulated prices to an electric power market with free market pricing has been set defining continuous price adjustments within stipulated intervals. From 2011 onwards the wholesale market target model should be in place and electric power should be traded at free market prices.

However, it remains difficult for the planer to prepare accurate and dependable tariff forecasts since the implementation of the reform plans is a complex and highly unpredictable process.

In view of the above uncertainties it is necessary to base the financial project appraisal on several alternative scenarios for describing future tariff structures and to estimate potential project revenues.

g) Assumptions and estimations covering imprecise input parameters

Due to the lack of confirmed information it is inevitable that appropriate assumptions have to be made for certain parameters and to estimate figures that usually require individual in-depth studies during the course of the project evaluation.

However, the necessary approximations influence deterministic and probabilistic calculations to the same extent and consequently do not impact the conclusions that can be drawn from the comparison between the two methodologies.

With regard to the assessed hydropower design optimisation, the aspects of relevance in the context of uncertain input parameters can be briefly summarised as follows:

- The flow measurements available from the relevant river section only consist of average monthly values. For optimisation of the design discharge with a high level of accuracy, hourly or at least daily discharge figures would be required, since the use of monthly average flow rates leads to a systematic underestimation of the design discharge and the installed capacity. Monthly averages are acceptable at feasibility stage of a project but may lead to inaccurate estimates for the energy production.
- The future operating modes of the HPPs located upstream, which are presently either projected or already under construction need to be clearly stipulated, since these parameters will have a major impact on the design of the investigated HPP due to the limited storage capacity of its comparably small reservoir.
- In cases of run of river schemes, the investigations of Ravn estimate that a design based on monthly values might overestimate the energy production by as much as 10-20% (Ravn 1992).
- Hourly, daily, weekly, monthly and annual characteristic load curves are not available to assess the demand for future peaking capacity, which is a requirement for the accurate determination of the installed capacity for the new power plant. Furthermore the conditions for the payment of a capacity fee need to be defined.
- Losses and efficiency factors for connection to the grid have not been considered since the exact determination of the connection point to the grid had not been decided prior to completion of the feasibility study.
- A definite confirmation regarding which party will have to carry the responsibility for the expenses related to reservoir preparation and grid connection could not be obtained. According to the information obtained from local authorities, costs for the reservoir preparation are to be borne by the government and have consequently not been taken into consideration for the financial project analysis.

2.4.2 Design optimisation

2.4.2.1 Hydropower Parameter

The inflow for the investigated project site is composed by the discharge gauged at the HPP situated upstream plus monthly discharges for the intervening drainage area. The combined values, which present the total natural inflow for the project, are presented in table format in section A1 of the appendix.

Based on these natural monthly discharge values a flow duration curve can be generated. To calculate the plant's potential for power generation and to simulate the operation of the scheme, adequate discharge deductions are made in order to account for losses related to ship lock and fish pass operation during applicable periods. The necessary adjustments consist of discharge deductions for fish pass operation from March until end of October while ship lock operation has been considered for a period of six months starting at the beginning of May.

The flow duration curve representing the rivers usable discharge is depicted below in figure 7 together with alternative design discharges for the plant and their corresponding exceedance probabilities.

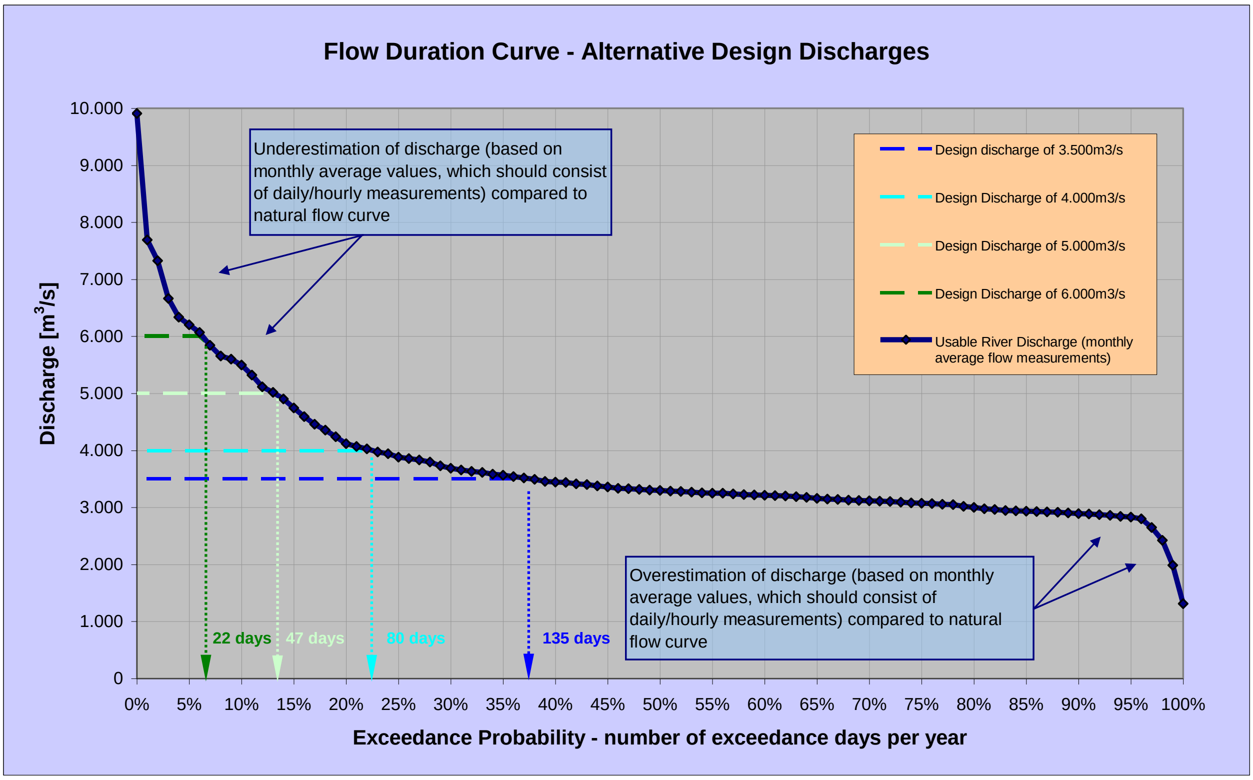


Figure 7: Flow duration curve at project site based on monthly average values

Based on the explanations given in chapter 2.1.2, the above diagram indicates that for the HPPs design optimisation a design discharge between 3.500m^3/s and 6.000m^3/s appears to be appropriate. The simulation of the plant operation will consequently focus on discharges within this range.

The computation of the tailwater rating curve is necessary to determine the gross hydraulic head of the hydropower development. Based on estimated roughness values for the riverbed and the riverbanks the curve is generated by means of the 1D- hydraulic model HEC-RAS.

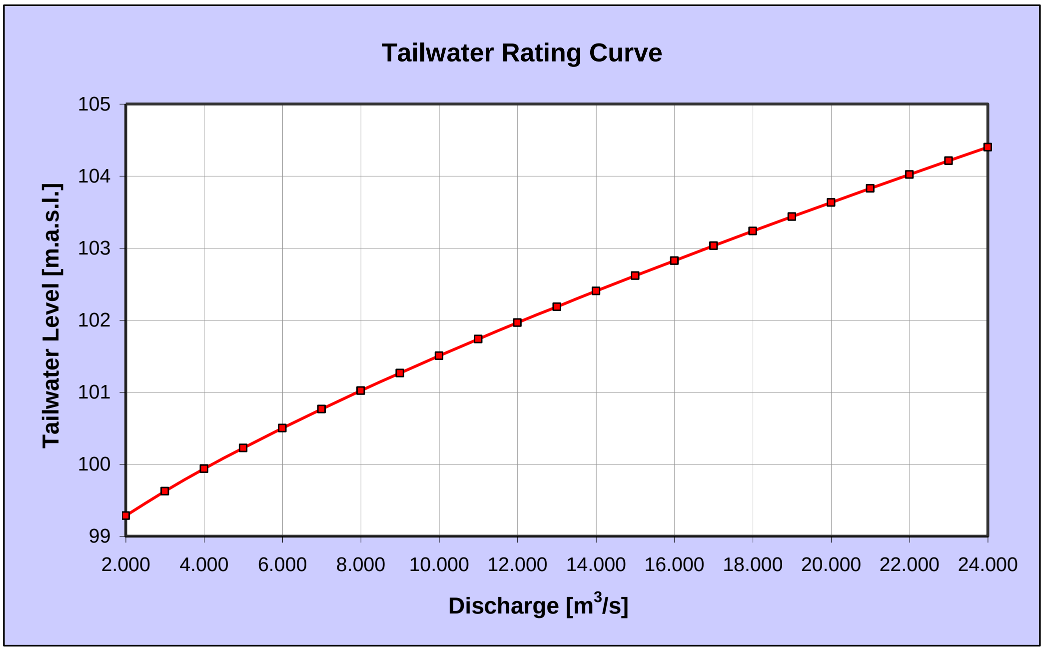


Figure 8: Tailwater Rating Curve

The gross hydraulic head of the hydropower development can now be calculated as the reservoir's normal operating level minus the tailwater elevation at the corresponding discharge.

The design discharge Q_d has been preliminary chosen at 4,200 m^3/s and the following elevations are selected as characteristic values for subsequent calculations:

Discharge m^3/s		Tailwater elevation m.a.s.l.
Q_{min}	1,321	99.0
Q_d	4,200	100.0
Q_{10000}	24,300	104.5

Table 1: Characteristic tailwater elevations

Hydraulic losses related to the water conduits to and from the turbines, which arise at the inlet, trash rack, penstock and outlet of the powerhouse are taken into account with 0.30m at full design discharge.

The E&M efficiency (turbine, generator and transformer) is considered with a total efficiency factor of 0.91 as described earlier in chapter 2.1.6.

Based on varying design discharges and different normal operating levels the hydropower parameters of the investigated alternative schemes can now be calculated. A summary of possible design scenarios is shown in table 2.

Discharge Qd	**NOL 123m a.s.l.**		**NOL 125m a.s.l.**		**NOL 127m a.s.l.**		**NOL 129m a.s.l.**	
m^3/s	Capacity MW	Energy TWh/a	Capacity MW	Energy TWh/a	Capacity MW	Energy TWh/a	Capacity MW	Energy TWh/a
2500	519	4.5	564	4.8	609	5.2	654	5.6
2850	589	5.1	640	5.5	691	5.9	742	6.4
3200	658	5.5	716	6.0	773	6.5	830	7.0
3550	727	5.8	790	6.3	854	6.9	917	7.4
3900	795	6.0	865	6.5	934	7.1	1004	7.6
4250	862	6.1	938	6.7	1014	7.2	1090	7.8
4600	929	6.3	1011	6.8	1094	7.4	1176	7.9
4950	995	6.3	1084	6.9	1172	7.5	1261	8.0
5300	1061	6.4	1156	7.0	1251	7.5	1345	8.1
5650	1126	6.5	1227	7.1	1328	7.6	1429	8.2
6000	1191	6.5	1298	7.1	1405	7.7	1513	8.2

Table 2: Hydropower characteristics of investigated project alternatives

2.4.2.2 Project costs and revenues

a) Powerhouse costs

Based on local cost estimates and completed Russian hydropower projects the cost curves developed by Gordon (refer to chapter 2.3.1.1) are calibrated and adopted. The resulting project specific cost curves representing powerhouse construction costs in accordance with the investigated project design alternatives are displayed in figure 9.

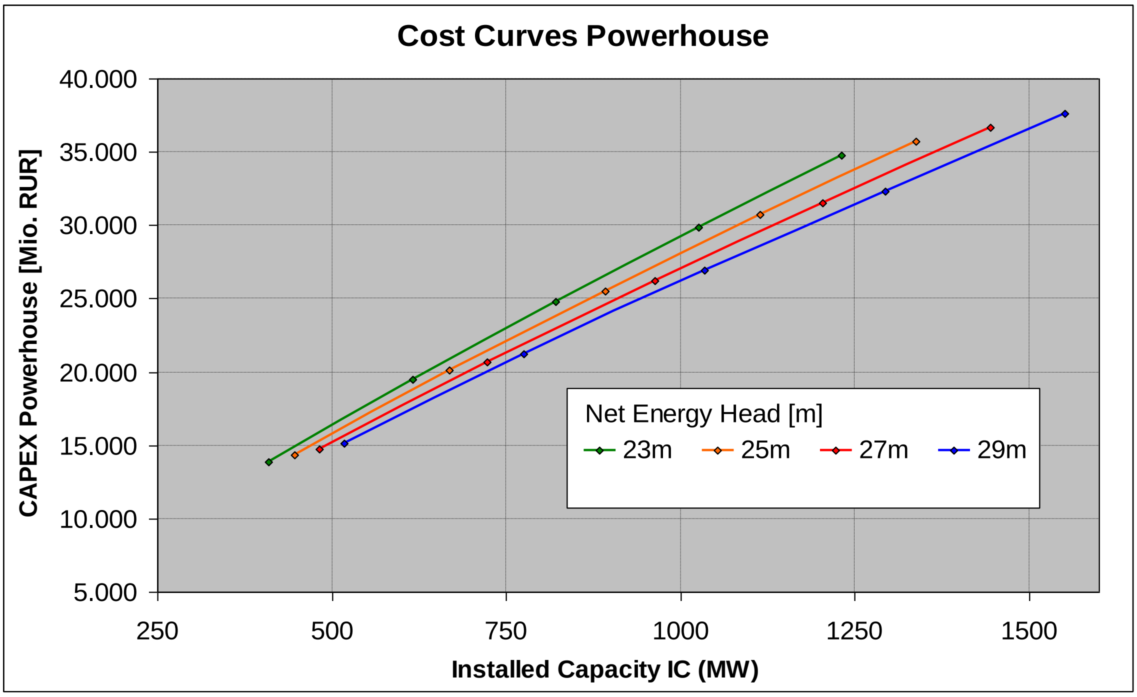


Figure 9: Cost Curves for alternative powerhouse dimensions

b) Dam costs

Costs for the dam have been estimated based on the technically and economically preferred design option at headwater levels of 123, 125, 127 and 129 m.a.s.l. The generated cost curve, which also includes costs for the main dam, cofferdams and lateral dams is show below:

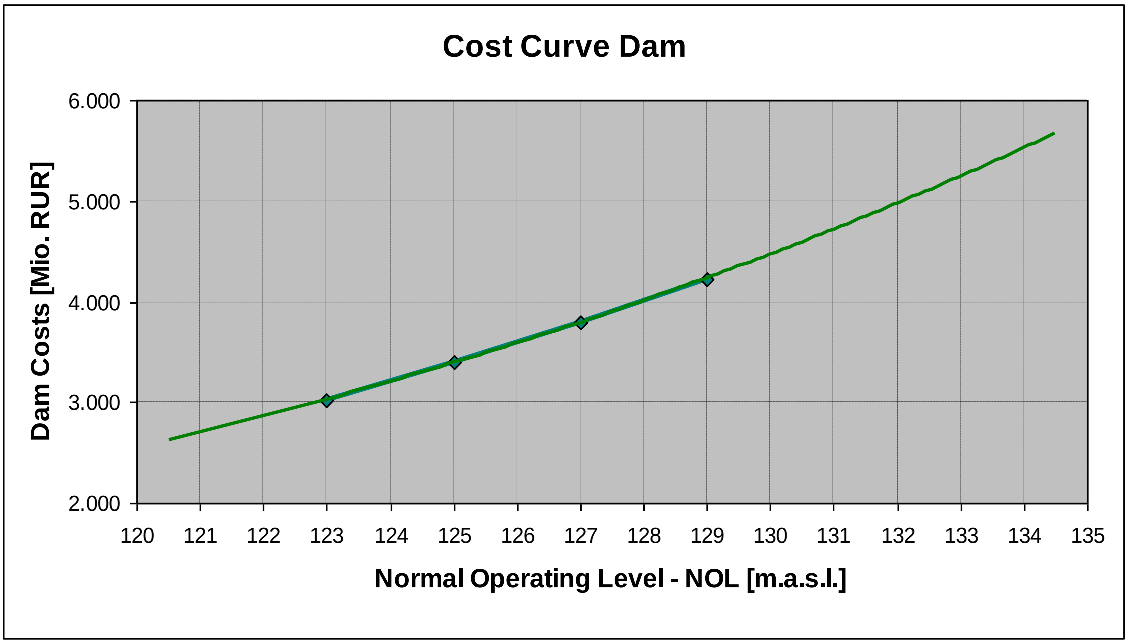


Figure 10: Estimated costs for alternative dam elevations in million Rubles

c) Other capital costs

Costs for the following components were taken into consideration using constant figures independently from the selected headwater level:

Other Costs	**Mio. RUR**
Spillway	**4,621**
Ship lock	**5,289**
Energy transmission	**4,344**
Fish pass	**55**
Temporary structures	**570**
Site installation	**2,289**

Table 3: Other civil construction costs in million Rubles

d) Operation and maintenance costs

The annual expenditures for operation and maintenance are taken into account with 1.5% of the overall capital costs for the project.

e) Project Revenues

Future tariff scenarios applicable for the project are extremely difficult to predict due the still ongoing process of liberalisation of the Russian energy market. Since the exact model of future remuneration still needs to be finalised and implemented, a mixed energy and capacity tariff has been used for the subsequent project optimisation. The projected scenario is based on extensive research and market studies carried out by the consulting engineers, Russian as well as European energy suppliers and international financing organisations. Furthermore, assessments carried out by the Russian government have also been incorporated into the projected tariff scenario.

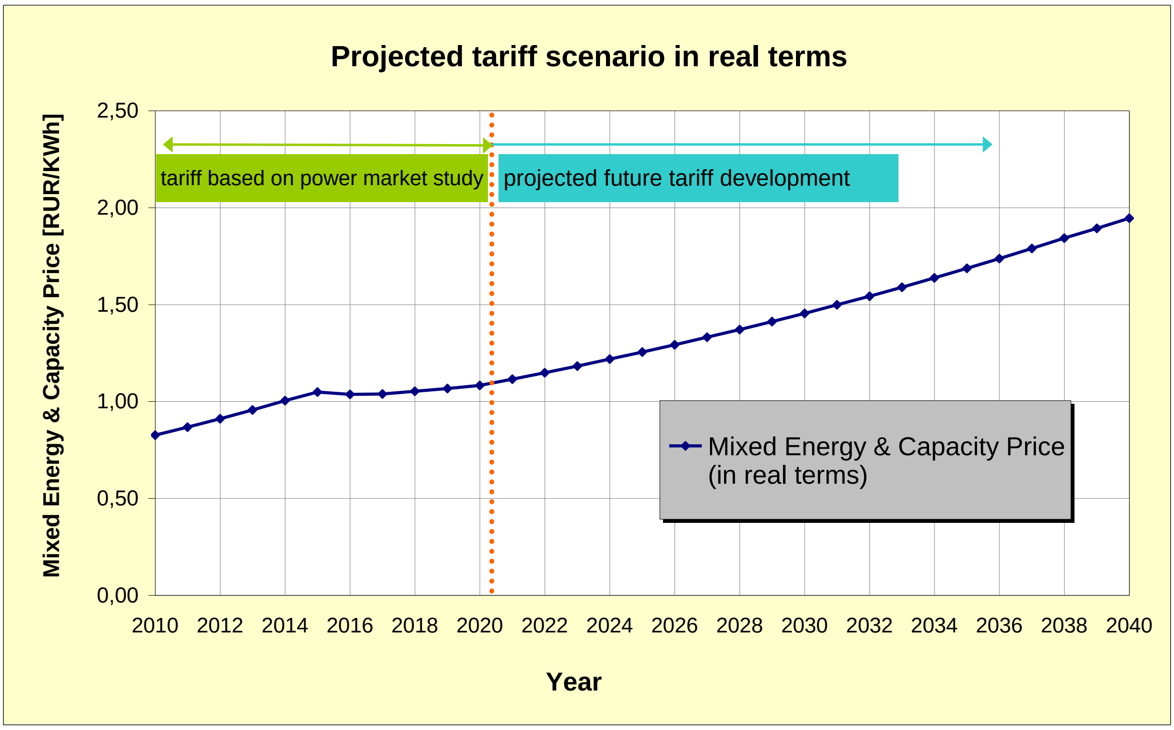


Figure 11: Projected energy and capacity prices during the economic project life

2.4.2.3 Cash flow analysis

A cash flow analysis is performed based on 4 alternative normal operation levels and 11 different design discharges of the hydropower plant. The assumptions for the cash flow model can be summarized as follows:

- Headwater levels: 123 m.a.s.l., 125 m.a.s.l., 127 m.a.s.l., 129 m.a.s.l.
- Investigated design discharges:
  Q=2.500, 2.850, 3.200, 3.550, 3.900, 4.250, 4.600, 4.950, 5.300, 5.650, 6.000 m^3/s
- Investigation period of 30 years (corresponding to the project life)
- Construction period of 5 years
- Interests during construction are not considered
- Discount rates of 6%, 8% and 10% (in real terms)

The net present value (NPV) is calculated for each combination of design discharge and normal operating level based on three different discount rates (in real terms). Results are illustrated in the following figures below.

NPV at varying normal operating levels and design discharges (discount rate of 6%):

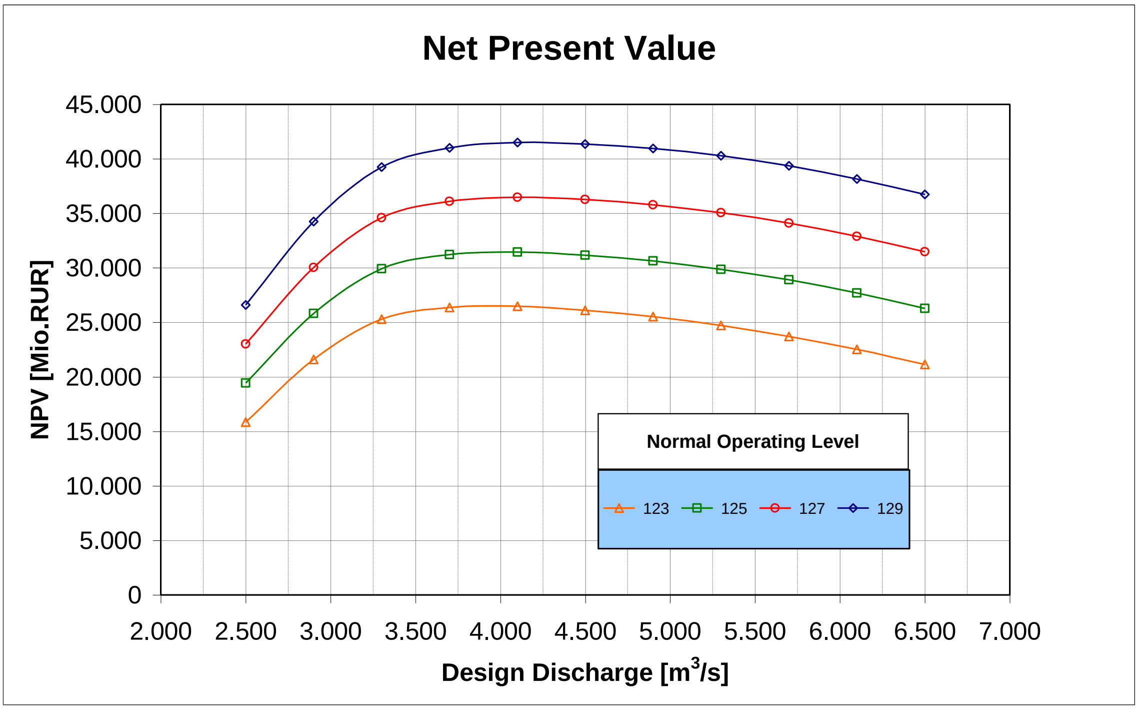


Figure 12: Net present values (discount rate for DCF of 6% in real terms)

NPV at varying normal operating levels and design discharges (discount rate of 8%):

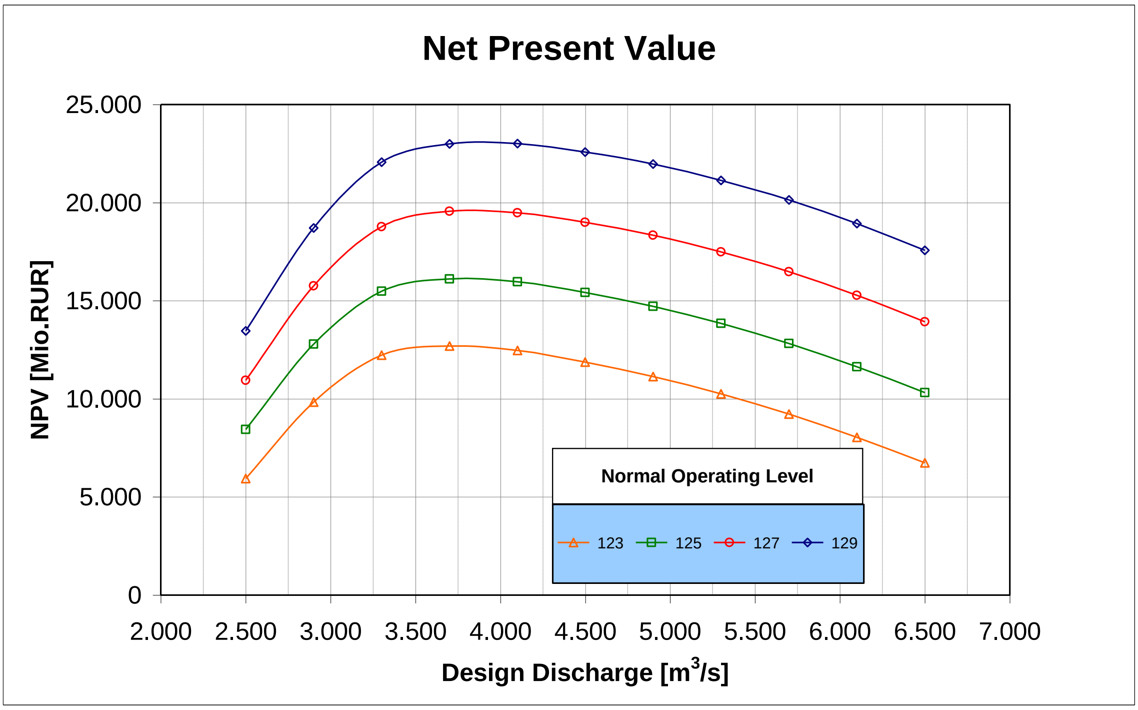


Figure 13: Net present values (discount rate for DCF of 8% in real terms)

NPV at varying normal operating levels and design discharges (discount rate of 10%):

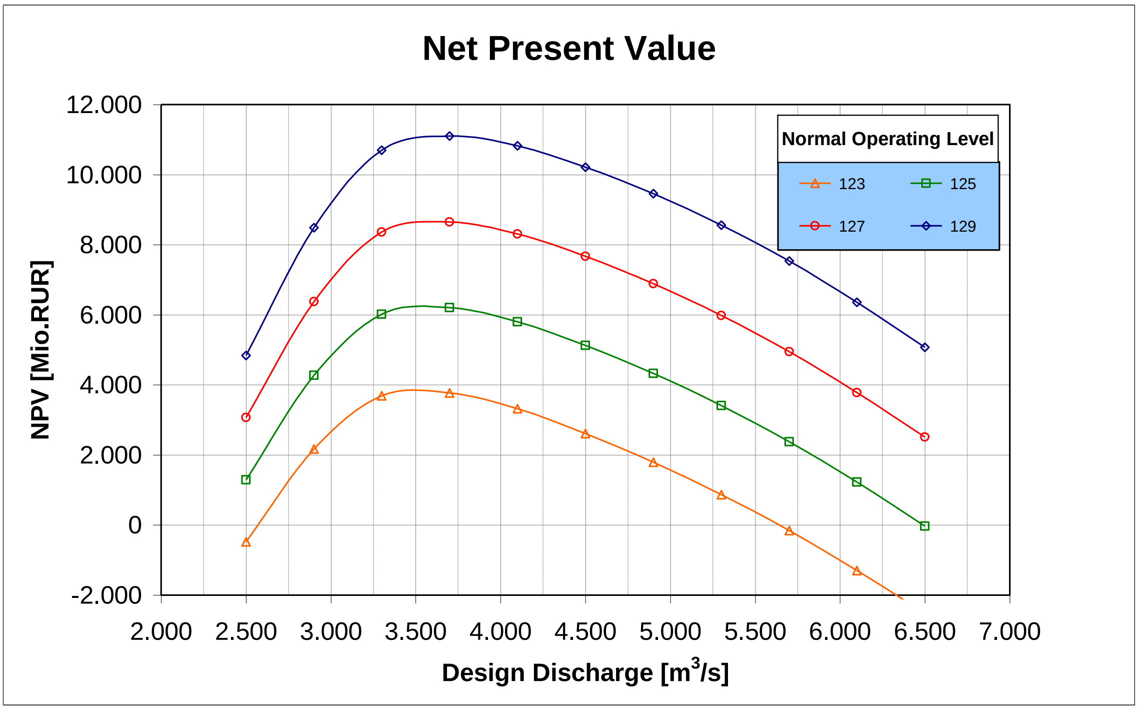


Figure 14: Net present values (discount rate for DCF of 10% in real terms)

For reasons explained in chapter 2.2 of the study, the net present value must be regarded as the most meaningful indicator for the economic merit of the project. Other financial feasibility indicators such as Internal Rate of Return and benefit cost ratio are also calculated but only used as secondary decision criteria since these parameters are of limited suitability for the comparison of projects with different investment costs.

Even if these parameters are not considered appropriate to represent the main criteria for determination of the project's optimum normal operating level and installed capacity they still denote valuable supplementary information to verify and further support the decision making.

The described calculations mainly indicate the following:

- Higher normal operating levels of the headwater lead to a higher economic efficiency for the project.
  For normal operating levels (NOLs) above 127m it is difficult to prove the existence of a sufficient future energy demand that guarantees adequate remuneration. The selected maximum NOL is therefore limited to 127m since it appears difficult to justify the additional expenses related to a higher reservoir operating level.

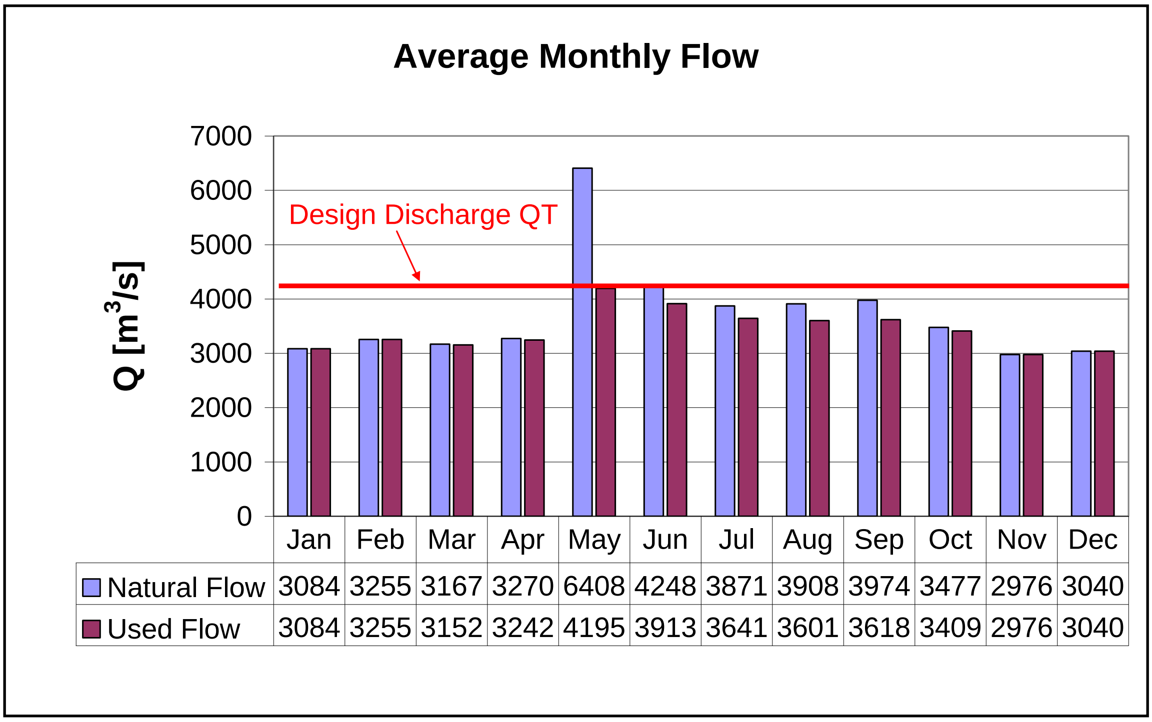
- The optimum design discharge based on the NPV index is between 3.750 m^3/s (DCF=10%) and 4.250 m^3/s (DCF= 6%).
  Due to the use of monthly discharges these results constitute low boundaries compared to the expected real conditions.

2.4.2.4 Conclusions for the project design

Based on the existing investigations, the hydropower parameter optimisation leads to the following main characteristics of the HPP:

- Design discharge Q_T= 4.200 m^3/s
- Number of Units n=8
- Normal Operation Level NOL= 127 m.a.s.l.
- Tailwater Level at Q_d TWL=100.0 m.a.s.l.
- Installed Capacity P= 1.000 MW.
- Annual Average Energy Production E_T=7.2 TWh
- Normal Utilization hours NUH= 7.200 h.

The final decision with regard to the installed capacity will largely depend on remuneration for the installed capacity. Attractive future remuneration for peaking capacity on the day-ahead capacity market will favor the implementation of additional generating units to increase the installed capacity accordingly. Therefore provisions should be made to allow for a future extension of the scheme by installing two additional generating units, increasing the design discharge to 5.250 m^3/s and leading to an installed capacity of 1.236 MW.



	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
🟦 Natural Flow	3084	3255	3167	3270	6408	4248	3871	3908	3974	3477	2976	3040
🟪 Used Flow	3084	3255	3152	3242	4195	3913	3641	3601	3618	3409	2976	3040

Figure 15: Natural and theoretically usable monthly flow (average for 45 year period)

The design discharge of 4.200 m³/s leads to an exceedance probability of 19 % or 69 days per average year. Since daily discharges fluctuate around the monthly discharge value, the exceeding probability of the real hourly and daily flows will be higher.

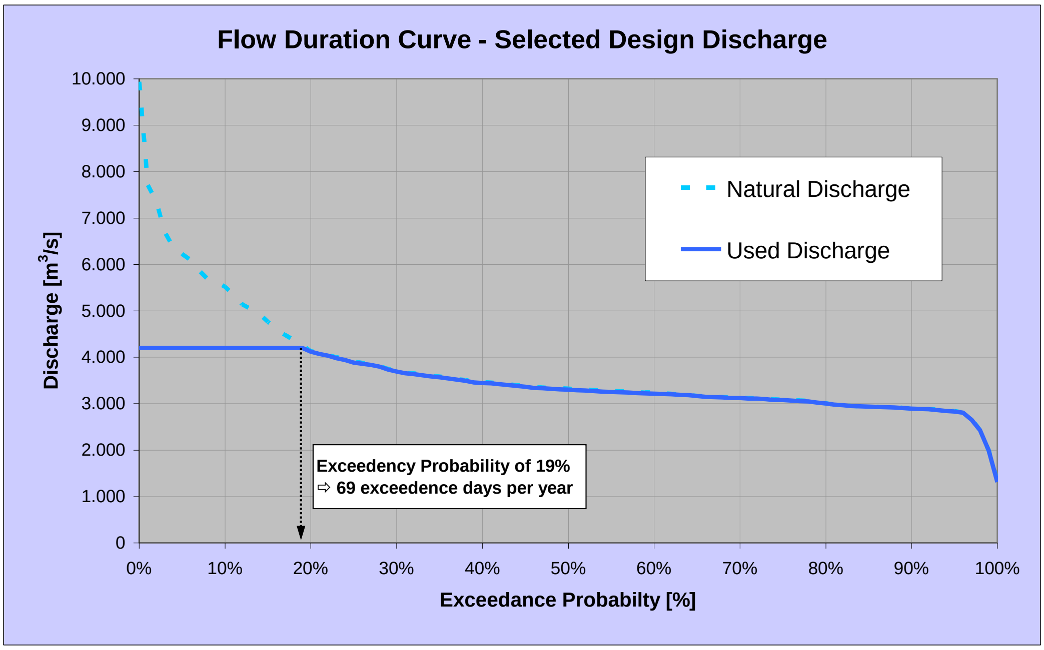


Figure 16: Used discharge duration curve (based on 45 year period)

The capacity factor, defined as the ratio of the average output to the installed capacity over a period of time, will be 0.80 for the proposed scheme. By means of a load diagram the relationship between natural flow, turbine flow, net energy head, power potential and produced power can be illustrated as follows:

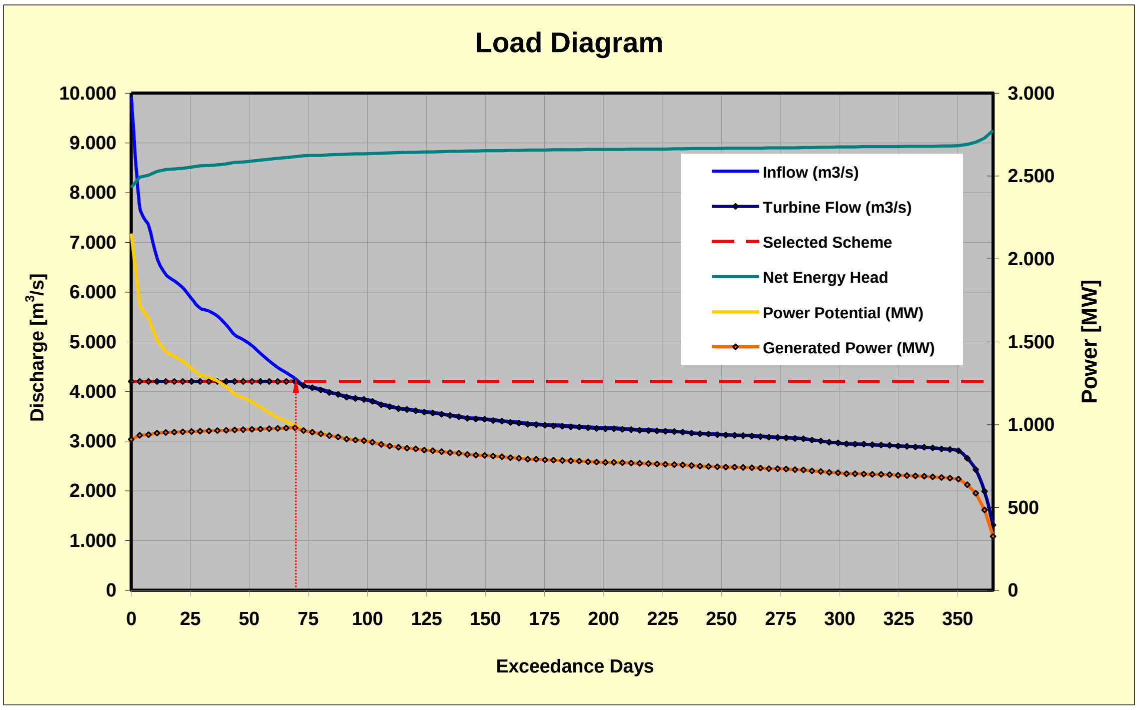


Figure 17: Used discharge duration curve (based on 45 year period)

2.4.3 Discussion of methodology and results

Although the described deterministic methodology represents a commonly accepted and widely used standard for project analysis, this approach is characterised by various deficiencies, which can be briefly summarised as follows:

- Existing uncertainties and information deficits related to input parameters used for the analysis have not been taken into consideration in a systematic and satisfactory manner.
- Different sources for input values and expert opinions cannot be utilised as input parameters for the project analysis.
- The possible range of results and ensuing consequences for the project development can only be vaguely estimated by means of selected scenarios, which are chosen on subjective grounds.
- The methodical calculation of a factual worst case and best case scenario is not included as part of the project analysis.
- The deterministic result of the calculation can not sufficiently describe the actual project situation and a detailed interpretation of the analysis is required to allow for responsible decision making.
- The information available about the design and engineering concepts that are to be evaluated cannot be taken into account without additional unjustified hypothesis.
- It does not appear reasonable to reduce the interval of confidence to a single central value and to force the statistics of intervals to a precise probability distribution. More information can be transported if a range of values is not condensed to a single figure.
- The analysis does not illustrate the extent of uncertainty related to individual input parameters and therefore cannot indicate to what extent the inherent imprecision impacts the result.

In order to account for the above listed limitations and to allow for responsible decision making a meaningful project assessment should always be accompanied by a comprehensive risk assessment.

2.4.4 Risk Assessment

Risks associated with the planning and implementation of hydro electric power projects can have a strong impact on the technical or economical project feasibility and the corresponding capital expenditures. The identification, analysis and management of project risks and their possible financial impacts must therefore be considered as an integral part of the project development including the phases of project implementation as well as operation.

Precondition for a successful financial closure is the comprehensive identification of all relevant project risks and the evaluation of their related financial impacts. In order to ensure an efficient risk management and successful risk mitigation, adequate concepts must be established based on the idea of a balanced sharing of project risks between the parties involved. Project risks must be allocated appropriately to ensure that they are manageable by the party accountable for the task. A responsible risk management concept has to consider the ability of all project partners to manage and mitigate risks at optimum costs. This should result in the allocation of each risk to the partner who possesses the highest ability to manage and mitigate these risks.

Complex infrastructure projects such as hydropower developments require the due consideration of a wide range of project risks reaching far beyond commonly renowned topics, such as geological and geotechnical conditions, cost overrun and delay of completion. In the context of risk assessment and risk mitigation subjects such as exchange rates and interest rates, changes in the financial or political environment, projections for energy demand, changing energy market conditions etc. represent equally important factors that need to be considered in view of the investment decision.

The common initial approach distinguishes between two broad risk categories for the purpose of risk identification:

- General country risks refer to factors such as a country’s economic situation and growth, its political environment, its legal system and its ruling regulatory framework. General Risks are subject to macro-economic management and are therefore within the responsibility of the government.

- Project Specific Risks relate to the project life cycle, namely the planning, development, construction, operation and maintenance of the project.
  Such risks strongly depend on the performance of the contractual partners and are usually within control of the designer, developer, contractor and/or operator.

In order to illustrate the procedures required for a comprehensive risk assessment the main steps of the risk management process are depicted below:

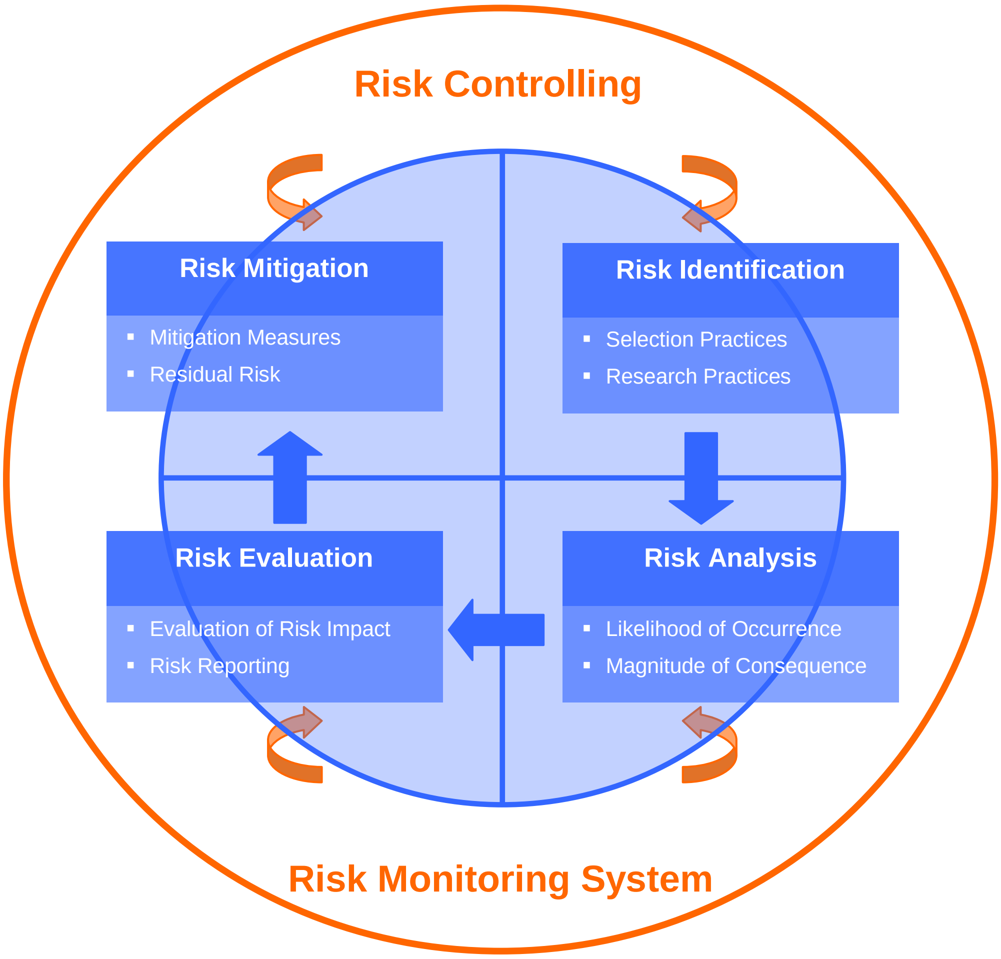


Figure 18: Risk assessment procedure

Appropriate measures for risk mitigation are always project specific and need to be selected according to the individual requirements.

In the context of risk evaluation it is a useful practice to present risks using a risk reporting landscape. This type of illustration categorises individual risks by their likelihood of occurrence as well as the magnitude of possible consequences and can be used as a basis for risk identification and the selection of appropriate risk mitigation measures.

Based on this concept a similar proposal will be introduced and recommended in chapter 5 of the study. The visualization of uncertainty levels illustrates identified areas of uncertainty and their potential impact on the feasibility of the project in order to support risk-informed decision making.

3 UNCERTAINTY AND PROBABILISTIC METHODS

3.1 Problem definition and objective

The traditional attitude toward uncertainty in science and engineering demands that scientific knowledge should be expressed in precise numerical terms. While ordinary life without uncertainty is unimaginable, the spirit of science prior to the 20th century stipulated that imprecision and other types of uncertainty were incompatible with science and should be completely eliminated. This preoccupation with precision and certainty prevented profound studies of the concept of uncertainty until the emergence of computer technology, which made it possible to handle increasingly complex problems. Fundamentally new concepts and their associated mathematical theories became necessary since deterministic systems, which were once regarded as ideals of scientific knowledge, proved to be too restrictive. These developments substantially enlarged the framework for formalisation of uncertainty and non-deterministic systems are now far more prevalent in contemporary science.

The concepts of uncertainty and information are tightly interconnected. As revealed by Klir (Klir 2006) "*uncertainty in a problem-solving situation can be viewed as a consequence of information deficiency pertaining to the system within which the situation is conceptualised*". Thus information is viewed as the capacity to reduce uncertainty. Various manifestations of information deficiency can be distinguished and will be explained in further detail.

Within the previous chapters it has been illustrated that a hydropower investment decision must be based on the conclusions drawn from the technical and economic project appraisal. The appropriateness of the investment decision therefore highly depends on the availability of suitable input data and the quality of the parameters utilised for the analysis.

Statistical data such as hydrology and flow measurements are affected by inherent uncertainties to the same extent as technical parameters defining material properties or existing ground conditions. Imprecise data may equally impact economical factors such as unit prices, anticipated costs of capital or projected tariff scenarios, which represent the basis for calculation of capital investment and project revenues.

Existing uncertainties and limitations of the modelling process must therefore be openly addressed and made accessible to responsible assessment by all project participants. During the design process a mathematical formalisation is required to provide a proper understanding of the effects inherent uncertainties may have on the feasibility of the project under investigation.

Current engineering practice frequently neglects the important aspect of uncertain input parameters or does not cover the subject in a satisfactory manner, although scientific tools have been developed over the past decades that allow for a rational description of uncertainties of all kinds, ranging from model uncertainty to data uncertainty. The ignorance of uncertainties can severely affect the project assessment and lead to an incorrect judgement regarding a projects technical or financial feasibility.

The utilisation of a probabilistic approach or specifically ‘imprecise probability’ allows and also forces the engineer to address uncertainties and enables planers to recognise and judge the possible range of outputs predicted by the probabilistic model. Further to an objective formalisation of vague data it facilitates the utilisation of additional sources of information by formalising expert knowledge.

When dealing with complex problems, such as the economic evaluation of a large hydropower project, it is therefore indispensable to model inherent data uncertainty and study its propagation through the model.

The importance of the above is repeatedly highlighted by Oberguggenberger in the context of analysing uncertainty in civil engineering (Oberguggenberger 2005):

“*An adequate understanding of the influence of input parameter variability on the output of engineering computations requires that the uncertainty itself is captured in mathematical terms. […] This input is in turn processed numerically and should deliver an output describing the behaviour of the structure under investigation plus an assessment of the output uncertainty. Thus, models of the data uncertainty should reflect and incorporate the level of information available on the data and must be able to propagate it through numerical computations and deliver an output whose uncertainty is formulated in the same terms*”.

3.2 Classification of imprecise input data

During the previous decades, the significant progress in computational power has enabled the scientific and engineering community to intensify their studies into the scope of uncertainty. As IT systems became computationally better equipped to handle complex analyses it is now possible to examine and model the full scope of uncertainty in more detail and greater depth. As stressed earlier uncertainty and information are interconnected and existing manifestations of information deficiency determine the type of associated uncertainty. The information may be fragmentary, incomplete, imprecise, unreliable, vague, or even contradictory.

Two fundamentally distinct forms of uncertainty must be recognised. Uncertainties that may arise in the context of project evaluation are usually of dual nature and can be described using the definitions developed by Helton.

Aleatory uncertainty

"*Aleatory uncertainty describes the type of uncertainty which results from the fact that a parameter can behave in random ways*" (Helton 1997).

Commonly used terms for aleatory uncertainty are also stochastic uncertainty, objective uncertainty, type A or type I uncertainty, irreducible uncertainty or variability.

The term aleatory is used to emphasise its relation to the randomness in gambling and games of chance. Aleatory uncertainty is associated with variability in known (or observable) populations and cannot be reduced by further empirical study. Typical sources of aleatory uncertainty are environmental stochasticity, inhomogeneity of materials etc. Oberkampf et al. define aleatory uncertainty as "*the inherent variation associated with the physical system or the environment under consideration*" (Oberkampf et al. 2004).

Epistemic uncertainty

"*Epistemic uncertainty defines the type of uncertainty which results from the lack of knowledge about a parameter or about a system and is a property of the analysts performing the analysis*" (Helton 1997).

Epistemic uncertainty describes the incertitude originating from scientific ignorance, lack of observability, measurement uncertainty, censoring, or other lack of knowledge.

It is also known as subjective uncertainty, type B or type II uncertainty, reducible uncertainty, state of knowledge uncertainty or ignorance. In contrast to aleatory uncertainty, epistemic uncertainty is not an inherent property of the system and can be reduced through additional empirical effort. Gain of information about the system or environmental factors can consequently lead to a reduction of epistemic uncertainty.

Typical examples for aleatory uncertainty in the context of hydropower engineering are rainfall events and corresponding river discharges. The natural variation of this data is inherent and cannot be influenced, which explains the significant advantage that a storage reservoir presents for the operation of the hydropower plant.

If the uncertainty is related to inaccurate parameter measurement or if statistical data can only be made available in limited or fragmentary amounts, the resulting uncertainty must be termed epistemic. In this case quality and quantity of the data could potentially be improved through optimised measuring techniques and enhanced modelling systems.

In the context of financial project analysis the dual nature of uncertainty can be observed through variations of anticipated construction costs or tariff projections, impacting project costs and revenues. This unavoidable aleatory element of uncertainty cannot be eliminated, as opposed to cost estimating methods and techniques employed for tariff projections, which may be further improved and optimised in order to reduce the epistemic uncertainty of the modelling process to the highest extent possible.

Since the concepts of information and uncertainty are intimately related, Klir and Wierman concluded that “*various information deficiencies may result in different types of uncertainty*” and established uncertainty as a multidimensional concept (Klir, Wierman 1998). Randomness is often referred to as objective uncertainty and describes the natural variation of observations. Imprecision is frequently referred to as subjective uncertainty and can result from incomplete or lacking information, as well as from incomplete assessment (Walley 1991). In tolerance analysis imprecision refers to the lack of knowledge about the value of a parameter and is expressed as a crisp tolerance interval. This interval represents the set of possible values of the parameters. Fuzziness differs from imprecision since it is characterised by an interval that has no sharp boundaries (Dubois, Prade 1994).

In summary, probabilistic models can be defined as approximations where input parameters are known only imprecisely.

The vagueness inherent to modelling procedures for engineering applications, which can be described by means of numerous different terms as illustrated above, must be traced to various reasons, which may be summarised as follows (compare Fetz et al. 2005):

- Limited availability or insufficient amount of statistical data
- Lacking knowledge with regard to boundary conditions
- Insufficient or contradicting information originating from different sources
- Simplification of complex circumstances leading to the necessity that a single parameter has to cover a wide range of situations
- Lack of precisely quantifiable definition of some verbally defined variable
- Uncertainty about future dispositions

3.3 Uncertainty modelling in civil engineering

3.3.1 Theories of uncertainty and the probabilistic approach of analysis

Most traditional engineering models are deterministic and can be described as input-output systems. If the input data consist of a single, deterministic data set, the model produces a uniquely determined output. Irrespective of the vagueness of the input data and uncertainties related to such a model, the analysis will yield a crisp and seemingly exact result. Probabilistic methods have been introduced to account for fluctuations in a rational manner and open new opportunities reflecting the lack of information and uncertainties related to the input parameters as well as the results of engineering computations. If the input data fluctuate, the output varies accordingly and may be described by valued intervals. This opens room for further assessment and responsible interpretation of results.

In view of the apparent deficiencies inherent to a deterministic approach Fetz et al. suggest "*…the engineer should face the limitations of the modelling process, put the range of imprecision into the open and make it accessible to responsible assessment by all participants in the construction process. This will involve processing not only data but also the available objective and subjective information on their uncertainty"* (Fetz et al. 2005). The proposal is strongly supported and reinforced by Oberguggenberger through the following conclusion: "*If the input data fluctuate, so does the output. If the fluctuation of the input is described by one or the other theories of uncertainty discussed so far, the fluctuation of the output should be captured on the same terms. This is the issue of this section:* how *is data uncertainty propagated through an input-output system*" (Oberguggenberger 2005).

The theories in use for quantifying the uncertainty spectrum are related mathematically as fuzzy measures. Klir and Folger (Klir, Folger 1988) demonstrated that the relationships among fuzzy set theory, probability theory, evidence theory, and possibility theory originate from a common framework of fuzzy measures, which have been used to characterise and model different forms of uncertainty. These theories represent commonly used instruments for modelling uncertainties arising in engineering problems and can provide convenient and flexible tools for processing subjective knowledge and expert estimates.

An extensive overview summarising existing probability applications has been compiled by Ross et al. (Ross et al. 2002). The study outlines the individual theories and provides comprehensive definitions with regard to the related terminology.
Ross et al. recapitulate: "*Uncertainty in numerical quantities can be random in nature, where probability theory is very useful, or it can be the result of bias or an unknown error, in which case fuzzy set theory, evidence theory, or possibility theory might prove useful.*

Probability theory also has been used almost exclusively to deal with the form of uncertainty due to chance (randomness), sometimes called variability, and with uncertainties arising from eliciting and analyzing expert information. [ ]...fuzzy set theory and probability theory have been used for all these forms of uncertainty”.

The general principles characterising a probabilistic approach in the context of engineering calculations are schematically illustrated in figure 19 comparing deterministic and probabilistic concepts of analysis (compare Fetz et al. 1997):

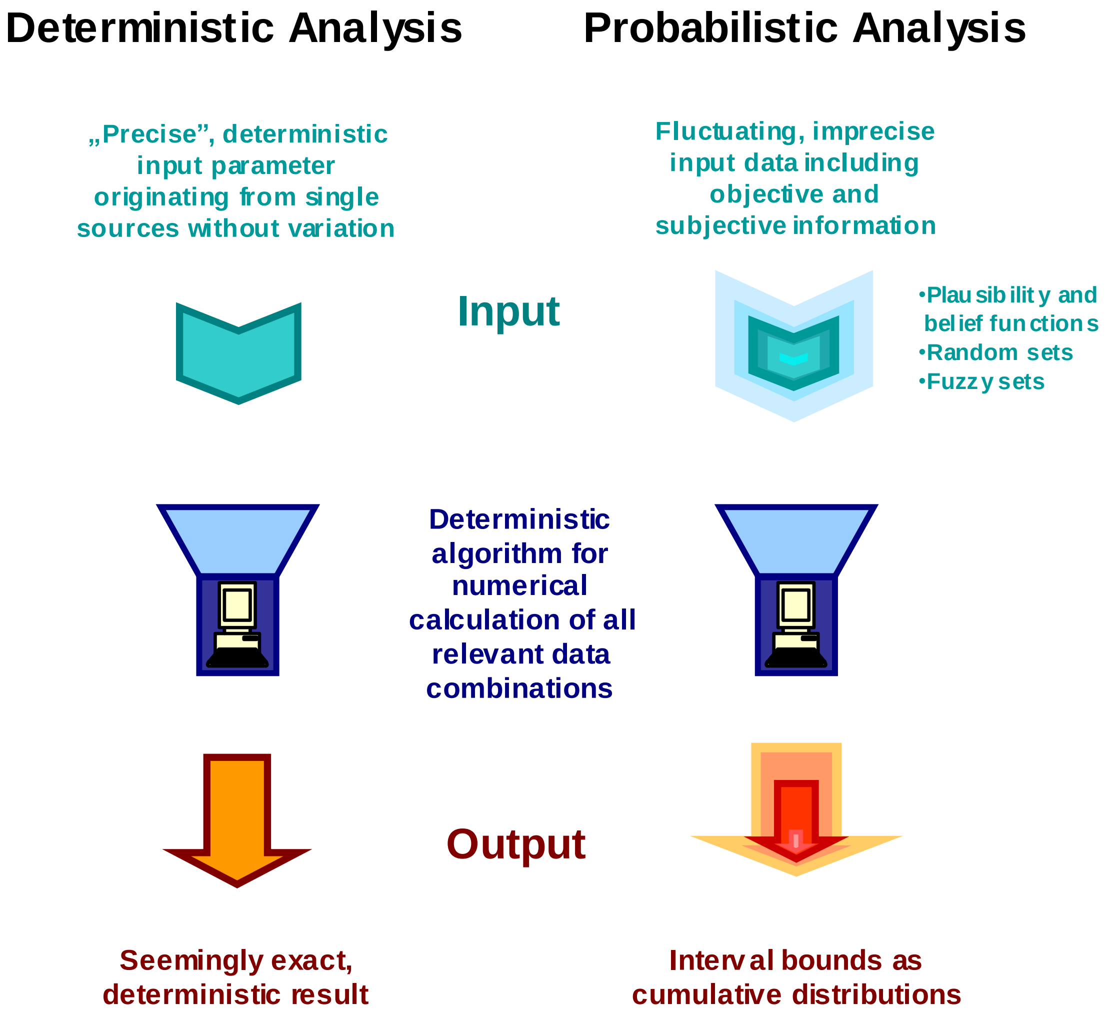


Figure 19: Deterministic versus probabilistic practice of analysis

To date probability theory, including random set theory and fuzzy sets, has been successfully utilised within numerous fields of engineering. The following areas represent typical civil engineering applications illustrating the widespread practical utilisation of probabilistic theories:

- Project planning and construction management, (Oberguggenberger 2005, Fetz et al. 2005, Lessmann, Vieider 2005, Lessmann et al. 1994).
- Treatment of imprecise data in rock mass characterisation and reliability calculations for tunnel linings (Tonon et al. 2000a, Tonon et al. 2000b, Tonon et al. 1996).
- Modelling of material parameters and the scatter of the parameter’s in situ behaviour for analysing tunnel excavation (Schweiger et al. 2007, Pöttler et al. 2005).
- Stability analysis in tunnelling (Schweiger et al. 2010, Pöttler et al. 2001).
- Reliability analysis in geotechnics using RS-FEM (Schweiger, Peschl 2005).
- Land recycling and Brownfield re-development (Klapperich, Pöttler 2007, Klapperich, Pöttler 2006).
- Risk evaluation and cost estimation for underground structures (Pöttler et al. 2007), as well as for traffic and transport infrastructure (Pöttler, Schweiger 2006).
- Determination of failure probabilities (Oberguggenberger, Fellin 2005).
- Probabilistic assessment of structural safety (Oberguggenberger, Fellin 2007).
- Modelling and propagation of uncertainty through mechanical system response (Tonon 2004), optimisation of uncertain structures (Tonon, Bernardini 1998).
- Safety assessment of structures incl. structures with textile reinforcement (Möller et al. 2003, Möller et al. 2001).
- Visualisation of control processes and instrumentation of hydro electric power plants. Operation and maintenance of hydro power developments, in particular planning of the plant operation, turbine control, monitoring of surge shafts, control of pumped storage plants and run-of-river plants (semi automatic swell operation), habitat and discharge modelling for streams and rivers (Giesecke et al. 2005 /// 2009).

References describing applications of probability theory and in particular Dempster-Shafer Theory have been summarised and presented by Sentz et al. (Sentz, Ferson 2002) ranging from classification (incl. target identification and pattern recognition), cartography (geography, map building and image processing), optimisation (expert systems, management and decision making), fault detection, failure diagnosis, robotics and signal processing to finance, risk- and sensitivity analysis etc. The publications by Klir (Klir, Folger 1988) and Ross (Ross et al. 2002), describing research in the field of fuzzy sets, uncertainty and information, further illustrate that successful applications of the above mathematical tools and models are widespread and extremely diverse.

3.3.2 Basic concepts and definitions

The purpose of this section is to provide the theoretical background and to outline basic principles of uncertainty models, with particular focus on the random set theory (RST). Only the main aspects are covered and the summary is limited to subjects, which are considered as fundamental for the subsequent engineering application.

Comprehensive mathematical background information as well as further theoretical explanations covering theories of probability (Fine 1973), interval analysis (Weichselberger, Augustin 2001) and random set theory in particular can be found in the studies of Tonon et al. (Tonon et al. 2000a, Tonon et al. 2000b), Dempster (Dempster 1967), Shafer (Shafer 1976), Dubois/Prade (Dubois, Prade 1990, Dubois, Prade 1991), Fetz/Oberguggenberger (Fetz, Oberguggenberger 2004), Goutsias (Goutsias 1997), Klir (Klir 1995), Nguyen (Nguyen 2006) and Schweiger/Peschl (Schweiger, Peschl 2005).

For the following description, parameters are denoted by upper case letters (e.g. X), while corresponding lower case letters are reserved for their realisations (e.g. x).

a) Deterministic values (one dimensional):

$$P(X = x) = p_k \qquad \sum p_k = 1$$

Deterministic description of uncertainty represents the simplest approach and describes the parameter X through a single value x as depicted in the following figure.

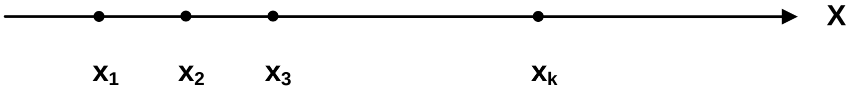


Figure 20: Deterministic value x of parameter X

b) Intervals:

Interval analysis represents uncertainty of the input X in terms of closed intervals $X \in [x_L, x_R]$.

The bounding by intervals can be interpreted as best and worst case analysis but does not provide detailed information of the uncertainty.

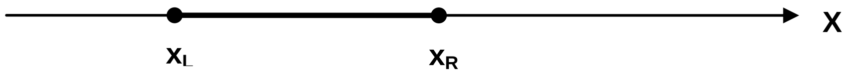


Figure 21: Interval bounds for parameter X

c) Precise probability:

Precise probability represents the most rigorous as well as the most informative description of the uncertainty of a parameter X .

The relative likelihood that a random variable assumes a particular value $P(a \leq X \leq b)$ is described by a probability distribution.

$$P(a \leq X \leq b) = \int_{a}^{b} f(x)dx$$

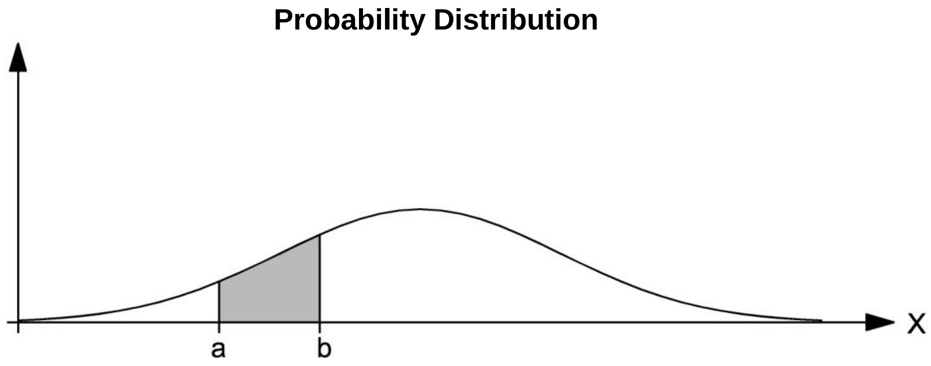


Figure 22: Precise probability distribution

d) Imprecise Probability:

For more detailed information with regard to imprecise probability and further theories covering the subject refer to (Fellin et al. 2005) and (Oberguggenberger 2005) as well as the literature listed in the introduction of the random set theory under 3.3.2.

e) Random Sets:

The concept of random set theory is closely related to the Dempster-Shafer-framework of evidence first described by Dempster (Dempster 1967) and later extended by Shafer (Shafer 1976). It has proven to present a well-suited framework for representing both epistemic and aleatory uncertainty and has found application in various fields.

The two figures 23 and 24 illustrate statistical information in histogram form (e.g. hydrological measurements, river discharges etc.) as well as their corresponding discrete probability distribution function. These descriptions are of significant importance for the subsequent explanations showing basic concepts of the random set theory.

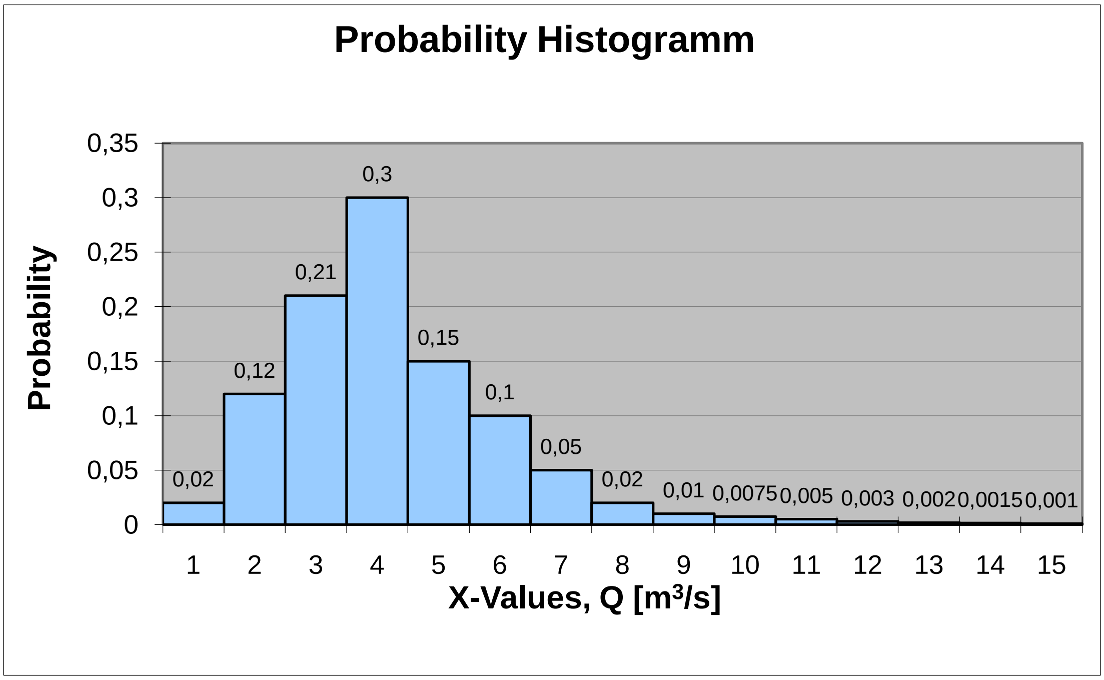


Figure 23: Probability Histogram

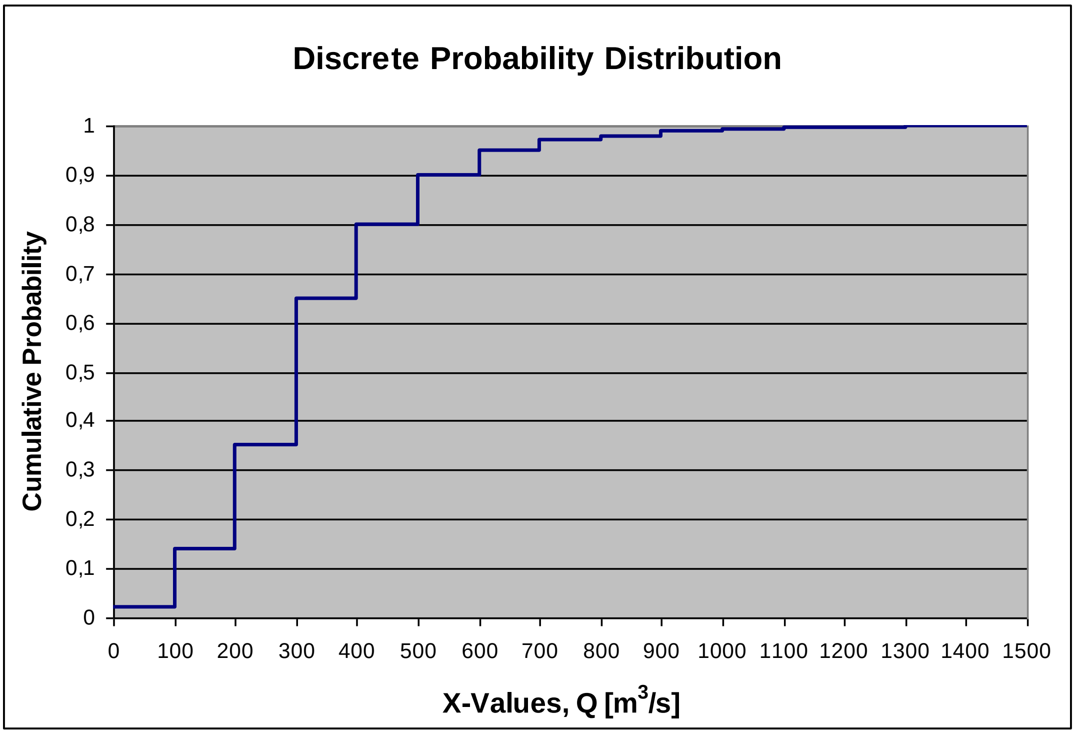


Figure 24: Corresponding function for discrete probability distribution

In order to construct an exemplary case it is assumed that the data illustrated in figure 23 represent statistical information on the river discharge at a projected hydropower site during a multi year period.

If the X-values represent river discharges Q [m^3/s], illustrated through interval ranges of $100m^3/s$, the probability histogram shows that the frequency m_4, indicating that the river discharge is within a range between $300m^3/s$ and $400m^3/s$ is 30%. The frequency m_5 that the river discharge falls within a range from $400m^3/s$ to $500m^3/s$ is 15%, m_6= 10%, m_7= 5% and so on.

It is also possible to calculate the frequency of a discharge between $300m^3/s$ and $600m^3/s$ by forming the sum of the related frequencies m_4, m_5 and m_6.

The result is obtained as the sum of m_4 [300, 400], m_5 [400, 500] and m_6 [500, 600], i.e. $m_4 + m_5 + m_6 = 55\%$.

The probability histogram shows the frequency of an event anywhere within a chosen interval, regardless of the exact location of the parameter within the boundaries. The collection of intervals (histogram columns) with weights (frequencies) attached can also be interpreted as a random set. As demonstrated by Bernadini (Bernardini 2010) it is also possible to calculate upper and lower bounds on the frequency of an event of interest.

3.4 Random Set Theory

3.4.1 Theoretical background

RST is closely related to the Dempster-Shafer Theory (DST), which represents a mathematical theory of evidence and can be interpreted as a generalisation of probability theory where probabilities are assigned to sets as opposed to singletons. In traditional probability theory, evidence is associated with only one possible event whereas in DST, evidence can be associated with multiple possible events, e.g. sets of events.

Dempster-Shafer-structures are similar to discrete probability distributions except for the difference that probability masses are assigned to sets instead of discrete values. Consequently their probability mass function is not a mapping $\mathrm{R} \rightarrow [0,1]$, but $2^{\mathrm{R}} \rightarrow [0,1]$.

Within the framework of classical discrete probability theories, a mass m(a) is defined for each possible value of X and $p(X = a) = m(a)$. A random set consists of a finite number of subsets A_i, i=1,…, n of a given set X , which are called focal sets. Each focal set possesses a probability weight $m_i = m(A_i), \sum m(A_i) = 1$.

The difference of a random set compared to a histogram as illustrated before is that the focal sets A_i may overlap (Oberguggenberger 2005).

As demonstrated by Tonon (Tonon et al. 2000a) each set A_i could represent the result of an interval valued measurement where m_i characterises its relative frequency in a sample. Alternatively, the focal sets A_i may symbolise ranges of a variable obtained from different sources i=1,..., n (e.g. expert opinions), each possessing a relative credibility of m_i. Random sets are thus suitable for bracketing probability estimates originating from different sources as well as for combining information of different type.

A random set can also be visualised by its contour function $a \to \overline{P}(\{a\})$, which assigns each singleton a its plausibility. An example illustrating a random set and its related contour function is shown below based on the parameters (focal sets A_i and corresponding probability weights $m(A_i)$) presented in table 4.

Source A_i	**Parameter L**	**Parameter U**	**Probability weights m_i**
A_1	60.0	90.0	0.50
A_2	10.0	70.0	0.35
A_3	30.0	80.0	0.15

Table 4: Parameters defining random set

The contour function of the random set is obtained by adding the probability weights $m(A_i)$ of those focal sets A_i to which a belongs:

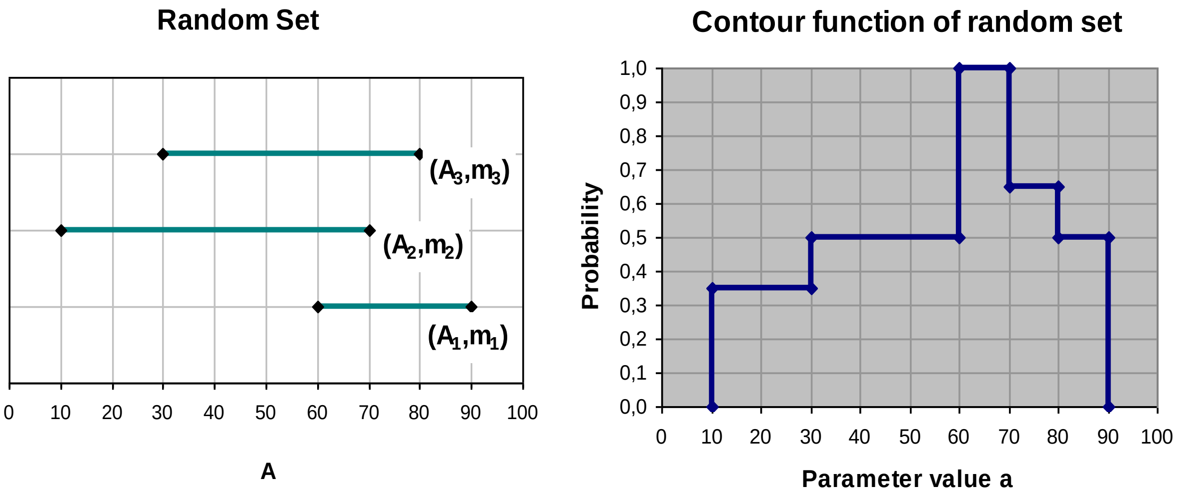


Figure 25: Example of random set and its corresponding contour function

For additional information covering the above subject please refer to the recommended literature (Oberguggenberger 2005 and Oberguggenberger, Fellin 2005).

Following Klir (Klir 2006), a set represents any collection of objects that are considered as a whole. Objects that are included in a set are called its members (or elements). Conventionally, sets are denoted by capital letters and elements of sets are denoted by lowercase letters. Symbolically, the statement ‘a is a member of a set A’ is written as $a \in A$. As defined by Dubois and Prade (Dubois, Prade 1990, Dubois, Prade 1991), a finite support random set on a universal set *X* under consideration is a pair $(\Im, m)$ where $\Im = \{A_i : i = 1,\ldots,n\}$ and a mass assignment is a mapping.

$$m: \Im \rightarrow [0,1] \tag{13}$$

such that m(Ø) = 0 and

$$\sum_{A \in \Im} m(A) = 1 \tag{14}$$

The correspondence of probability masses associated with the focal elements is called a basic probability assignment although the term ‘basic probability assignment’ does not refer to probability in the classical sense. $\Im$ is called the support of the random set and every $A \in X$ for which $m(A) \neq 0$ is referred to as focal element ($A_i \subseteq X$). Each set, $A \in \Im$, contains some possible values of the variable *x*, and *m*(*A*) can be viewed as the probability that *A* is the range of *x*.

The focal elements of a Dempster-Shafer structure may overlap each other in contrast to a discrete probability distribution, where the mass is concentrated at distinct points. According to Ferson et al. this can be regarded as “the fundamental difference that distinguishes Dempster-Shafer theory from traditional probability theory” (Ferson et al. 2003). The probability distribution functions in probability theory are consequently defined on *X*, while basic probability assignments in DST are defined on $P(X)$ as highlighted by Hall and Lawry (Hall, Lawry 2004).

Founded on the basic probability assignment it is possible to define the upper and lower bounds of an interval that contains the precise probability of a set of interest, which is enclosed by two non-additive continuous measures called Belief and Plausibility. The imprecise nature of the formulation prevents the calculation of the 'precise' probability *Pro* of a generic $x \in X$ or of a generic subset $E \subset X$.

Consequently it is only possible to determine lower and upper bounds of this probability in the following format:

$$Bel(E) \leq Pro(E) \leq Pl(E) \tag{15}$$

Figure 26 below shows possible 'precise' probabilities (*Pro*) bounded by *Pl* and *Bel*. In the limiting case, when $\Im$ is composed of single values only (singletons), then *Bel*(*E*) = *Pro*(*E*) = *Pl*(*E*) and *m* is a probability distribution function.

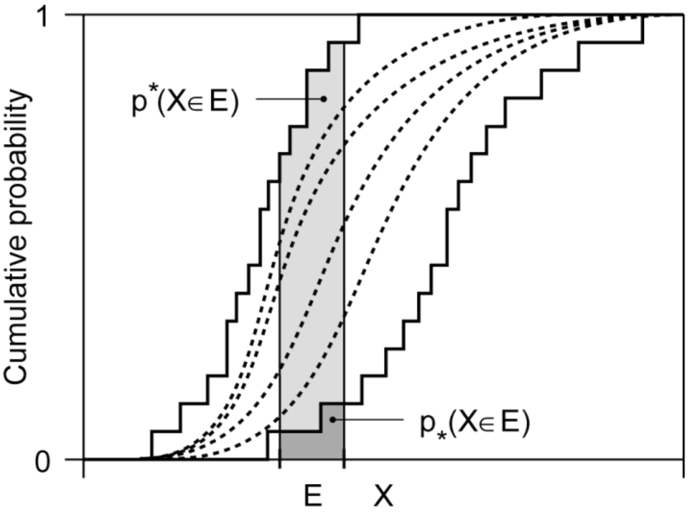


Figure 26: Upper bound (*Pl*) and lower bound (*Bel*) on ‚precise' probability (*Pro*)

Following Dempster (Dempster 1967) and Shafer (Shafer 1976) for every subset $E \in X$ the belief function Bel can be defined as the following set function:

$$Bel(E) = \sum_{A_i : A_i \subseteq E} m(A_i) \tag{16}$$

The dual plausibility function $Pl(E)$ of its probability measure can be defined as follows:

$$Pl(E) = \sum_{A_i : A_i \cap E \neq \phi} m(A_i) \tag{17}$$

The belief function Bel, of a subset E is a set-valued function obtained through summation of basic probability assignments of subsets A_i included in E. The plausibility function Pl, of a subset E is a set-valued function obtained through summation of basic probability assignments of subsets A_i having a non-zero intersection with E. As described by Hall and Lawry (Hall, Lawry 2004) "*Bel (E) can be viewed as the lower bound on a set of probability measures and Pl(E) as the upper bound, although the converse is not true, i.e. upper and lower probabilities are more general than belief and plausibility functions.*"

Bel and Pl are envelopes of all possible cumulative distribution functions compatible with the data. Informally the belief function represents the maximum value that we, despite all epistemic uncertainty, 'believe' to be smaller than $p(X \in E)$ and the plausibility function represents the highest 'plausible' value of $p(X \in E)$.

Imprecise probabilities are usually a consequence of set-valued parameters, which may occur due to insufficient quantity or quality of information available and can originate from the following sources:

- Analysis of statistical data through histograms as illustrated in figure 23 and 24.
- Set-valued measurements arising from direct field observations such as geological surveys, flow measurements and hydrological observations etc.
- Alternative sources of information such as expert opinions, reference projects, market studies etc. may need to be utilised in case of lacking experimental data and unavailability of a dependable database directly related to the investigated project.

3.4.2 Upper and lower bounds on the cumulative probabilities

As described by Tonon et al. (Tonon et al. 2000a, Tonon et al. 2000b) and further elaborated by Schweiger and Peschl (Schweiger, Peschl 2005) the upper and lower cumulative probability distribution functions, $F^*(x)$ and $F_*(x)$ respectively, at distinct points *x* can be obtained as

$$F^*(x) = \sum_{i:x \geq l_i} m(A_i) \tag{18}$$

and

$$F_*(x) = \sum_{i:x \geq u_i} m(A_i) \tag{19}$$

provided that the focal set A_i is a closed interval of real numbers.

Based on the values shown in table 5 an example illustrating the above is depicted in the subsequent diagram. The focal sets A_i represent parameters obtained from independent sources. Their probability assignments m_i, representing the credibility of the information sources, are all counted with the same probability weight of m=1/4.

Index No.	**Source**	**Parameter L**	**Parameter U**	**Probability Assignments**
1	A_1	30.0	40.0	0.25
2	A_2	25.0	32.5	0.25
3	A_3	22.5	42.5	0.25
4	A_4	35.0	50.0	0.25

Table 5: Focal elements characterised by closed intervals of real numbers

Upper and lower discrete cumulative probability distributions based on the previous parameters, originating from multiple sources of information, are shown in figure 27 below. The intervals are described through 4 focal elements A_1, …, A_4 and their corresponding probability assignments m_1, …, m_4.

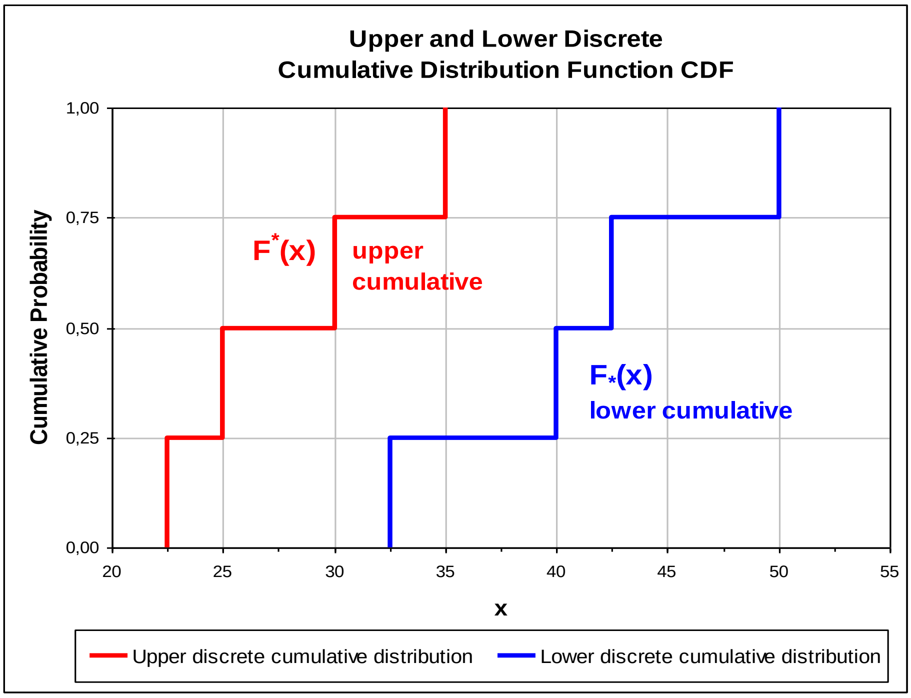


Figure 27: Upper and lower discrete cumulative distribution function

Peschl illustrates, that by assuming stochastic independence between marginal random sets a so-called calculation matrix can be constructed, which implies bounds on a corresponding discrete cumulative distribution function CDF (Peschl 2004).

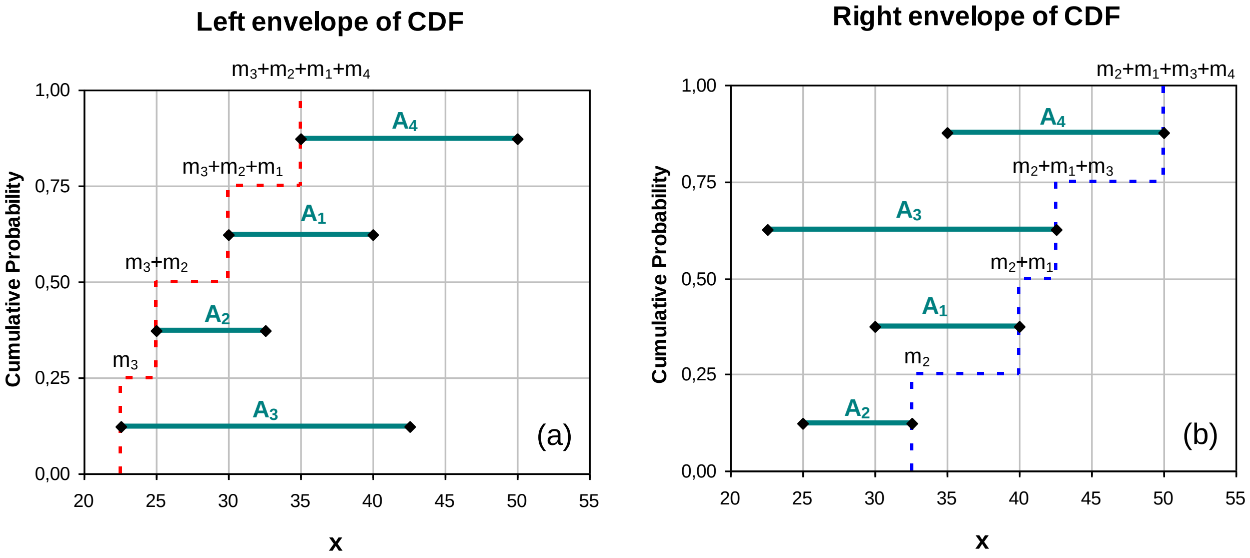


Figure 28: Left and right interval bounds as CDF (compare Peschl 2004)

The left envelope is obtained by concentrating the distribution of each interval's probability mass at the left bound as depicted in Fig. 28(a). The envelope is constructed through systematic arrangement of the cumulative distribution starting with the smallest value and adding an increment to the left interval bound for each step of the CDF. The dimension of each vertical step is determined by the probability weight of the corresponding basic probability assignment it represents.

The right envelope is formed accordingly, by concentrating the distribution of each interval's probability mass at the right bound of the interval and integration of the basic probability assignment across all upper bounds as depicted in Fig. 28(b).

The upper and lower bounds on a corresponding discrete cumulative distribution function (CDF) are created as illustrated in the following figure. Based on the previous example, Fig. 29 schematically illustrates the construction of random sets from multiple sources of information given as intervals (focal elements $A_1,...,A_4$ and basic probability assignments $m_1,...,m_4$).

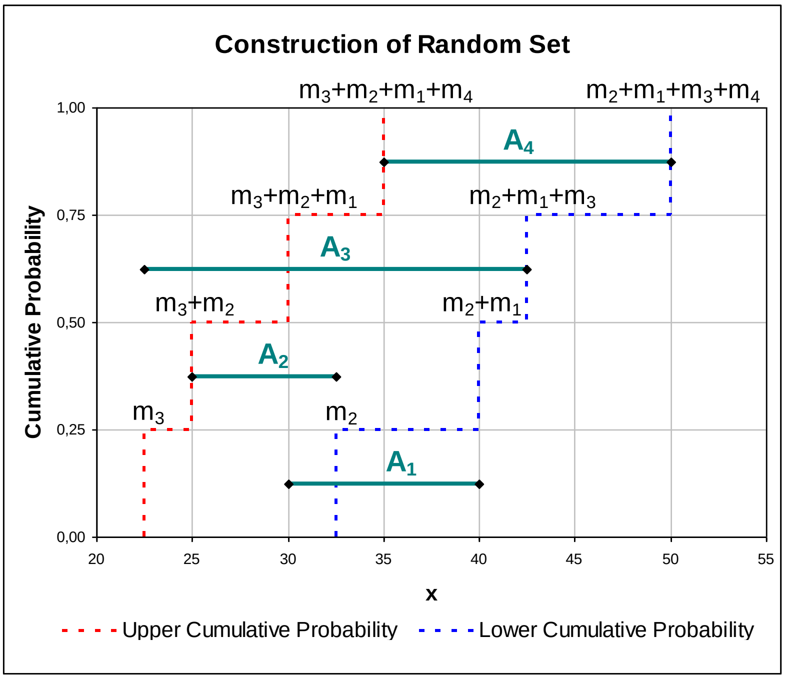


Figure 29: Construction of random set (compare Peschl 2004)

For further analysis of the above results and a comprehensive interpretation of their dual nature please refer to the elaborations of Peschl (Peschl 2004).

3.4.3 Probability weights of random sets

If more than one independent source of information exists for a certain parameter a procedure is required to allow for due consideration of all sources available.

In case that a variable *x* is described by *n* alternative focal elements, with each one corresponding to an independent source of information, the probability weight $m_i = m(A_i)$ for each focal element $A \in X$ *can be calculated as*

$$m(A) = \frac{1}{n}\sum_{i=1}^{n} m_i(A) \tag{20}$$

The above equation is valid in case of an unbiased combination of *n* random sets.

Averaging procedures should be adopted in case that only one source of information is believed to be correct but it is, in the absence of any further information, not known which source is true (Hall, Lawry 2004).

If one source of information is known to be more likely, the basic probability assignment of that information can be weighted as illustrated by means of the following three examples, which are based on the parameters summarised in table 6:

No. Sources	Source	Parameter L	Parameter U	Probability Assignments
4	A_1	30.0	40.0	0.25
	A_2	25.0	32.5	0.25
	A_3	22.5	42.5	0.25
	A_4	35.0	50.0	0.25
5	A_1	30.0	40.0	0.20
	A_2	25.0	32.5	0.20
	A_3	22.5	42.5	0.20
	A_4	35.0	50.0	0.20
	A_5	37.5	42.5	0.20
5	A_1	30.0	40.0	0.20
	A_2	25.0	32.5	0.10
	A_3	22.5	42.5	0.10
	A_4	35.0	50.0	0.20
	A_5	37.5	42.5	0.40

Table 6: Varying nos. of information sources *n* with different probability weights *m*

The graphical presentation of the focal elements obtained from 4 independent sources of information and characterised by the same probability assignment m(A)=1/n (in this case 0.25) is depicted in figure 30:

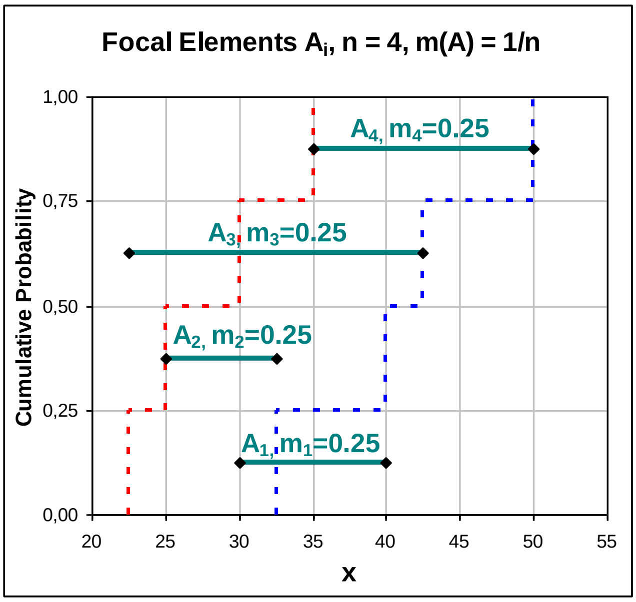


Figure 30: No. of sources n=4, probability assignments m_i=1/n=0.25

The next diagram illustrates the above scenario extended by one additional independent source of information while the probability assignment is maintained at mi(A)=1/n (in this case 0.20):

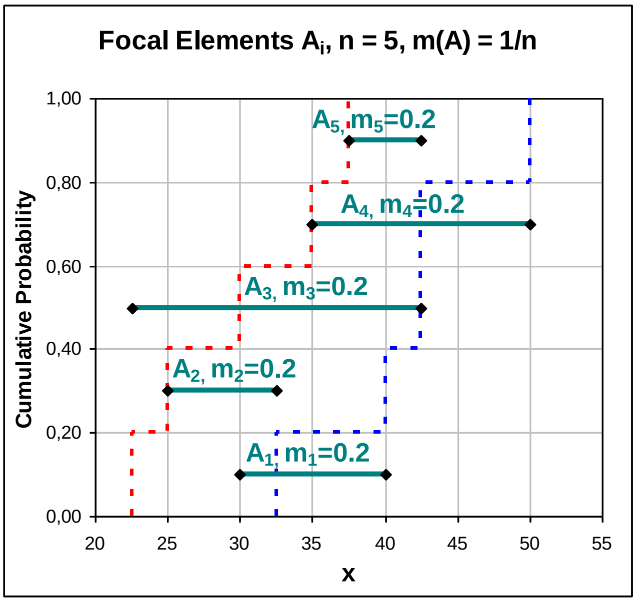


Figure 31: No. of sources n=5, probability assignments m_i =1/n (0.20)

The influence of one additional source of information can be recognised when comparing figure 30 and 31. The left and right envelopes are shifted towards each other reducing the width of the gap that indicates existing parameter ranges.

This effect is even more pronounced if the additional independent source of information is weighted with a higher probability. In the example illustrated below, the basic probability assignments m_1 and m_4 are maintained at values of 0.2, while the probability assignment m_5 is increased to 0.4 and the probability assignments m_2 and m_3 are reduced to values of 0.1.

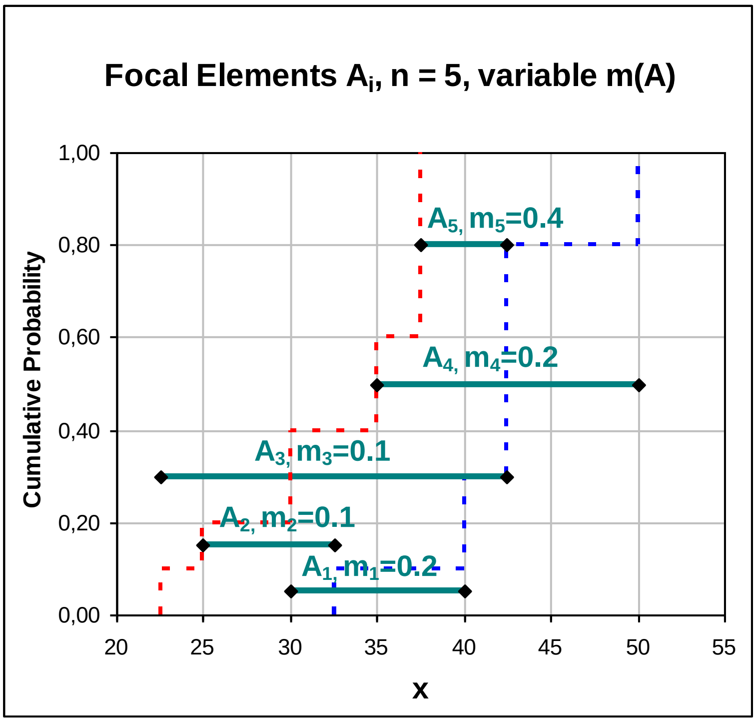


Figure 32: No. of sources n=5, m_1=0.2, m_2=0.1, m_3=0.1, m_4=0.2, m_5=0.4

Provided that additional sources contribute sufficiently precise information, i.e. the interval ranges must be smaller than for the sets already used, it can be concluded that an increasing number of independent information sources reduces the distance between the left and right envelopes, representing upper and lower bounds of cumulative probabilities. The effect of a narrowing gap between the envelopes can be further strengthened if the additional information is weighted. The converse effect will occur if the additional source of information denotes a large interval range characterised by a comparably high probability assignment. These observations indicate that not only the uncertainty due to lack of knowledge but also the aleatory type of uncertainty will be impacted by the parameter range and probability weight of the interval (Peschl 2004).

3.4.4 Civil engineering application and current developments

The study of random sets is a large and rapidly growing field with connections to many areas of mathematics and applications in widely varying disciplines, ranging from economics and decision theory to biostatistics and image analysis. With regard to civil engineering applications the methodology has been used most extensively within the field of geotechnical engineering.

The typical sequence of calculations involving the RSM consists of the following steps and is depicted in figure 33 and figure 34:

- Determination of parameters that should be considered as basic variables
- Construction of random sets
- Sensitivity analysis to reduce computational effort (if necessary)
- Generation of calculation matrix (random set model)
- Execution of all calculations
- Interval bounds as cumulative distributions

Schematic example of random set finite element (RS-FEM) calculation:

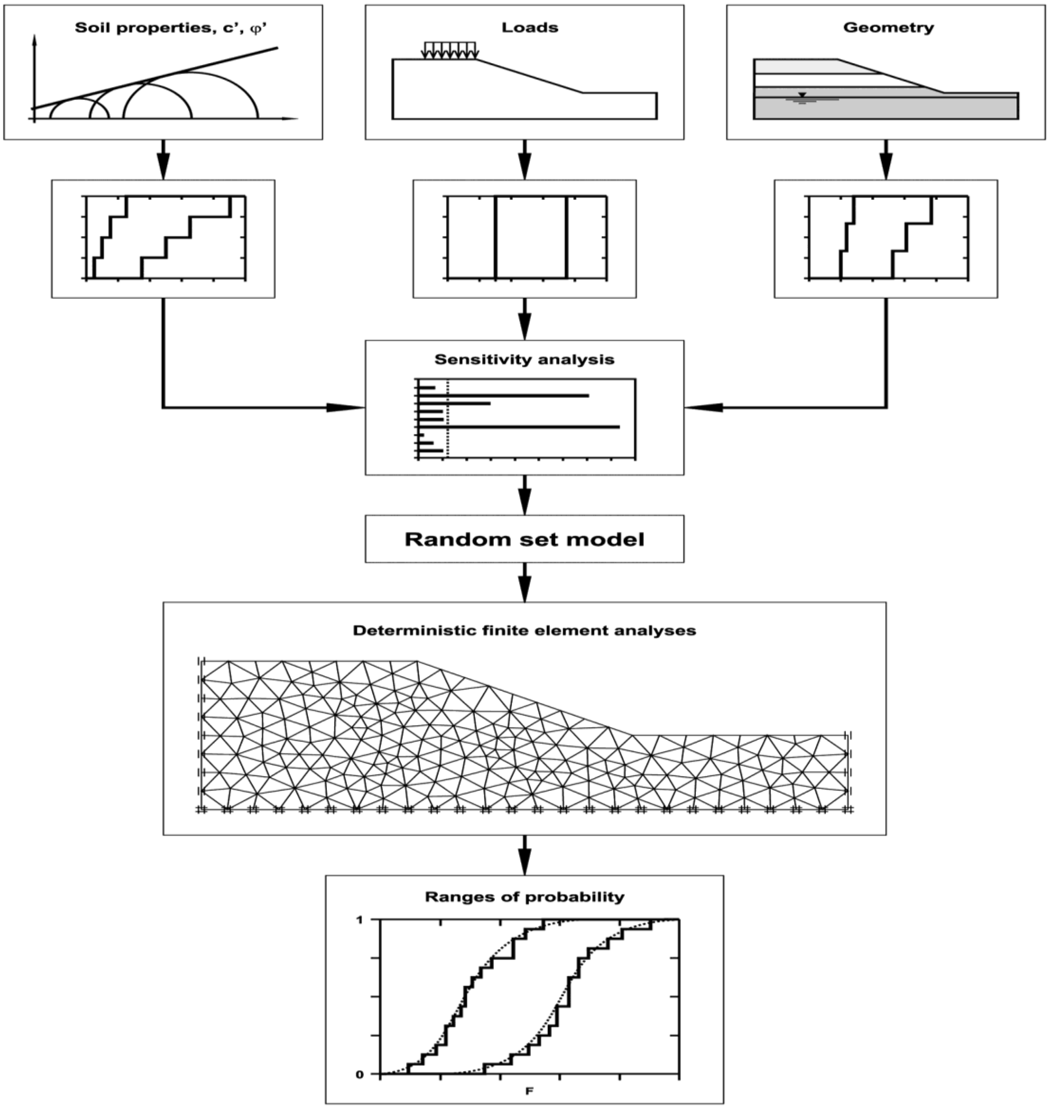


Figure 33: Concept of RS-FEM calculation in geotechnical engineering (Peschl 2004)

Application of the RSM for cost evaluation of underground construction projects:

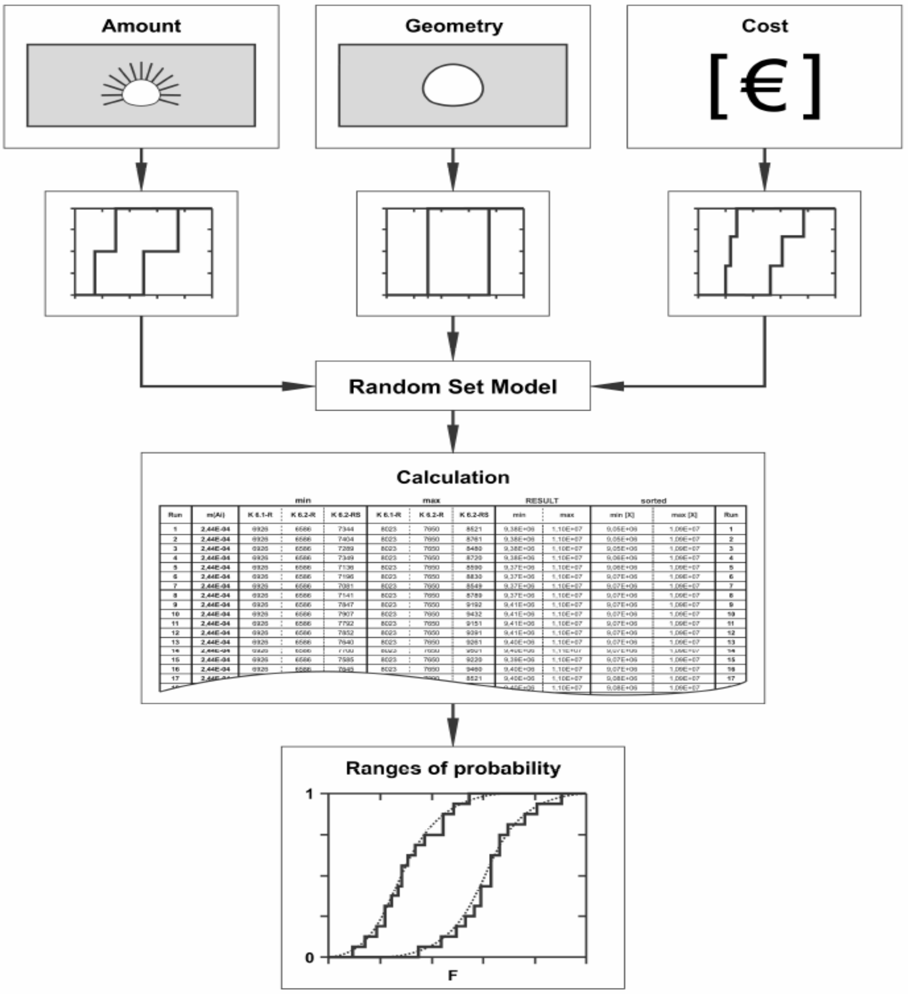


Figure 34: Schematic representation of RSM analysis (Pöttler et al. 2007)

Based on experience gained in geotechnical engineering the benefits of utilising the random set finite element calculation can be summarised as follows:

- RSM offers a convenient tool to account for the scatter in material and model parameters
- Worst Case and Best Case assumptions are automatically generated
- RSM allows an assessment of the quality of the geotechnical model when comparing with case histories
- RSM can significantly increase the value of numerical analysis
- In geotechnical engineering RSM provides interval bounds of cumulative distributions for lining design and deformation prediction
- RSM incorporates model uncertainties in an objective, theoretically rigorous manner

3.4.5 Distinctive characteristics of random set theory

The most appropriate approach for modelling of a specific problem mainly depends on the type of information that can be made available. For the modelling of imprecise probabilities related to the described hydropower optimisation task, random set theory has been considered as the most appropriate instrument in comparison with alternative probabilistic methods. The methodology offers certain advantages compared to other stochastic methods, which can be summarised as follows:

- The framework of RST is able to represent the dual nature of uncertainty consisting of both existing types, epistemic and aleatory uncertainty.
- Probability distribution functions are not required since the RST uses intervals (bounds of probability). Best and worst case scenarios are generated automatically.
- RST is expected to represent a robust method for modelling uncertainty, ensuring that the obtained results can be used as a basis for investment decision making.
- Computations can be performed directly with focal sets using interval analysis, which limits computational efforts.
- The RST is expected to provide a consistent mathematical framework for dealing with uncertainties throughout the various planning stages of the project.
- The RST allows for elicitation of and educated guesses based on experience and can therefore be used for bracketing probability estimates originating from different sources.

For the financial project analysis of hydropower developments probability distributions are usually not available to describe the required input parameters. This can be explained with the unique attributes differentiating individual schemes, which is a distinctive attribute for these types of projects. Since hydropower developments are characterised by very specific individual requirements it is very difficult to draw general conclusions from experiences gained in a particular, perhaps comparable project and even more troublesome to develop probability distributions for input parameters. At early planning stages expert opinions and planning experience are of major importance for the approximation of input parameters, which usually require further adjustment during a later stage of the project, once the initial assumptions can be confirmed by factual information. In comparison with other probabilistic concepts the RST seems to represent the most suitable and appropriate approach for this kind of application and therefore the subsequent analysis will be focused on the utilisation of this theory. The application of the random set method in the context of hydropower optimisation is illustrated in the following chapter of the study, where the methodology is used for a verification of the preliminary results obtained for the design parameters $Q_d(m^3/s)$ and H(m). The study also assesses the suitability of the random set method as a support for the investment decision making.

4 RSM TO EVALUATE THE FINANCIAL FEASIBILITY OF THE PROJECT

4.1 Overview

4.1.1 Hydropower case study – results obtained through deterministic analysis

Based on a deterministic approach, the preliminary assessment of the main design parameters for the hydropower project resulted in a design discharge of Q_d= 4.200 m^3/s and a normal operating level NOL of 127 m.a.s.l. Due to the existing boundary conditions the operating level of the future reservoir must not exceed 129 m.a.s.l. and to achieve the objective of maximising the exploitation of the rivers hydropower potential, operating levels which are significantly below this elevation do not need to be considered. The scope for optimisation of the hydraulic pressure head is therefore limited to a range from 123 m.a.s.l. to 129 m.a.s.l. for the reservoir's normal operating level. As depicted in figure 7 an investigation of the optimum design discharge Q_d appears appropriate only within an interval ranging from 3.500m^3/s to 6.000m^3/s since values above or below this range do not suggest economical solutions.

For reasons that have been discussed in chapter 2.4 of the study, the appropriateness of the calculated design parameters must be regarded as questionable due to the fact that their calculation has been based on precise, deterministic input parameters, which does not reflect a realistic scenario.

Before the optimisation of the design parameters can be further refined, the next step of the analysis must include a comprehensive verification of the calculation that lead to the selection of the plant's design parameters Q_d and NOL.

4.1.2 Random set method for result verification and to support the investment decision

The lack of suitable project information and the uncertainty inherent to the employed input parameters is more appropriately represented by parameter ranges in form of intervals than by sharp, deterministic values.

The input parameters for the financial project analysis, which are subject to uncertain variations, comprise at a minimum, figures such as capital expenses, discount rate, construction time and project revenues. For the analysis by means of the random set model these parameters are treated as input ranges. Further input parameters may be considered for a similar approach if found necessary and appropriate.

As a result of the probabilistic approach for the financial analysis, the project's economic indicators are calculated as upper and lower bounds of the cumulative probability.

The general sequence of the analysis based on the use of the random set method is depicted in figure 35:

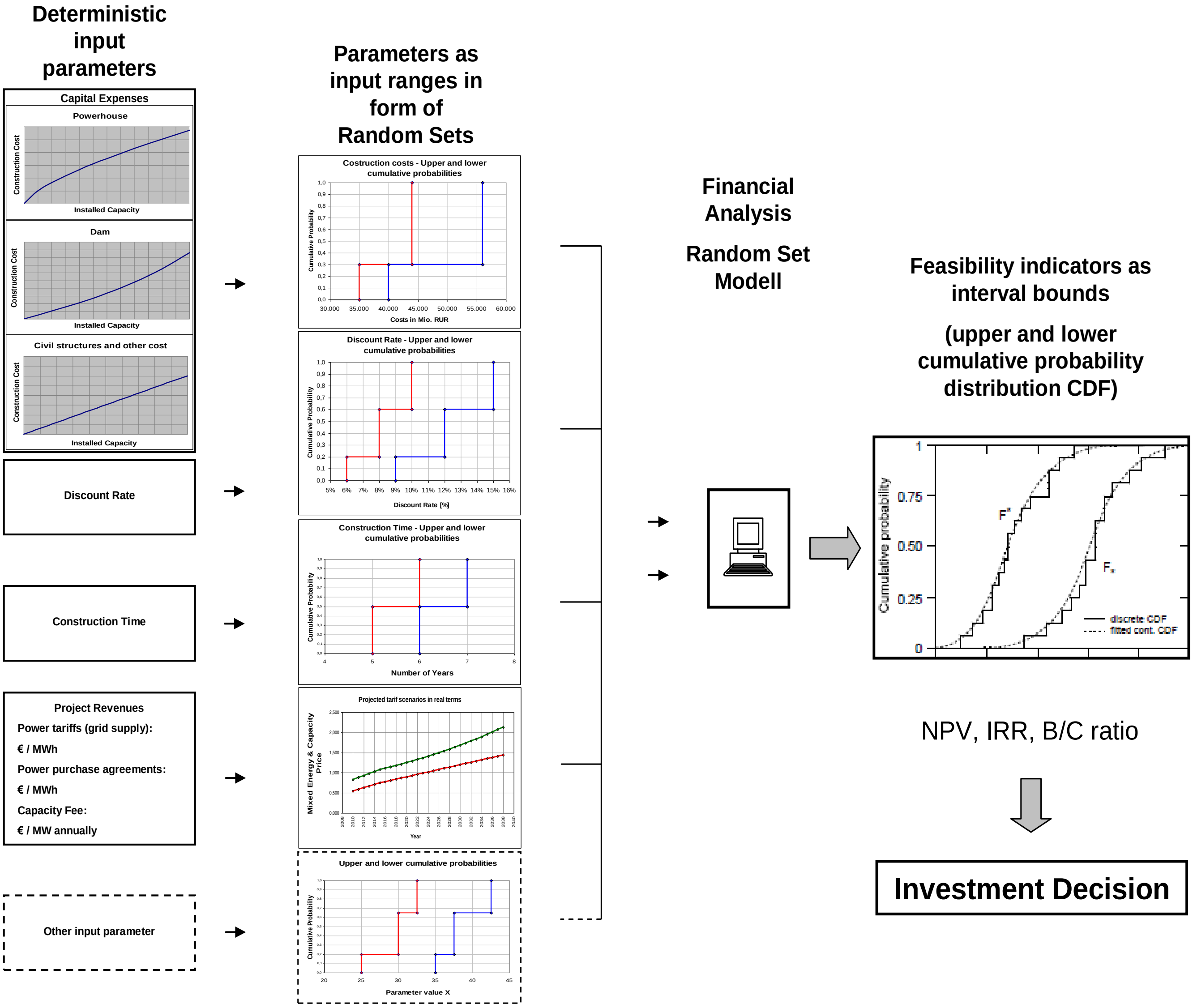


Figure 35: Random set approach to support hydropower investment decision

4.2 Data sources for input parameters

Size and complexity of a large hydropower project make it inevitable, that numerous different sources of information have to be used to obtain the input parameters that are required for the technical and financial project analysis. Especially during early planning stages the available input data does not always represent accurate information that can be acquired from confirmed and reliable sources. This may lead to input data that can be described as incomplete, imprecise, inappropriate and sometimes even contradicting. Conflicting interests between the parties involved in the planning of the project and different interpretation of the same observations may further increase the difficulties inherent to the planning process. A number of exemplary information sources, which may be utilised to obtain necessary input parameters for the project planning and the project analysis are listed below.

4.2.1 Field investigations

4.2.1.1 Hydrological data and flow measurements

Runoff forecasting systems are indispensable tools for flood forecasting, planning of reservoir operation and for elaborating the most favourable design and operation of the power plant. Since the inflow of a hydropower development is a stochastic variable, the parameter represents a high degree of uncertainty with regard to the plant’s future production capacity. Long term runoff forecasting is usually based on volumes rather than on the actual distribution in time and the precondition for suitable inflow forecasts are correct observations and the availability of representative inflow data. Discharge measurements obtained by means of gauges and recording stations represent a major part of the data base that is required to generate flow series and rating curves, which are required for the design elaboration and the dimensioning of the plant.

Statistical correlation techniques may have to be employed if the available data records are insufficient or fragmentary. The use of automatic hydrological data acquisition systems ensures that these procedures are only required for projects, which are located in extremely remote or undeveloped regions. The concept of modern and reliable automatic data acquisition systems is based on local data recording and transmission via radio communication. The transmission of data to the forecasting models, which is recorded by sensors installed in situ, is characterised by a high efficiency without human interruption and delays.

4.2.1.2 Ground investigations and laboratory testing

The existing ground conditions at a hydropower project site have a major impact on the design of all structural components, the availability of construction materials and the selection of suitable construction methods. These dependencies result in equally significant effects on the required construction time, the overall costs and ultimately the financial attractiveness of the project.

The suitability of the parameters obtained from a geological site investigation program will mainly depend on factors such as selection of representative drilling locations, amount and condition of the available soil samples (e.g., disturbed, undisturbed etc.) and the accuracy of laboratory testing procedures. Especially at early planning stages, the geological and geotechnical information available to planning engineers does not always satisfy their requirements and needs to be complemented by other sources of information as described below.

4.2.1.3 Environmental data

Depending on the nature, scale and conception of a hydropower scheme, the resulting environmental impact can be substantial and far-reaching. The merit of the project may be seriously impaired by the disturbance created owing to its implementation. It is therefore mandatory to adequately appraise environmental as well as socio-economic impacts during early planning stages and to determine in what way such impacts may affect the investment decision.

Environmental impacts deal with the effects of a scheme on ambient conditions, in particular ecology, flora, fauna and living conditions, comprising all quantifiable and also intangible by-products and consequences arising from the project planning, implementation and operation. In order to assist the concept of a sustainable project development, the planning of a new hydropower scheme requires the preparation of an environmental and social impact assessment. Possible environmental concerns must be identified, described and evaluated in order to develop adequate mitigation measures, monitoring systems and the necessary documentation. Comprehensive project screening in form of surveys and site investigation programs, data processing and predictive modelling are necessary to ensure that environmental as well as socio-economic considerations enter into the project selection. Full transparency provided through an effective public participation process is one of the key requirements in the planning of a new project to guarantee full and active stakeholder representation. Joint negotiations with adversely affected parties are intended to result in mutually agreed and legally enforceable mitigation and development provisions.

Procedural guidelines have been developed by governments, international support agencies and lending organisations to accurately specify the activities required by an EIA. Although it is difficult to define and evaluate socio-economic impacts and intangible benefits (e.g., improved employment opportunities and strengthening of local economy) in numerical terms, the ability to fulfil procedural guidelines related to EIA requirements is a mandatory prerequisite to achieve the projects ‘bankability’ in environmental terms. Since 1987 the World Bank has made significant efforts to incorporate environmental concerns into its lending programs requesting an EIA for all projects that are expected to have major impacts on the environment. The African Development Bank (AfDB), the Asian Development Bank (ADB), the Inter-American Development Bank (IDB) and the European Bank for Reconstruction and Development (EBRD) all have environmental policies and guidelines which resemble those of the World Bank in most respects.

For more information covering environmental considerations refer to Helland-Hansen et al. (Helland-Hansen et al. 2005).

4.2.2 Literature and research

If reliable first hand information originating from in-situ field investigations cannot be made available, design parameters are usually acquired from technical literature and standard textbooks. Regardless of their individual quality, these sources of information cannot reflect the project specific site conditions and therefore only represent a vague approximation of the actual existing parameters.

4.2.3 Expert opinions and experience gained from previous projects

The experience of the planning staff involved plays an important role for the planning and implementation of a hydropower project and becomes even more critical if lacking parameters have to be estimated or uncertain data needs to be interpreted. As already described, these expert opinions may differ due to different individual interpretations, conflicting interests resulting from political motives or commercial reasons etc. The selection of appropriate input parameters may also be based on experience that has been gained from previously completed projects. In this case it has to be ensured that the employed references are in fact comparable, which may be possible for selected items such as electrical and hydro-mechanical equipment, certain construction methods, remuneration models etc. In contrast, hydrological and geological conditions, available construction materials, environmental aspects etc. are always project specific factors that exclusively apply to the individual project.

4.2.4 Market studies and future projections

The prediction of energy demand growth and the projection of tariff scenarios in competitive electricity markets are extremely difficult tasks, since these parameters are characterised by a high volatility. Numerous approaches have been developed to analyse and predict future electricity prices, which are described by Weber (Weber 2005) as "*…a key source of uncertainty and a key challenge for decision support in competitive electricity markets*." The non-storability of electricity represents one of the main reasons why electricity exhibits the highest volatilities among all traded commodities, but electricity prices also depend on various additional factors such as general economic growth rates and market liquidity, customer demand growth and demand patterns, price elasticity, load capacities and transmission constraints, financial and political risks etc., which are complex and difficult to model. For a comprehensive representation of the subject, including a detailed description of different market models, computation models for the support of energy management, power plant portfolio management, risk management and risk controlling strategies please refer to Weber (Weber 2005) and the publication by Førsund (Førsund 2008) covering hydropower economics in particular.

4.3 Selection of key parameter sets for RSM approach

4.3.1 Deterministic input values and basic assumptions for the financial model

Although, at least theoretically, most of the input parameters for the financial model could be represented as intervals or input ranges, it is for practical reasons advisable to keep the number of parameter sets within sensible limits. This approach ensures that the required computational efforts are minimised and that the focus of the assessment remains on the most critical parameters. One of the main objectives for modelling input parameter uncertainties in the context of project evaluation is the intention to relate their existing variations to the values computed for the financial feasibility indicators, which are calculated by means of the financial model. This assessment, showing the possible impact of input parameter variations on the profitability of the project, is based on a transparent linkage between model input and output. The existing dependencies between input parameters and the results of the financial analysis are not accessible if the number of selected random sets is too high. The calculation model can always be further refined in a next step through the variation of additional input parameters if required and regarded as beneficial for the analysis. A sensitivity analysis to support the decision, of which variables should be defined as imprecise probabilities for further calculations and which data can be treated as deterministic values, is not performed since a responsible judgement regarding the magnitude of influence for individual parameters on the result of the analysis is considered feasible without this procedure.

The following parameters are treated as sharp, deterministic values during the optimisation process:

- Independent from slightly varying water levels and turbine discharges the total efficiency factor for the power generation units $\eta_{tot,PGU}$ is maintained at 0.91 for all power and energy calculations as described in chapter 2.1.6. of the study.
- Costs for operation and maintenance of the plant, which mainly comprise material costs, production costs, personnel costs, taxes and miscellaneous imbursements to the electric power market, are estimated at 1.5% of the plants capital value.
- Costs for engineering, supervision and construction management are estimated at 5.0% of the total construction costs.
- Costs for reservoir preparation, resettlement and grid connection are not included in the financial model as capital expenses since, in this particular project, these costs are considered to be under the responsibility of the government and do not contribute to the expenses of the project developer.

Costs for land acquisition, development costs (e.g., front-end engineering, establishing and operation of the project company), legal advice and management fees etc. are included in the capital expenses as a lump sum. The financial model is based on a project life of 30 years without the necessity for re-investments.

4.3.2 Uncertain input parameters displayed in form of random sets

4.3.2.1 Construction Cost – Capital Expenses

As depicted in chapter 2.4.1 of the study, the calculation of capital expenses required for implementation of the project must be based on local cost estimates as well as internationally recognised cost estimating methods and selection criteria. Consequently a minimum of two independent cost estimations should be used as sources of input data in order to adequately represent the conclusions developed by the planning organisations involved. The probability mass assignments of the focal sets may be identical if both sources are rated with the same credibility. Alternatively a higher probability weight $m(A_i)$ may be assigned to the cost estimation elaborated by the international planner to reflect a higher level of experience and engineering competence. In this case the result of the local consultant is rated with a reduced credibility. The selected interval ranges are based on the deterministic calculations of capital expenses as established in the feasibility study.

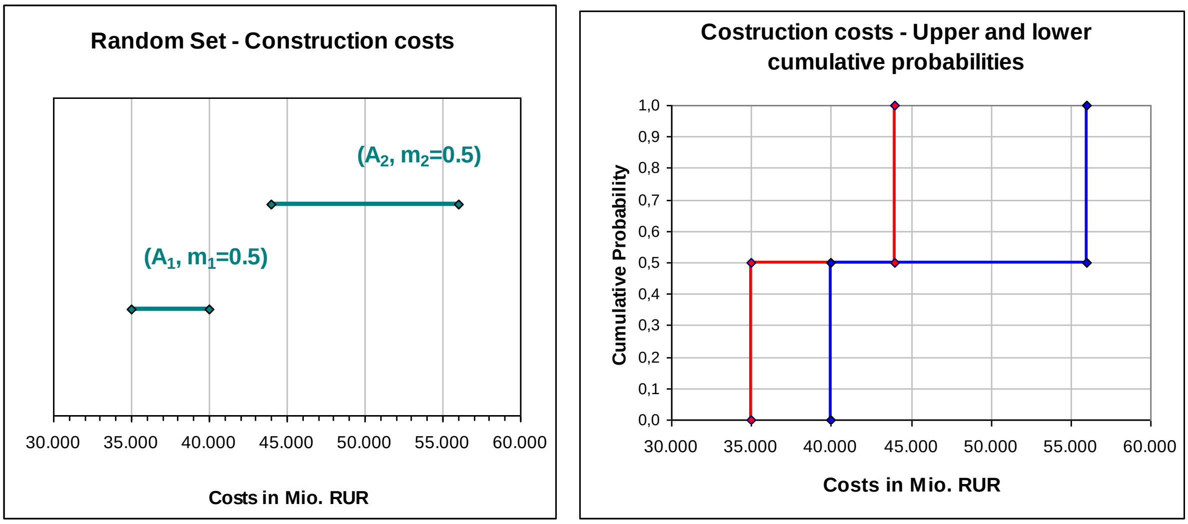


Figure 36: Interval ranges for capital expenses (m = 1/n = 0.5)

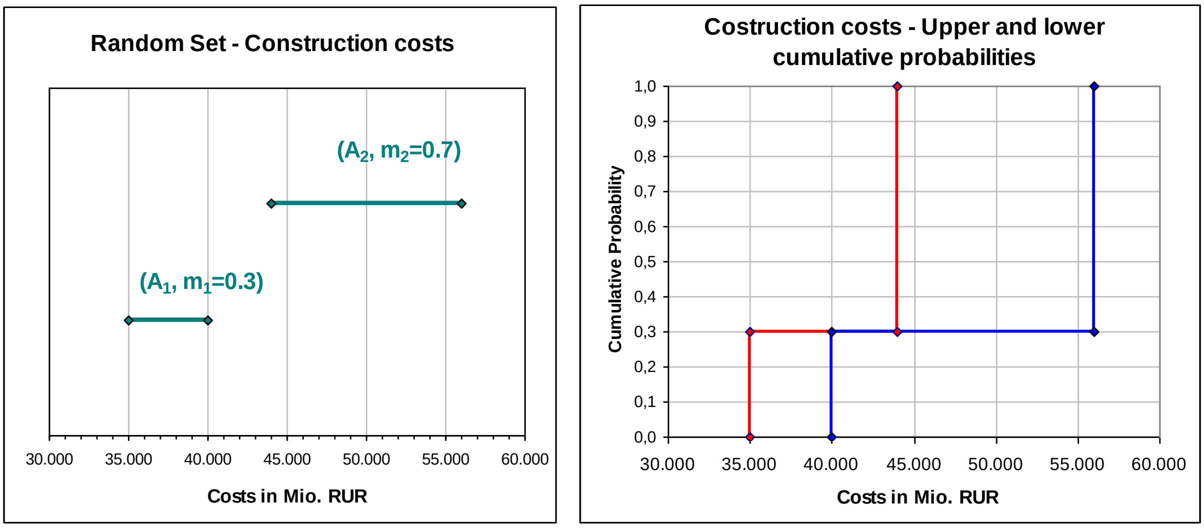


Figure 37: Interval ranges for capital expenses ($m_1 = 0.3$, $m_2 = 0.7$)

One main advantage of the RSM is the possibility to further refine the simulation model to reflect the progress achieved in different planning stages when more detailed information has been elaborated or can be made available.

The typical planning process for a power project can be described by the following sequence of planning activities:

a) Reconnaissance studies

b) Prefeasibility study

c) Feasibility study

d) Conceptual design (permit application)

e) Preparation of tender documents

f) Detailed design

g) Construction design

Under normal conditions, each step of the planning process is characterised by an additional gain of information resulting in a higher level of accuracy for the corresponding calculations. The amount of uncertainty and risk caused by uncertain input parameters is gradually reduced during each consecutive step of the planning process.

During initial planning stages construction costs can only be roughly estimated, since exact quantities and factual unit prices are not available. At this stage the estimate is usually based on specific costs (e.g., € per m^3 of reinforced concrete, € per m^3 of excavated material or € per KW installed capacity), which does not provide a high level of precision. The accuracy level for the cost estimation is considerably improved at prefeasibility and feasibility level, after possible construction methods have been assessed in further detail and cost estimates are based on calculated quantities and unit prices. Realistic prices may be obtained from comparable projects that have been completed under similar conditions in the same or, as far as cost levels are concerned, in a comparable region. The estimate for very cost intensive items such as electrical and hydro-mechanical equipment (e.g., turbines, generators etc.) should be backed up by quotations received from potential future suppliers.

The highest level of accuracy for the cost estimates is usually achieved at completion of the final design phase, once the construction methods for all structures and exact quantities have been finalised, including unquantifiable items such as site installation, temporary structures etc. At this stage calculated unit prices and quotations received from suppliers and subcontractors do reflect the real costs that have to be expected.

Even if all planning activities have been carried out with a high level of accuracy and competence, project costs may not be determined with absolute precision before the implementation of the project has been completed. Uncertainties such as the occurrence of delays and cost overruns resulting in claims as well as other unforeseen incidents must still be anticipated during the implementation of a complex hydropower project. If the project developer or project owner seeks protection against such project risks, this can be supported by establishing appropriate legal measures (EPC contract, insurance etc.) to guarantee effective risk mitigation and risk management.

The increased accuracy level of the cost estimation, corresponding to the individual project phases, is illustrated in figure 38.

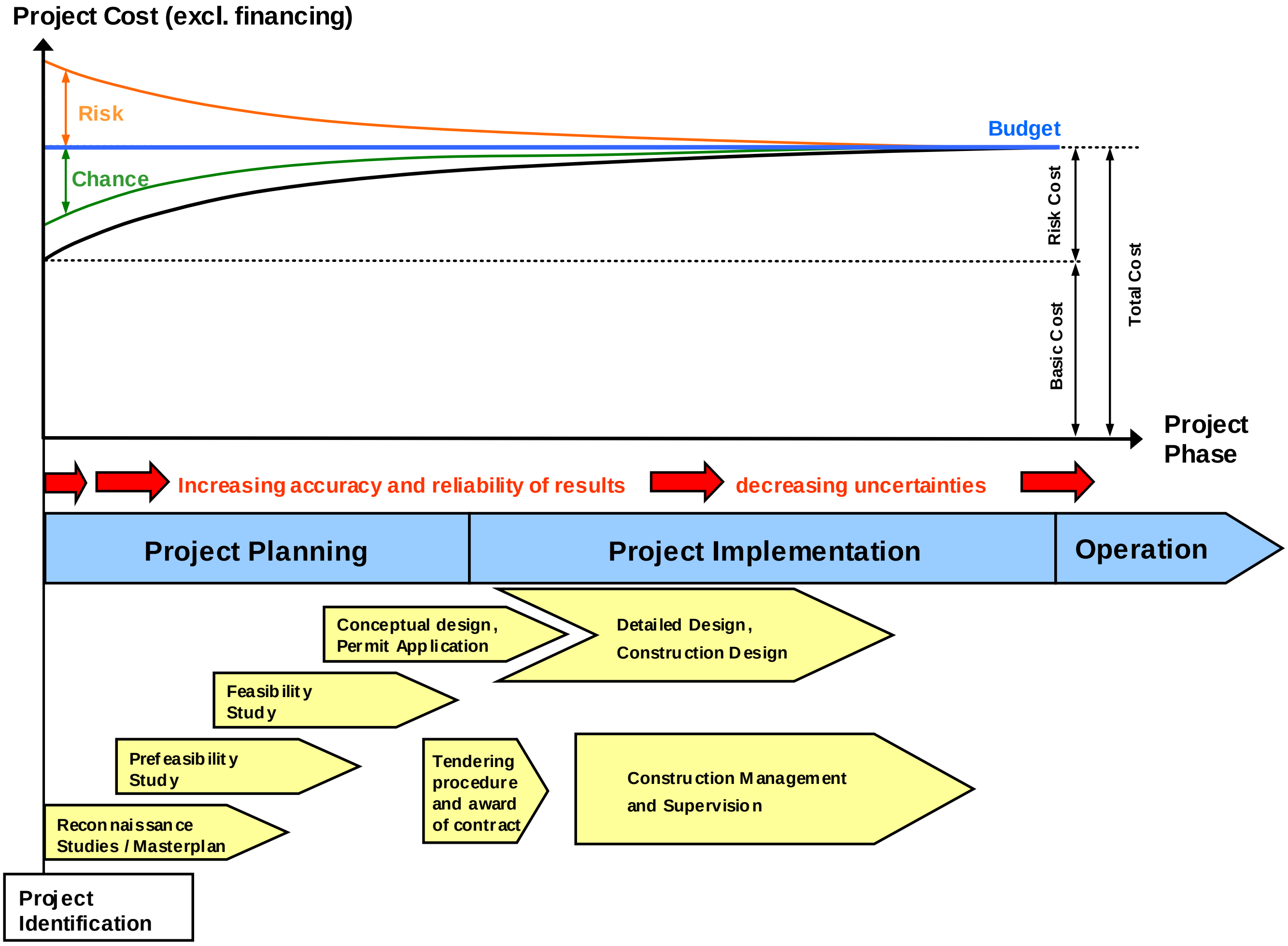


Figure 38: Accuracy of cost estimation during the project development cycle

The random set method represents an efficient tool to model the various, changing levels of accuracy that characterise different planning phases. The increased level of precision that can be achieved at each consecutive planning stage is modelled by reducing the interval range of the input parameters accordingly. The parameter range describing capital expenses (CAPEX) is reduced reflecting the additional gain of precision for the cost estimation or the decreasing amount of uncertainty inherent to the calculations respectively. The same principle can also be applied for other input parameters of the financial model as described in the following chapter of the study.

4.3.2.2 Projected construction period and the impact on expected revenue generation

To account for uncertainties and risks related to the selected construction methods and their possible effects on the required construction time two alternative scenarios describing the length of the construction period are incorporated into the financial model. In addition to the basic assumption of a 5+1 year construction period an alternative scenario accounts for a period of 6+1 years for completion of all construction activities. Both scenarios take into account that government authorities will assume responsibility for establishing of the required infrastructure such as roads, transportation systems, power supply etc. Consequently not cost occur for the project during the first year.

The capital expenses including construction costs are distributed over the different construction periods as depicted in the following table:

Year of construction	**Cost distribution**	
Activity	**Scenario 1** (5+1 years)	**Scenario 2** (6+1 years)
1st year (infrastructure and preparatory works)	0%	0%
2nd year (1st year of construction activities on site)	25%	20%
3rd year	15%	15%
4th year	20%	15%
5th year	15%	15%
6th year (last year of construction activities on site for scenario 1)	15%	15%
7th year (last year of construction activities on site for scenario 2)	10%	15%
8th year	0%	5%

Table 7: Distribution of costs over the construction period

Apart from defining the timely distribution of project expenditures, the assumptions for the required construction time have a direct impact on the commencement of revenue generation. Since the construction of the power house and delivery of the required electro-mechanical equipment (e.g., turbines and generators) extend over several years, it is assumed that during the last year of construction 3 out of 8 hydropower units are already operational. The operation of the plant with reduced capacity indicates the commencement of revenue generation and remaining hydropower units will become operational upon completion of all construction activities.

In case that the required total construction time can be reduced by one year (e.g. by introducing accelerating measures or implementation of faster construction methods) the generation of revenues is consequently scheduled to commence one year earlier as well.

Due to the earlier commencement of revenue generation the reduction of construction time by one year is expected to result in a considerable impact on the profitability of the project and should increase its attractiveness for further development. To ensure a profound assessment of the projects economic merit, the varying length of the construction period is incorporated in the financial model in form of two alternative scenarios describing the required construction times as well as the impact on the commencement of turbine operation. The revenue generation is directly linked to progress and completion date of the construction activities.

4.3.2.3 Estimated development of future electricity prices

Since the exact development of future power tariffs under immature market conditions is extremely difficult to predict the expected prices can only be estimated as tariff ranges, which are indicated in figure 39 below.

Instead of relying on a curve that is expected to denote the future tariff situation, upper and lower boundaries of the tariff development are represented by an upside case (green curve) indicating an optimistic tariff scenario and a base case (red curve), which represents a pessimistic or worst case scenario.

It can be considered as highly unlikely that the actual market development will lead to prices exceeding the boundaries of the described tariff interval.

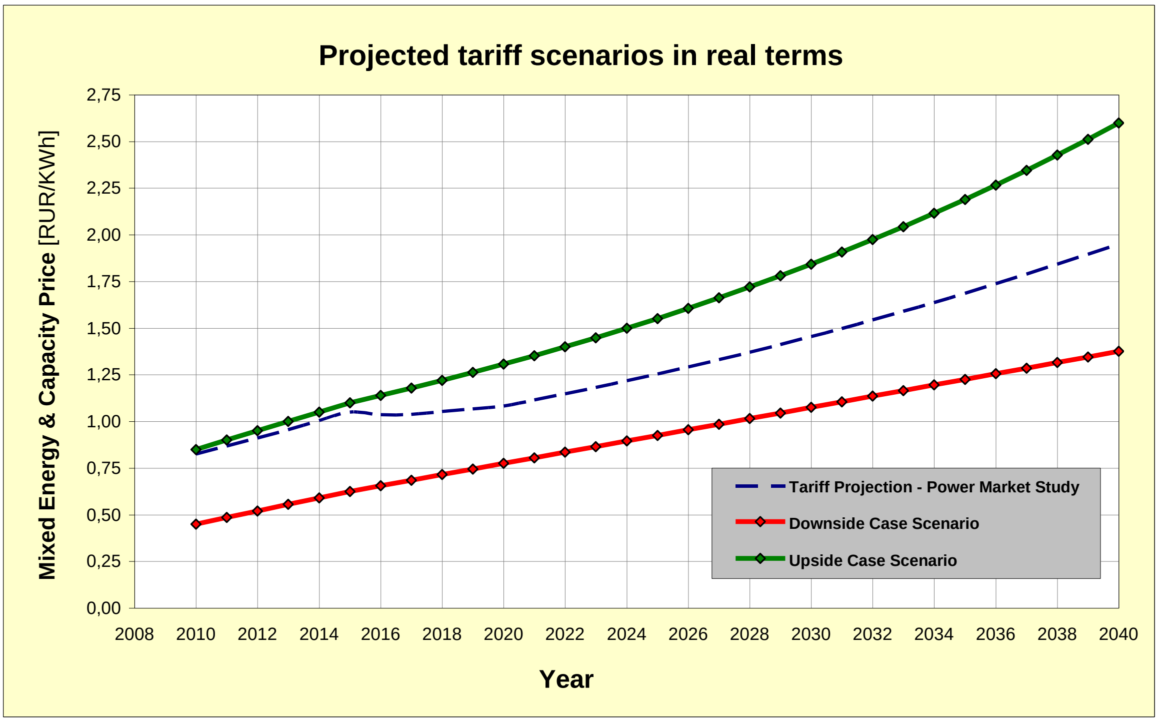


Figure 39: Interval ranges bounding future tariff projections

The diagram illustrating the future price development is based on tariff predictions reflecting free electricity market prices, which are a result of the existing supply and demand. Due to the high level of uncertainty inherent to future tariff projections it appears much more realistic to provide estimates as price ranges rather than attempting to generate a deterministic price curve consisting of single values. The tariff prediction could be extended by incorporating capacity remuneration, in case that future markets do not rely on government subsidy and value the installed capacity of the power plant.

An expansive price range as shown in the previous diagram is probably too substantial to provide a clear indication regarding the financial feasibility of a power project. The resulting lack of sufficient planning security may not be acceptable to the project developer and potential investors.

Projected tariff scenarios as illustrated in figure 39 are based on the operation of a merchant power plant that sells electricity within the competitive wholesale power market. Merchant power plants, by definition, do not have pre-identified customers and are not tied up with long-term power purchase agreements (PPAs). The development of a merchant power plant will mostly require balance sheet financing by the developer, given that financial institutions and lenders may not be comfortable with the risks inherent to projects that are not based on long-term PPAs.

As part of chapter 5, the subject of PPAs will be referred to in further detail, when possible measures are described that contribute to uncertainty reduction for the investment decision making.

4.3.2.4 Discount rate

The important role of the discount rate for the calculation of the project's financial feasibility indicators is described in chapter 2.2 of the study.

In order to account for possible variations of the discount rate, which is subject to the definite future project financing conditions, the random set analysis is performed with alternative values for this key parameter. By means of the random set analysis the major influence of the discount rate on the profitability of the project will be confirmed.

Three different information sources have been selected to represent possible parameter ranges for the discount rate. The random set is illustrated in figure 40. Two focal elements indicating parameter ranges from 8% to 12% and 10% to 15% possess a probability weight of 0.4 each.

The third interval, representing a parameter range from 6% to 9%, is weighted with a reduced probability of 0.2 since this rather low discount rate appears unrealistic for a merchant power plant in the described economic and political environment.

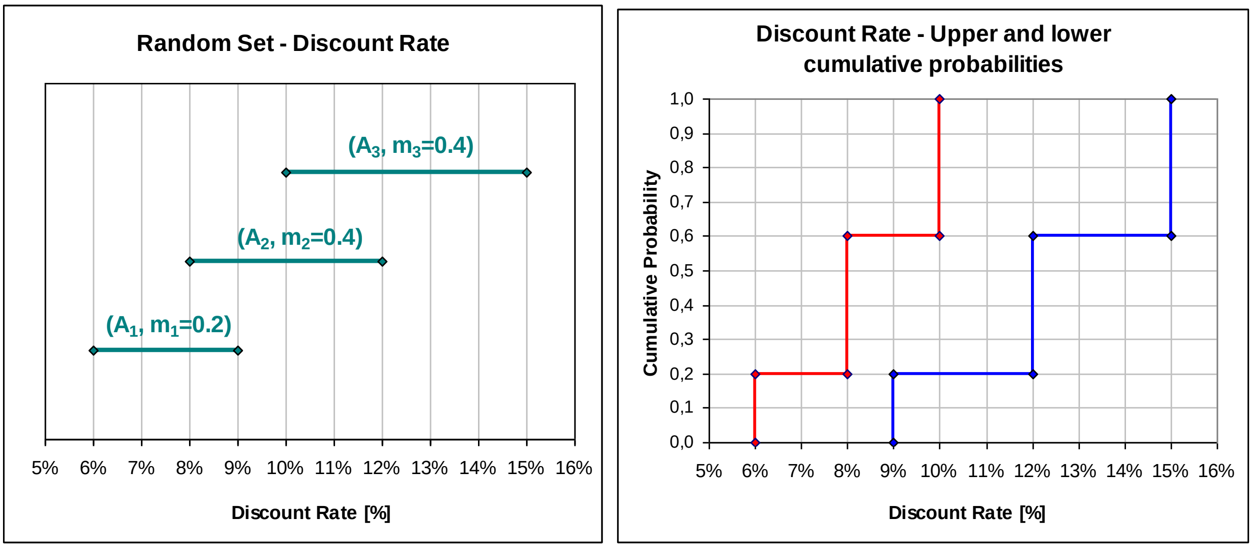


Figure 40: Interval ranges for the selected discount rate

The different sources of information as well as the considerable parameter ranges reflect an early planning stage (prefeasibility level) of the study. Once the planning works are more advanced (e.g., at feasibility level or final design stage) it can be expected that the number of information sources that need to be considered can be reduced and the interval ranges will decrease.

4.3.2.5 Further parameters for random set input

For the verification of the deterministically calculated design parameters, the input parameters that are displayed as random sets have been limited to the following figures:

- capital expenses
- construction time
- power tariff
- discount rate

This approach is deemed to be appropriate to achieve the purpose of this study, which is to assess the suitability of the random set method for handling of imprecise input parameters. If the number of random sets is not limited to the key parameters, the analysis may not benefit from the use of the RSM due to a loss of transparency and increased requirements for calculating capacity and computational effort. Once the methodology based on parameter intervals has been established and its suitability for the project evaluation been demonstrated, the construction of random sets can be expanded to other parameters as well.

The estimated construction costs for example may be further refined by breaking the total amount of expenditures down into individual costs items describing the plant's main components such as dam, spillway, powerhouse, ship lock, transmission etc. Each cost item can be defined as an interval characterised by a minimum and maximum monetary value and may also represent different sources of information where applicable.

The application of the same methodology can be considered for costs that are difficult to quantify such as expenditures for temporary structures, site installation, preparation of the reservoir etc. In addition to civil costs, items such as development costs, costs for engineering and supervision, management fees, contingencies etc. may also be managed through interval analysis. Especially during early stages of the project assessment, the identification and exact specification of the scope for certain activities is often difficult, since confirmed and dependable information cannot be obtained. The RSM may also offer support for the formal description of such problems.

In principal, random sets may also be created to describe and manage figures such as plant efficiency, annual power production etc. However, the experience gained during preparation of this study confirmed that the use of the random set method should be strictly limited to input parameters that are expected to have a significant impact on the result of the analysis and where a deterministic description does not seem to be appropriate.

5 RESULT OF ANALYSIS AND CONCLUSIONS FOR INVESTMENT DECISION

5.1 Calculation of discrete cumulative probability distributions

Initially the analysis assesses the overall risk and profit potential of the project based on the key input parameter sets illustrated in chapter 4.3.

The input parameter intervals are defined below and do not have probability weights assigned, i.e. they are all rated with the same credibility.

a) Capital expenses (million RUR)

Number of information sources: 2

A_1 = [35000; 40000],

A_2 = [44000; 56000]

b) Construction time (years)

Number of information sources: 1

A = [6; 7]

c) Tariff Scenarios (RUR/KWh)

Number of information sources: 1

Upside case scenario, downside case scenario according to figure 39

d) Discount rate (%)

Number of information sources: 3

A_1 = [6; 9],

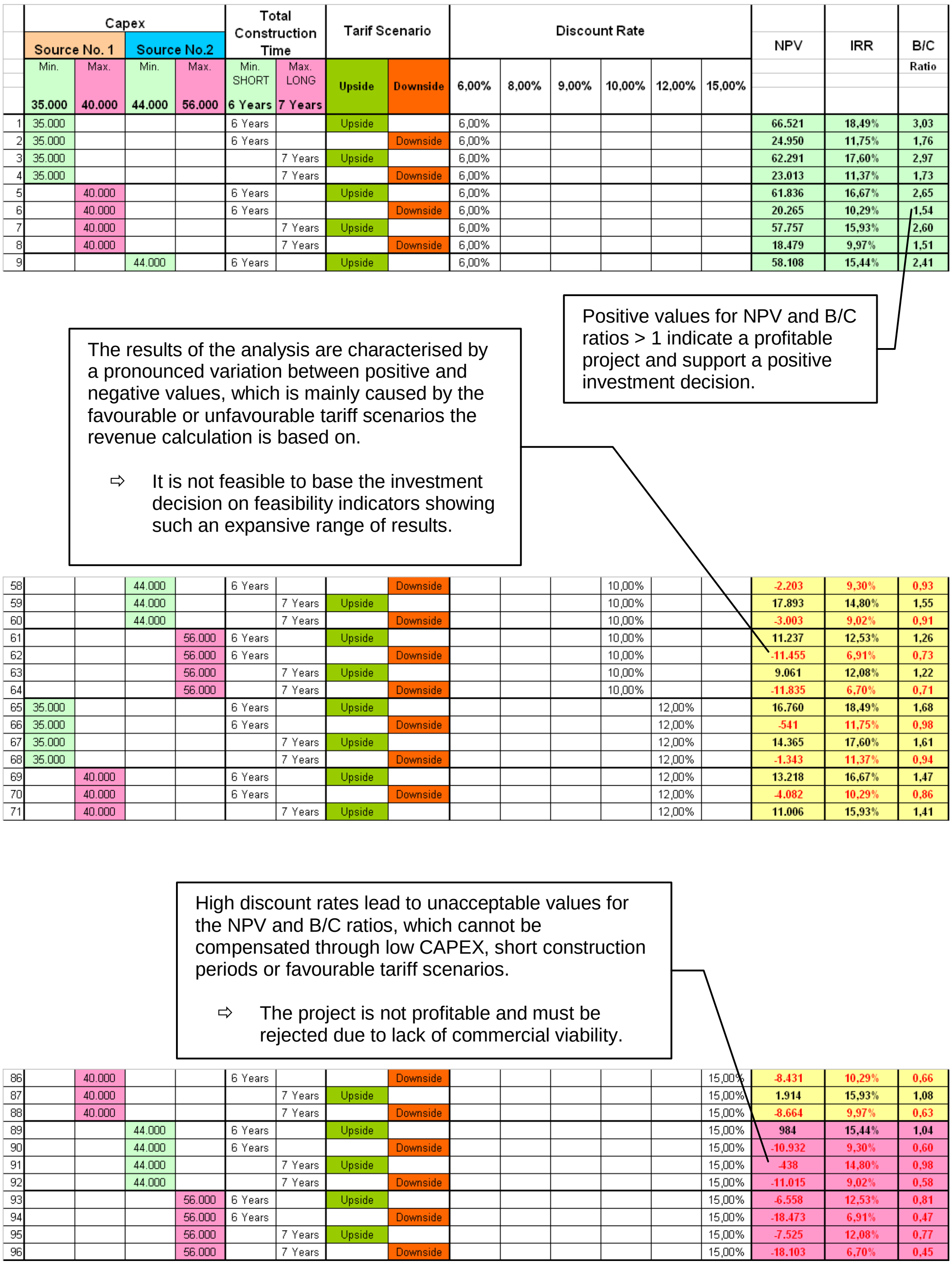
A_2 = [8; 12],

A_3 = [10; 15]

The model used for the financial analysis calculates values for the financial feasibility indicators NPV, IRR and BCR (benefit cost ratio).

The combination of 4 input parameter sets based on two information sources for capital expenses and three information sources for the discount rate leads to $2^4 \cdot 2 \cdot 3 = 96$ results for each parameter as illustrated in appendix A2.

The results of the financial analysis based on the described input parameter ranges are illustrated in figure 41. The complete table is depicted in section A2 of the appendix. NPV values below zero (NPV < 0), BCRs smaller than one (BCR < 1) and IRRs which are below the assumed discount rate are marked in red colour since these parameters indicate an unprofitable project, which leads to a negative investment decision.



	Capex				Total Construction Time		Tarif Scenario		Discount Rate						NPV	IRR	B/C
	Source No. 1		Source No.2														
	Min. 35.000	Max. 40.000	Min. 44.000	Max. 56.000	Min. SHORT 6 Years	Max. LONG 7 Years	Upside	Downside	6,00%	8,00%	9,00%	10,00%	12,00%	15,00%			Ratio
1	35.000				6 Years		Upside		6,00%						66.521	18,49%	3,03
2	35.000				6 Years			Downside	6,00%						24.950	11,75%	1,76
3	35.000					7 Years	Upside		6,00%						62.291	17,60%	2,97
4	35.000					7 Years		Downside	6,00%						23.013	11,37%	1,73
5		40.000			6 Years		Upside		6,00%						61.836	16,67%	2,65
6		40.000			6 Years			Downside	6,00%						20.265	10,29%	1,54
7		40.000				7 Years	Upside		6,00%						57.757	15,93%	2,60
8		40.000				7 Years		Downside	6,00%						18.479	9,97%	1,51
9			44.000		6 Years		Upside		6,00%						58.108	15,44%	2,41
58			44.000		6 Years			Downside				10,00%			-2.203	9,30%	0,93
59			44.000			7 Years	Upside					10,00%			17.893	14,80%	1,55
60			44.000			7 Years		Downside				10,00%			-3.003	9,02%	0,91
61				56.000	6 Years		Upside					10,00%			11.237	12,53%	1,26
62				56.000	6 Years			Downside				10,00%			-11.455	6,91%	0,73
63				56.000		7 Years	Upside					10,00%			9.061	12,08%	1,22
64				56.000		7 Years		Downside				10,00%			-11.835	6,70%	0,71
65	35.000				6 Years		Upside						12,00%		16.760	18,49%	1,68
66	35.000				6 Years			Downside					12,00%		-541	11,75%	0,98
67	35.000					7 Years	Upside						12,00%		14.365	17,60%	1,61
68	35.000					7 Years		Downside					12,00%		-1.343	11,37%	0,94
69		40.000			6 Years		Upside						12,00%		13.218	16,67%	1,47
70		40.000			6 Years			Downside					12,00%		-4.082	10,29%	0,86
71		40.000				7 Years	Upside						12,00%		11.006	15,93%	1,41
86		40.000			6 Years			Downside						15,00%	-8.431	10,29%	0,66
87		40.000				7 Years	Upside							15,00%	1.914	15,93%	1,08
88		40.000				7 Years		Downside						15,00%	-8.664	9,97%	0,63
89			44.000		6 Years		Upside							15,00%	984	15,44%	1,04
90			44.000		6 Years			Downside						15,00%	-10.932	9,30%	0,60
91			44.000			7 Years	Upside							15,00%	-438	14,80%	0,98
92			44.000			7 Years		Downside						15,00%	-11.015	9,02%	0,58
93				56.000	6 Years		Upside							15,00%	-6.558	12,53%	0,81
94				56.000	6 Years			Downside						15,00%	-18.473	6,91%	0,47
95				56.000		7 Years	Upside							15,00%	-7.525	12,08%	0,77
96				56.000		7 Years		Downside						15,00%	-18.103	6,70%	0,45

Positive values for NPV and B/C ratios > 1 indicate a profitable project and support a positive investment decision.

The results of the analysis are characterised by a pronounced variation between positive and negative values, which is mainly caused by the favourable or unfavourable tariff scenarios the revenue calculation is based on.

⇨ It is not feasible to base the investment decision on feasibility indicators showing such an expansive range of results.

High discount rates lead to unacceptable values for the NPV and B/C ratios, which cannot be compensated through low CAPEX, short construction periods or favourable tariff scenarios.

⇨ The project is not profitable and must be rejected due to lack of commercial viability.

Figure 41: Results of interval based financial analysis for NPV, IRR and BCR

Figures 42 and 43 illustrate the results of the analysis for NPV and BCR in form of cumulative probability distributions. The acceptable ranges for the calculated feasibility indicators denoting a profitable project are highlighted in the diagrams.

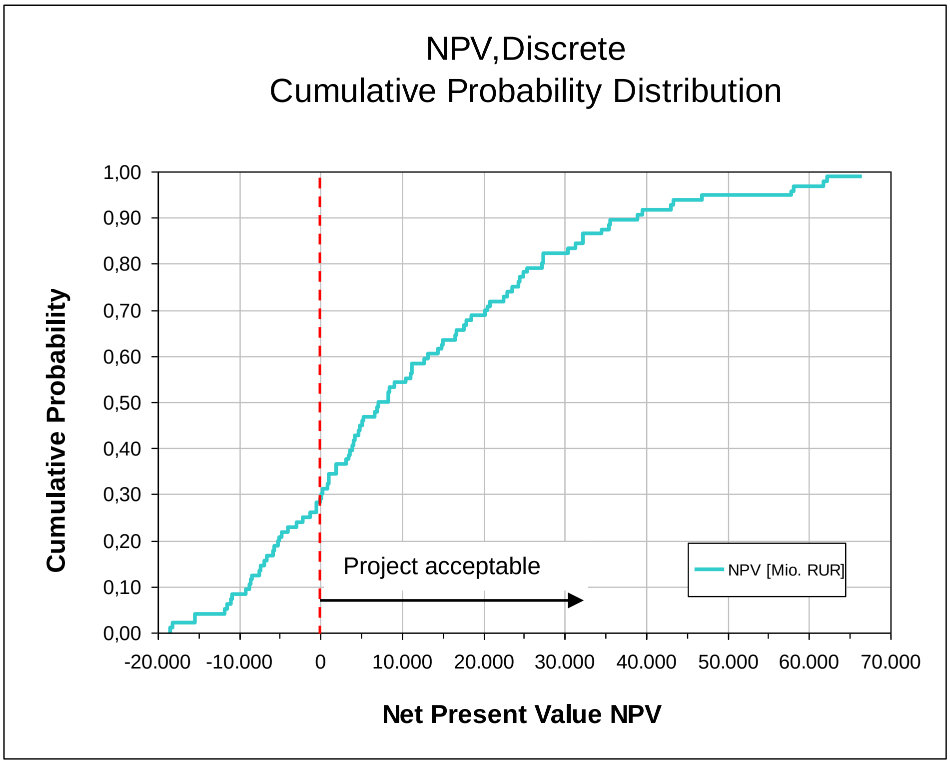


Figure 42: NPV depicted as cumulative probability distribution

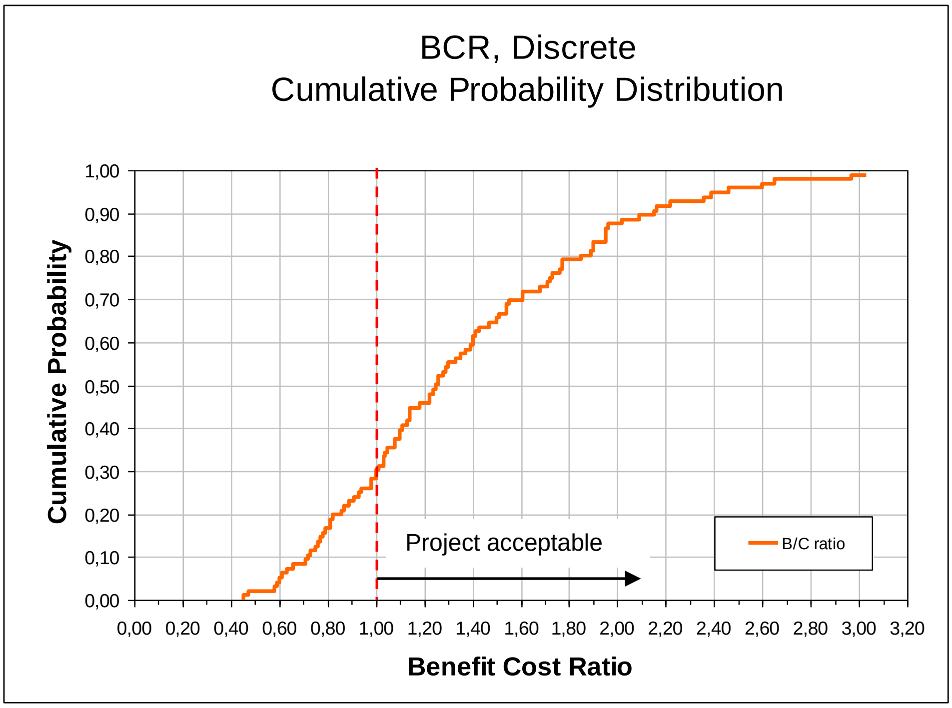


Figure 43: BCR depicted as cumulative probability distribution

As described in chapter 2.2 of the study a desirable capital investment is characterised by a NPV > 0 and a BCR > 1, indicating that the discounted benefits of the project exceed the total of the discounted costs.

The probability distributions for both feasibility indicators NPV and BCR exhibit a probability of approximately 30% that the minimum requirements for a positive investment decision (NPV > 0, BCR > 1) cannot be meet. This high level of uncertainty is most probably not acceptable for investors or lending organisations and therefore likely to lead to a rejection of the investment, although the project may generally possess good prospects for being profitable. The existence of a potentially attractive investment opportunity is indicated by the fact that the potential for exceeding the minimum requirements appears to be by far higher than the risks indicated by the CDF. While the negative range for the NPV is limited by a value of -18,500 million RUR, the maximum NPV extends to values above 66,500 million RUR as illustrated in figure 42. The minimum value for the BCR of 0.45, representing a worst case scenario, is contrasted by a maximum value of 3.03, which clearly indicates the projects evident potential for added profits (see figure 43).

The extreme cases correspond to a combination of all favourable or unfavourable parameter combinations for CAPEX, construction time, tariff scenario and discount rate. These best and worse cases are very unlikely to represent realistic scenarios for the implementation and operation of the project. It is therefore required that appropriate acceptance criteria are developed by the decision maker to define an acceptable risk level, which justifies the financial participation in the project.

A possible criterion for the investment decision could be that the probability for NPVs < 0 and BCRs< 1 must not exceed a certain percentage (e.g. 20%) and that the potential for added benefits must remain higher than the risk, that the project may represent an unprofitable investment. Secondary investment criteria as described in chapter 2.2 may require additional consideration if the primary targets are met by the project.

In addition to the above, the results of the preliminary analysis clearly indicate that discount rates of 15% and more do not lead to a profitable project even if favourable parameters are selected for CAPEX, construction time and tariff scenario. It must therefore be concluded that the project is commercially not viable if discount rates of 15% or more must be considered in order to appropriately reflect the opportunity cost of capital. Since this constraint must be regarded as a key requirement for achieving the financial feasibility of the project, discount rates selected for all subsequent calculations do not exceed 15%.

The following figure illustrates the results of the analysis for the IRR in form of a cumulative probability distribution:

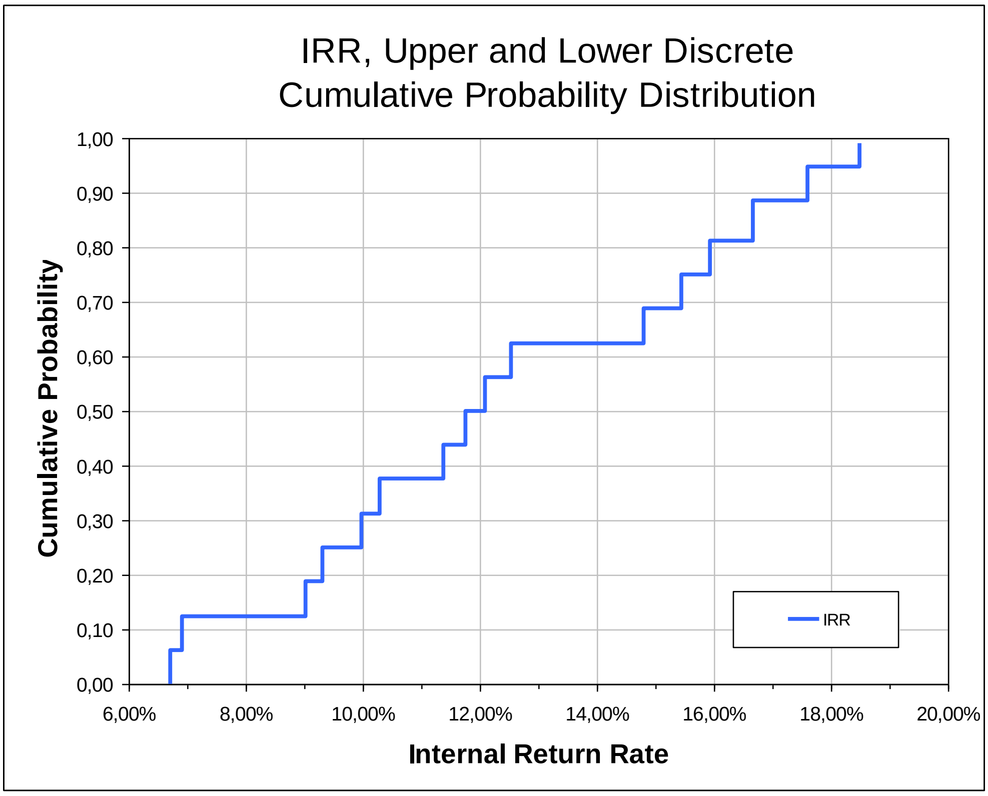


Figure 44: IRR depicted as cumulative probability distribution

The graphical presentation of the IRR in form of a CDF confirms the clarifications conveyed in chapter 2.2.4, which conclude that the IRR only provides limited suitability as a primary criterion to support the investment decision. The CDF illustrates the results of the IRR calculation as absolute values and does not provide information regarding the discount rates the calculations are based on. It is therefore not possible to identify the opportunity costs of capital, which have been assumed for the individual IRR calculations and relate the two figures to each other, even though this represents the acceptance criterion of the methodology.

In addition, the CDF indicates that a variation of the input parameter discount rate does not affect the result of the IRR calculation. Under variation of the discount rate, the different input parameter combinations entering into the financial analysis lead to the same results for the IRR. This explains why the interval bounds illustrated in figure 44 and table A2 of the appendix, ranging from 6.70% to 18.49% for the IRR, are identical for each discount rate and why the CDF displays just 16 values for the IRR although 96 calculations are carried out. Each value is calculated six times corresponding to six different discount rates, which the calculations have been based on.

As a consequence of the above observations the IRR will be regarded as a secondary investment criterion for all subsequent calculations and is not further displayed as a CDF.

5.2 Calculation of upper and lower cumulative probabilities

The analysis described in chapter 5.1 can also be performed with random sets representing input parameter ranges. In this case a probability weight is assigned to each focal set and the results of the financial analysis are depicted as upper and lower bounds of the cumulative probability distribution for the financial feasibility indicators.

The focal sets, which denote parameter ranges for the input parameters CAPEX, construction time, tariff scenario and discount rate are summarised in table 8 below. The information sources for CAPEX are rated with the same credibility. The probability weights for the three information sources representing expected discount rates are also balanced, with a slightly reduced probability assigned to the rather optimistic parameter range from 6% to 9%.

Parameter	Source	Parameter L	Parameter U	Probability Assignments
CAPEX [Mio. RUR]	A_1	35,000	40,000	0.50
	A_2	44,000	56,000	0.50
Construction Time	A	6 years	7 years	1.00
Tariff Scenario	A	Upside case	Downside case	1.00
Discount Rate [%]	A_1	6	9	0.30
	A_2	8	12	0.35
	A_3	10	15	0.35

Table 8: Random sets and focal elements representing 4 input parameters

The focal sets A_1 and A_2 as well as A_2 and A_3, indicating parameter ranges for the discount rate, are in partial agreement since their parameter ranges partially overlap. The focal sets A_1 and A_2 defining parameter ranges for capital expenses are dissonant (compare Tonon 2004).

The upper and lower cumulative probability functions are calculated and displayed for the financial feasibility indicators NPV and BCR only. The IRR is not used as a primary indicator for assessing the projects financial feasibility.

The results of the random set based analysis are depicted in table format in section A4 of the appendix and include a summary of all possible parameter combinations.

The calculated values for NPV and BCR for all possible input parameter combinations as well as the bounds of the CDF are summarised in table 9 below:

NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
		LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
1																			
2	NPV	66.521	34.487	24.950	62.291	8.305	23.013	31.286	7.010	61.836	30.450	20.265	57.757	4.267	18.479	27.419	3.143	**3.143**	**66.521**
3	BCR	3,03	2,22	1,76	2,97	1,29	1,73	2,16	1,26	2,65	1,95	1,54	2,60	1,13	1,51	1,89	1,10	**1,10**	**3,03**
4																			
5																			
6	NPV	58.108	27.237	16.537	54.149	1.055	14.871	24.343	66	46.875	17.556	5.304	43.277	-8.627	3.999	15.070	-9.206	**-9.206**	**58.108**
7	BCR	2,41	1,77	1,40	2,36	1,03	1,37	1,72	1,00	1,90	1,39	1,10	1,85	0,81	1,08	1,35	0,79	**0,79**	**2,41**
8																			
9																			
10	NPV	43.094	16.760	12.721	39.578	-541	11.231	14.365	-1.343	38.861	13.218	8.488	35.509	-4.082	7.163	11.006	-4.701	**-4.701**	**43.094**
11	BCR	2,46	1,68	1,43	2,39	0,98	1,40	1,61	0,94	2,15	1,47	1,25	2,09	0,86	1,22	1,41	0,82	**0,82**	**2,46**
12																			
13																			
14	NPV	35.493	10.401	5.120	32.272	-6.900	3.926	8.335	-7.373	25.342	1.910	-5.031	22.517	-15.391	-5.829	281	-15.426	**-15.426**	**35.493**
15	BCR	1,96	1,33	1,14	1,90	0,78	1,11	1,28	0,75	1,54	1,05	0,89	1,50	0,61	0,87	1,01	0,59	**0,59**	**1,96**
16																			
17																			
18	NPV	27.417	6.630	4.725	24.506	-5.285	3.610	4.870	-5.708	23.558	3.485	867	20.823	-8.431	-73	1.914	-8.664	**-8.664**	**27.417**
19	BCR	2,02	1,30	1,18	1,95	0,76	1,14	1,24	0,72	1,77	1,14	1,03	1,71	0,66	1,00	1,08	0,63	**0,63**	**2,02**
20																			
21																			
22	NPV	20.488	984	-2.203	17.893	-10.932	-3.003	-438	-11.015	11.237	-6.558	-11.455	9.061	-18.473	-11.835	-7.525	-18.103	**-18.473**	**20.488**
23	BCR	1,61	1,04	0,93	1,55	0,60	0,91	0,98	0,58	1,26	0,81	0,73	1,22	0,47	0,71	0,77	0,45	**0,45**	**1,61**
24																			

Table 9: Results of the random set based financial analysis

The results of the analysis indicate that the criteria leading a positive investment decision can only be met if the calculation is based on the most favourable parameter combinations. Unfavourable parameter combinations lead to values for the NPV < 0 and BCR < 1. Upper and lower bounds of the cumulative probability can be displayed graphically and are illustrated in the following figures 45 and 46.

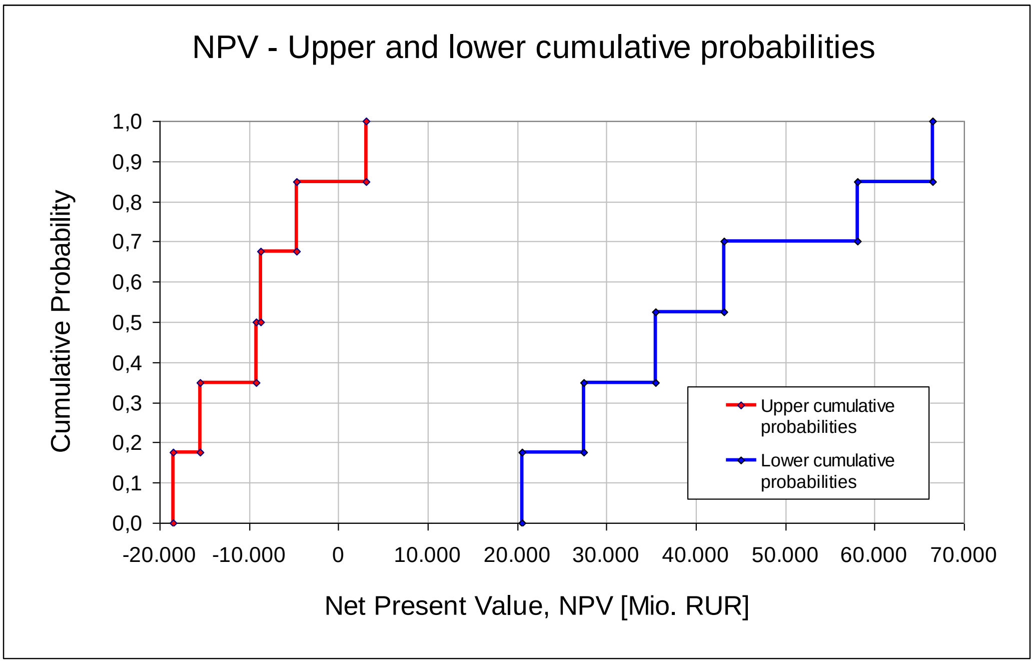


Figure 45: DCF for NPV based on parameter sets summarised in table 8

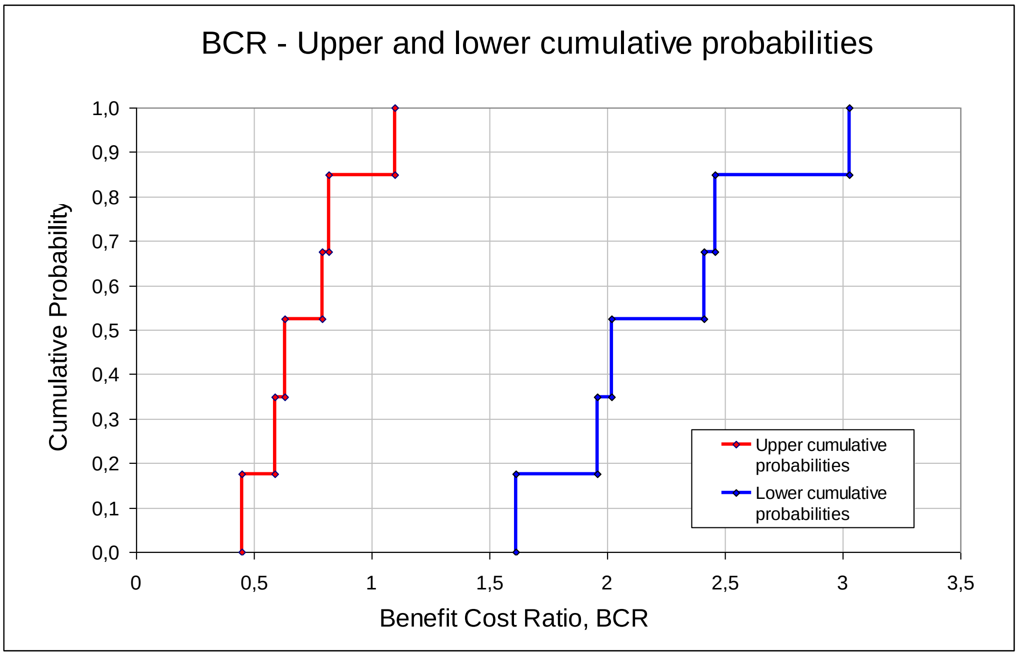


Figure 46: DCF for BCR based on parameter sets as shown in table 8

The calculated cumulative probabilities indicate that the analysis has been based on random sets consisting of focal elements, which are characterised by balanced probability assignments. This does not adequately reflect the real situation as described in chapter 4.3 of the study.

To account for the different credibility ratings associated with the selected information sources, the random set analysis must be performed using different probability weights assigned to the input parameter ranges as illustrated in table 10.

Parameter	Source	Parameter L	Parameter U	Probability Assignments
CAPEX [Mio. RUR]	A_1	35,000	40,000	0.30
	A_2	44,000	56,000	0.70
Construction Time	A	6 years	7 years	1.00
Tariff Scenario	A	Upside case	Downside case	1.00
Discount Rate [%]	A_1	6	9	0.20
	A_2	8	12	0.40
	A_3	10	15	0.40

Table 10: Different probability weights assigned to individual information sources

The results of the financial analysis based on the assignment of different probability weights to the individual information sources are illustrated in figure 47 and figure 48.

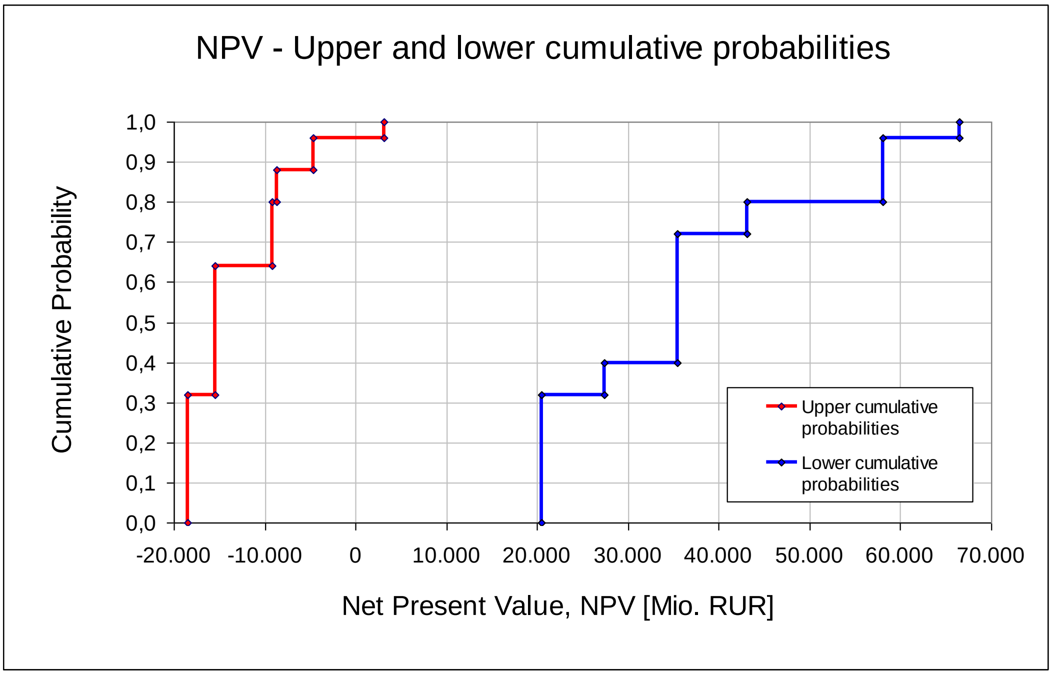


Figure 47: DCF for NPV based on parameter sets as shown in table 10

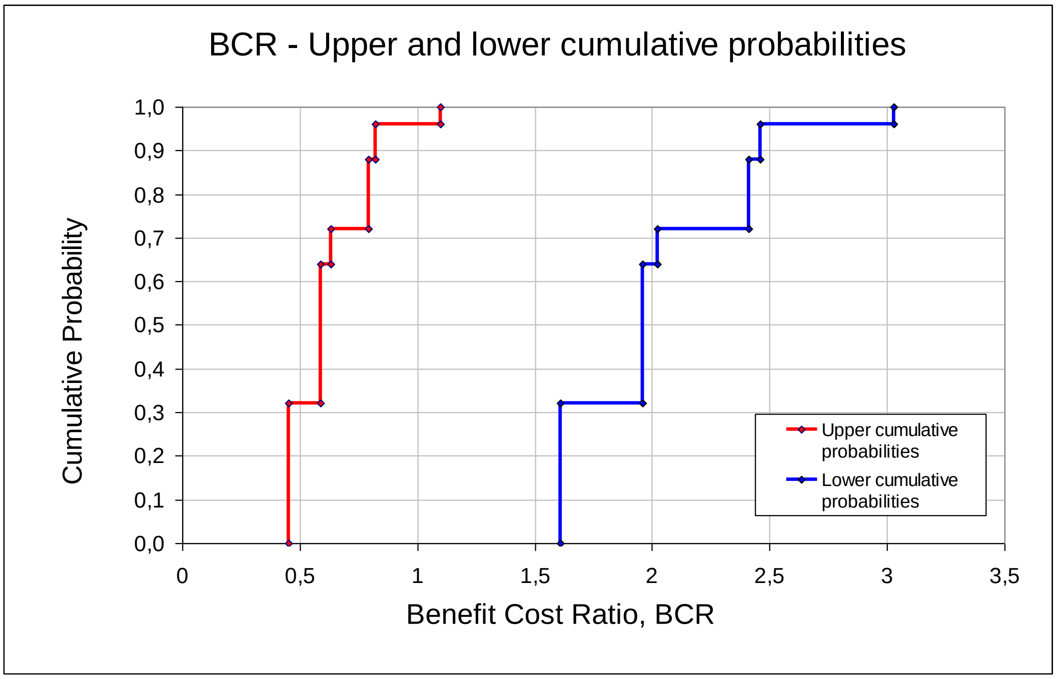


Figure 48: DCF for BCR based on parameter sets as shown in table 10

The results of the analysis confirm that the assignment of probability weights to the information sources as summarised in table 10 has a negative effect on the rating of the project as an investment opportunity.

The increased probability weight assigned to information sources, which represent higher financial expenditures and a wider parameter range for CAPEX, in conjunction with a reduced probability weight for the more favourable (lower) parameter range defining the discount rate, lead to a reduction of the financial project feasibility. The results of the analysis indicate that the modified probability assignments increase the likelihood that the project cannot achieve the minimum requirements stipulated for the financial indicators NPV and BRC. The adjustments made for the probability weights characterising CAPEX and discount rate increase the chances that the financial project analysis produce NPVs < 0 and BCRs < 1 to a probability level above 95%, which makes the project unacceptable for further development.

However, this assessment does not necessarily have to lead to a categorical rejection of the project. The only conclusion that can be drawn from the analysis so far is the awareness, that the profitability of the project cannot be demonstrated based on the currently existing input parameter ranges.

In view of the project’s obvious potential for being profitable (compare chapter 5.1) the financial viability should be further assessed by means of a refined analysis based on more precise information. As described in chapter 3.4 of the study, this can be achieved through the introduction of additional sources of information and by reducing the interval ranges for selected input parameter sets. This procedure and possible options that may lead to a reduction of uncertainties inherent to the project are described in detail in the following section of the study.

5.3 Uncertainty Reduction

As described in chapter 4.3, it can be expected that each consecutive planning stage of the project will provide more detailed and also more reliable project information. During the progression of planning activities, the amount of uncertainties with regard to project design, construction methods, costs etc. should be greatly reduced and technical as well as commercial figures can be trusted with more confidence.

With regard to the application of the RSM, this reduction of uncertainties should lead to modified and in most cases, reduced interval ranges of the input parameters where applicable.

5.3.1 Construction time

The implementation of a large hydropower scheme represents a highly complex, technically and logistically demanding task, with many stakeholders involved. Due to its complexity, the project implementation remains a rather unpredictable process characterised by its inherent uncertainties that are difficult to reduce. From the prospective of the project owner and project developer the key factors that can support the efficient construction and project implementation are summarised as follows:

- Transparent procedures and clear allocation of responsibilities and contractual obligations for all parties involved.
- Diligent planning of resources and activities through a competent and experienced construction management and engineering team.
- Ensured availability and timely provision of all data required for planning activities (e.g., results of site investigation programs and corresponding laboratory tests, hydrological data, flow measurements, environmental data, legal documents, necessary permits etc.).
- A stringent project management founded on systematic planning, scheduling and reporting.
- Selection of an experienced and competent civil contractor, sub-contractors and suppliers.
- Effective risk, quality and cost management.

For a more detailed description of factors that need be considered in this context please refer to Ravlo (Ravlo 2003).

In view of the above, the two alternative scenarios, reflecting the required construction time are maintained in the course of further project analysis to reflect the prevailing uncertainties and their possible impact on the profitability of the project. A more precise prediction of the construction time required does not seem appropriate.

5.3.2 Capital expenses - construction costs

In order to account for the additional knowledge and information available at a more progressed planning stage (e.g. feasibility level or final design stage), the uncertainties with respect to the capital expenses can be reduced, which is indicated through reduced interval ranges. At a more advanced planning stage the cost estimations prepared by the local and international planning team do not show pronounced disparities any more compared to the initial calculations as summarised in table 8.

The focal elements A_1 and A_2 are now in partial agreement since their parameter ranges partially overlap. The adjustment of input parameter ranges reflecting the uncertainty reduction is illustrated in the following diagrams:

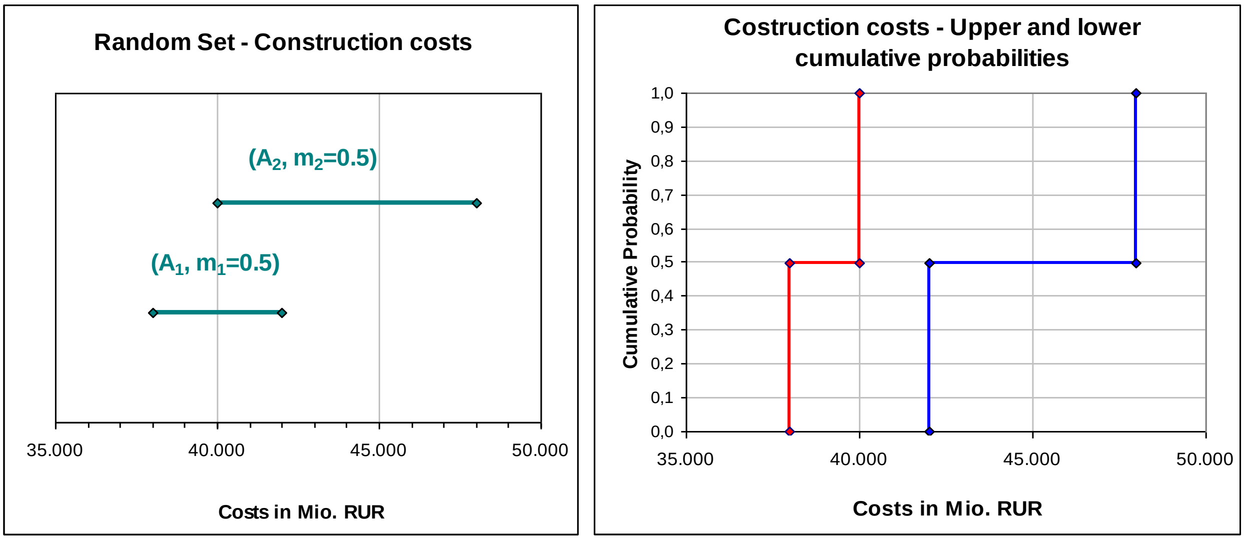


Figure 49: Interval ranges CAPEX at progressed project phase (m = 1/n = 0.5)

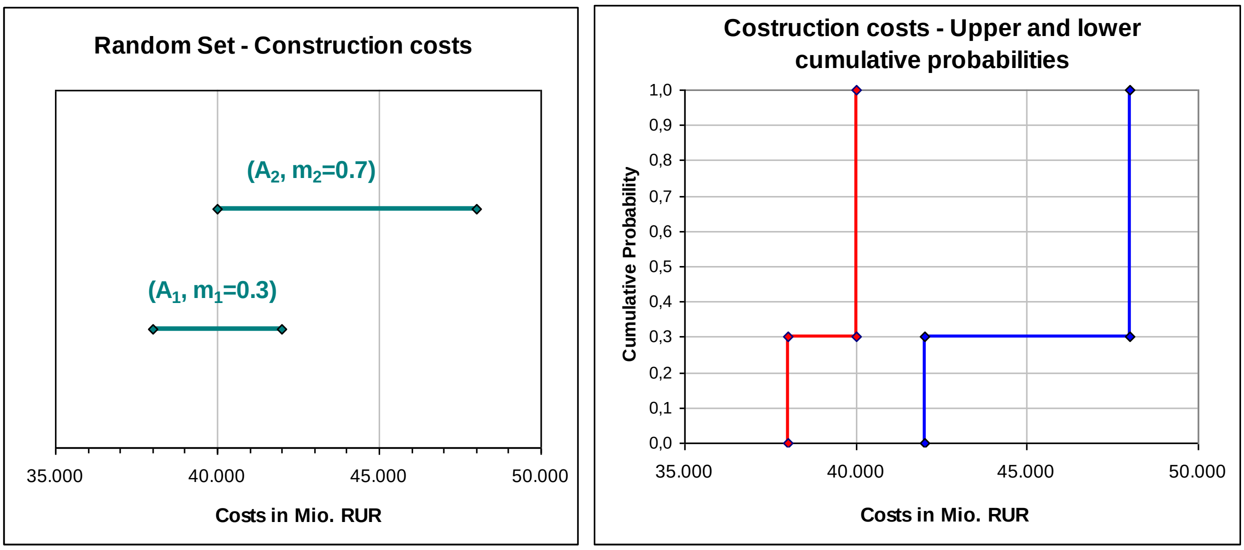


Figure 50: Interval ranges CAPEX at progressed project phase ($m_1 = 0.3$, $m_2 = 0.7$)

5.3.3 Discount rate

The progressed level of planning activities during a more developed project phase should also reduce the uncertainties related to financial issues and financing concerns. This includes the question of which parameter range may be appropriate for the discount rates used in the financial project analysis. The investigation of the financial markets, negotiations with potential lenders as well as the availability of more accurate and reliable project information allows for a more precise judgment, regarding which discount rate can be expected considering the project specific conditions.

In order to represent a more progressed phase of the project development, the further analysis will be based on two independent sources of information for the discount rate, characterised by different interval ranges.

The parameter intervals are ranging from 8% to 12% and from 10% to 14% as illustrated below. Each source of information is rated with the same credibility of 0.5 in the financial analysis.

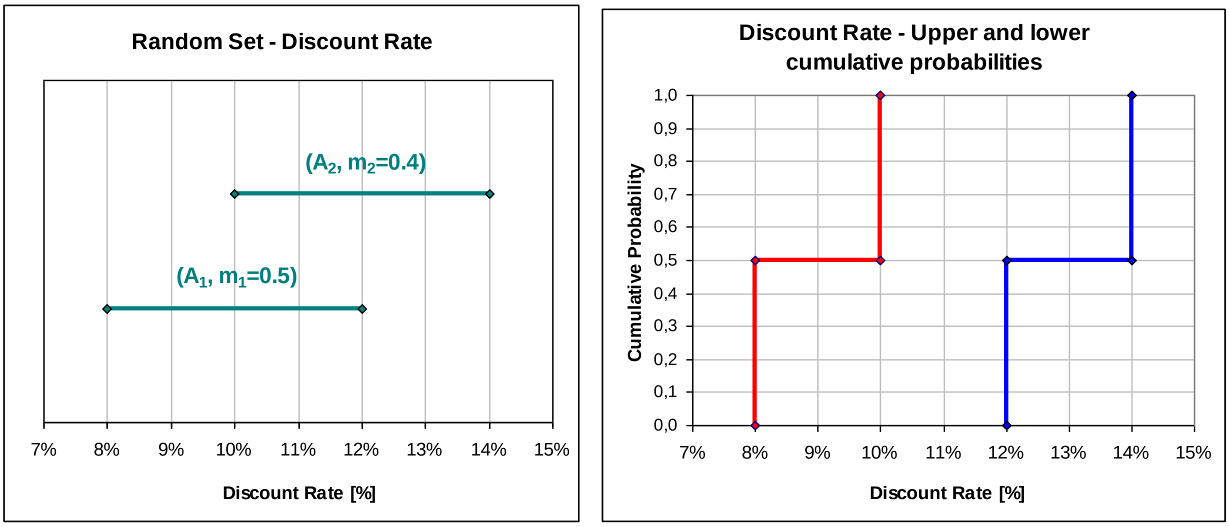


Figure 51: Interval ranges for the discount rate at a progressed planning phase

5.3.4 Tariff projection

Instead of operating the hydropower scheme as a merchant power plant, the possibility exists to sign contracts with industrial consumers. Such agreements define amount and price of the purchased power in advance. This option represents a commonly used alternative to reduce price variations and the corresponding risks related to revenue generation. By means of so called power purchase agreements (PPAs), the width of the interval indicating the possible price range for the remuneration of generated power can be significantly reduced.

In the event of a signed PPA, a contractually agreed amount of the generated power output produced by the plant is sold to specified parties at a predetermined rate, which obviously eliminates the risk of price fluctuations for the power producer.

The contract price for energy and capacity is agreed in advance between producer and consumer and rates are stipulated for a defined period. The agreed tariff will usually be above the minimum and below the maximum prices that can be expected for the future spot market and provides planning security and reduces the financial risks for both parties.

The predetermined tariff as illustrated in the following diagram is based on a signed power purchase agreement and will be used for the following calculations.

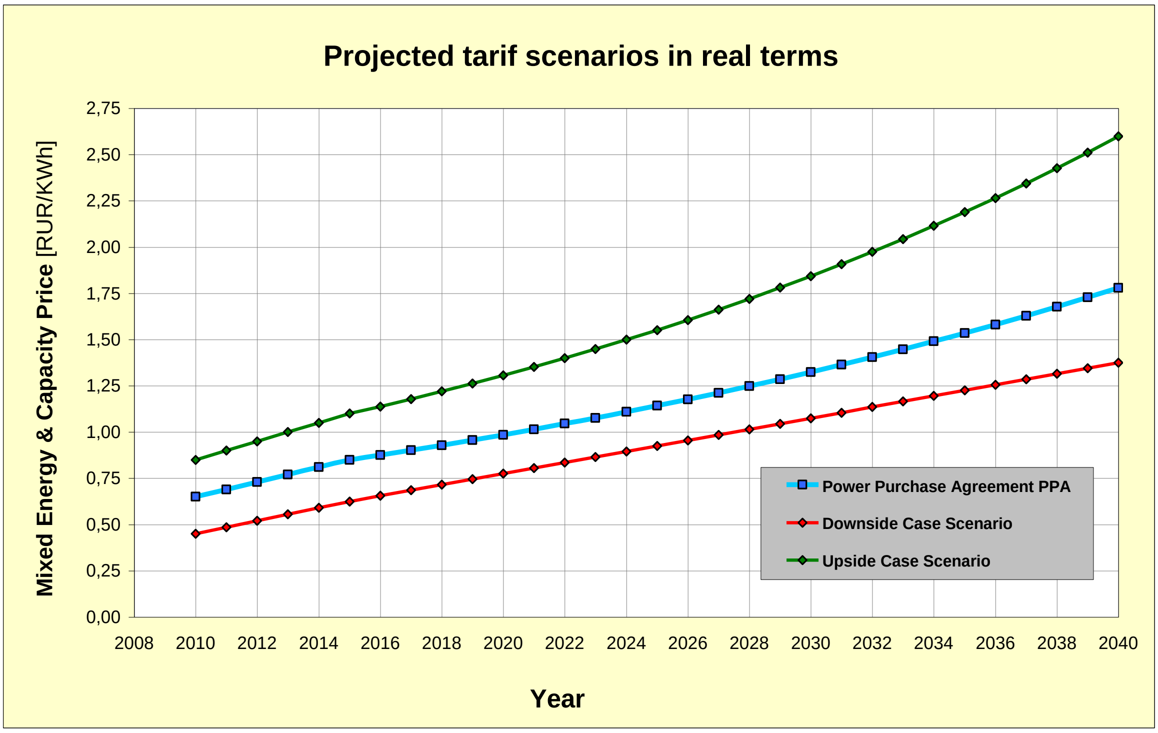


Figure 52: Tariff projection based on power purchase agreement

The columns depicted in figure 53 below represent annual project revenues resulting from the sale of power into a competitive market. The upper and lower boundaries are a consequence of the possible price ranges, which correspond to the upside case and downside case of the tariff scenarios as projected for the case study.

For the project developer the significant price range indicates a substantial amount of risk related to the potential project revenues, as future income cannot be predicted with a high level of accuracy.

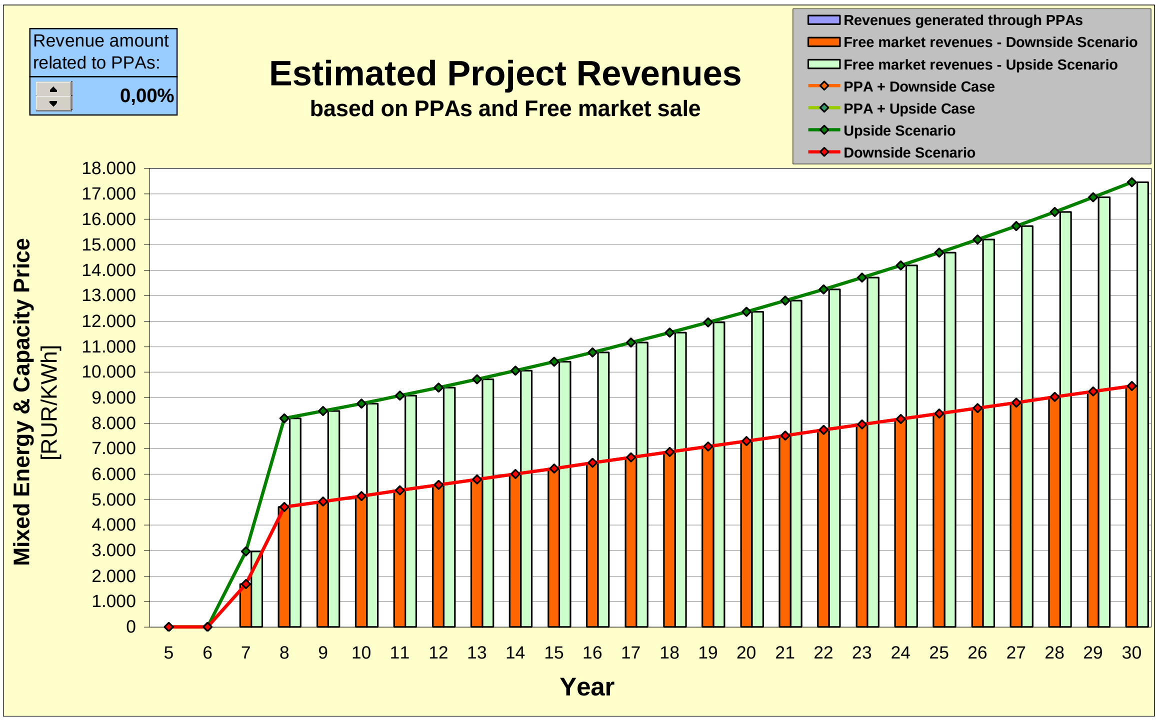


Figure 53: Possible range of project revenues without PPA

The remuneration risk can be drastically reduced for the producer if a certain amount of the plant’s output can be sold on the basis of signed power purchase agreements as illustrated in the following diagrams.

The predetermined annual remuneration is illustrated by the blue columns, representing 50% and 90% of the annual power generation capacity. Only the remaining amount is sold on the competitive day-ahead market at higher or lower rates. Thus the annual revenues generated by the plant are much more predictable and the revenue risk is reduced accordingly.

Annual project revenues based on the existence of signed power purchase agreements:

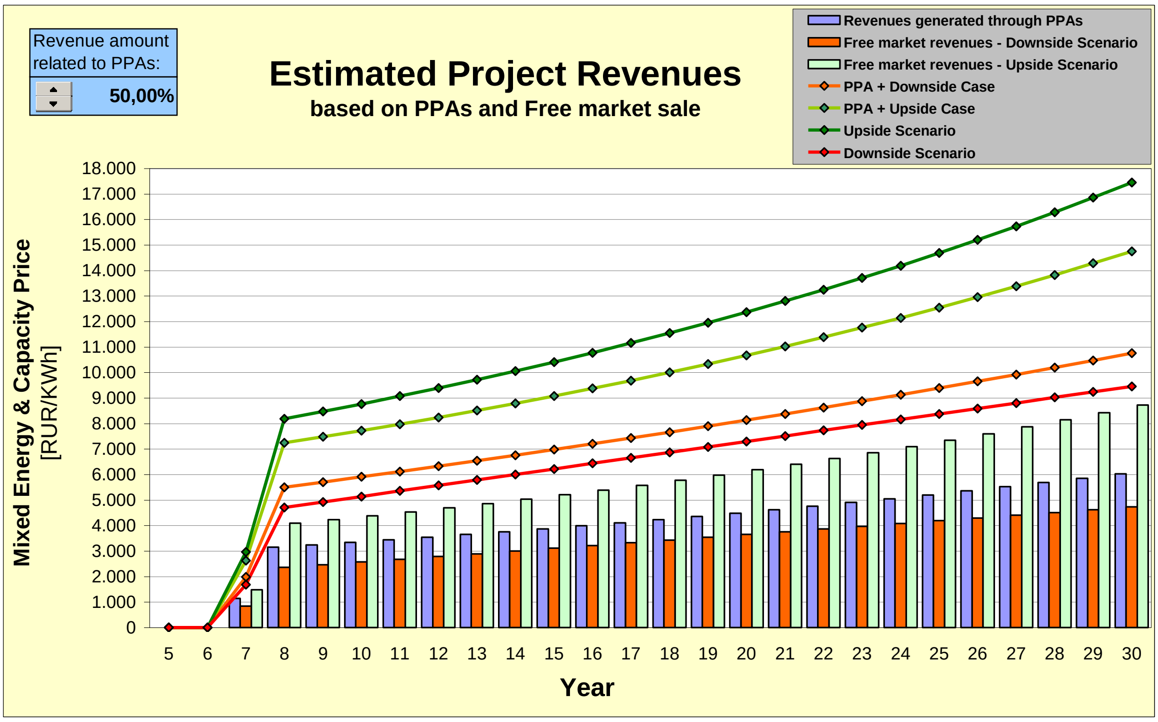


Figure 54: Range of project revenues based on the sale of 50% through PPAs

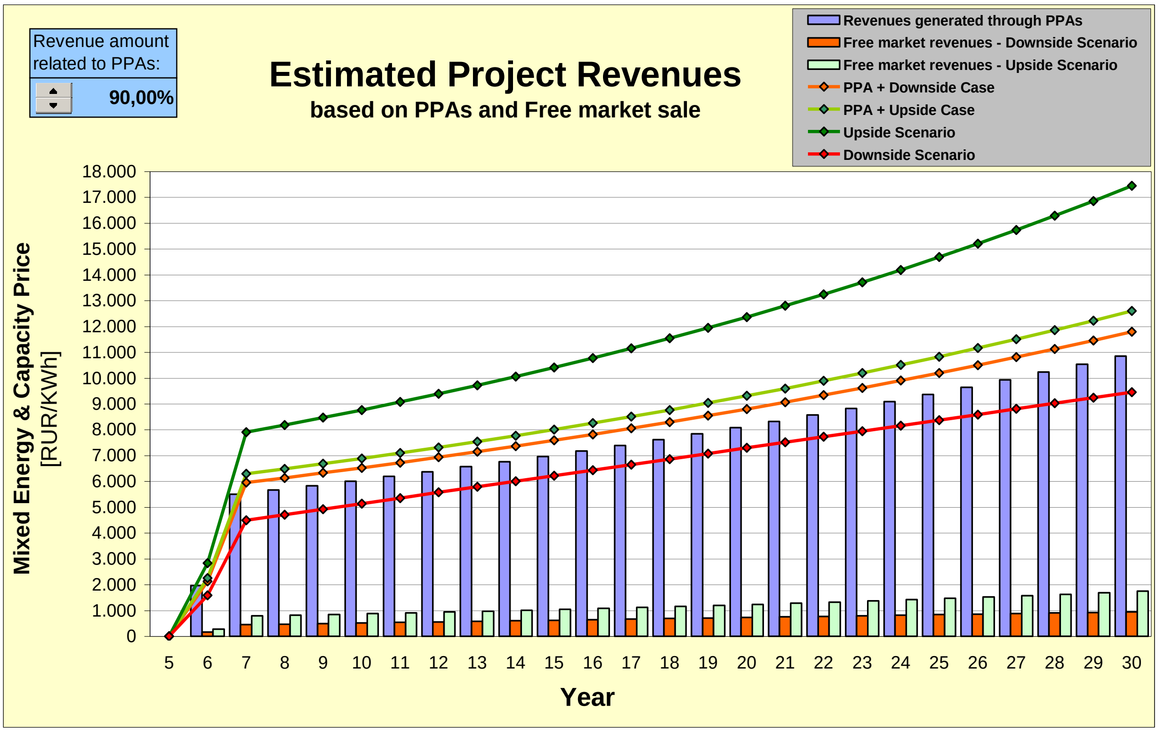


Figure 55: Range of project revenues based on the sale of 90% through PPAs

5.3.5 Financial project analysis based on a refined random set model

The focal sets representing revised parameter ranges for the input parameters CAPEX, construction time, tariff scenario and discount rate are depicted in table 11 below. Evident adjustments for the input parameter ranges compared to table 10 have been made for CAPEX and discount rate. The parameter intervals representing capital expenses have been adjusted as described in chapter 5.3.2, the parameter intervals defining possible discount rates are reduced to two focal sets as illustrated in chapter 5.3.3. All information sources are rated with the same credibility.

Parameter	**Source**	**Parameter L**	**Parameter U**	**Probability Assignments**
CAPEX [Mio. RUR]	A_1	38,000	42,000	0.50
	A_2	44,000	56,000	0.50
Construction Time	A	6 years	7 years	1.00
Tariff Scenario	A	Upside case	Downside case	1.00
Discount Rate [%]	A_1	8	12	0.50
	A_2	10	14	0.50

Table 11: Input parameter sets for refined random set model

The results of the analysis, displayed as upper and lower bounds of the cumulative probabilities, are characterised by a decreasing variability as illustrated in the following figures 56 and 57. The range of results calculated for NPV and BCR is considerably reduced and the bounds of the cumulative probabilities are shifted in a positive direction (characterised by higher values).

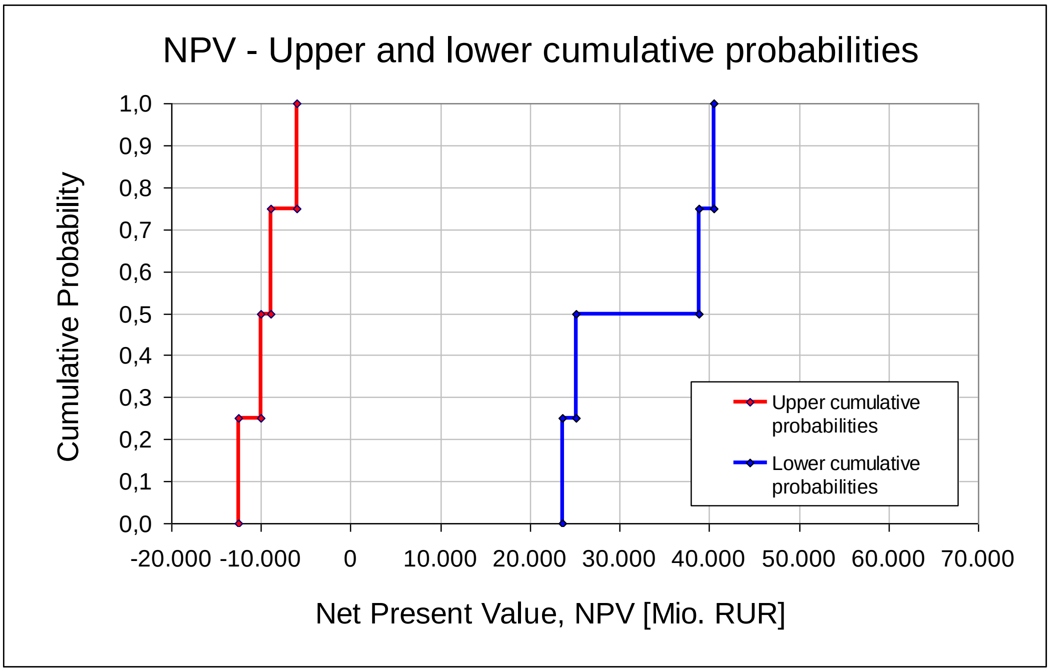


Figure 56: DCF for NPV based on parameter sets as shown in table 11

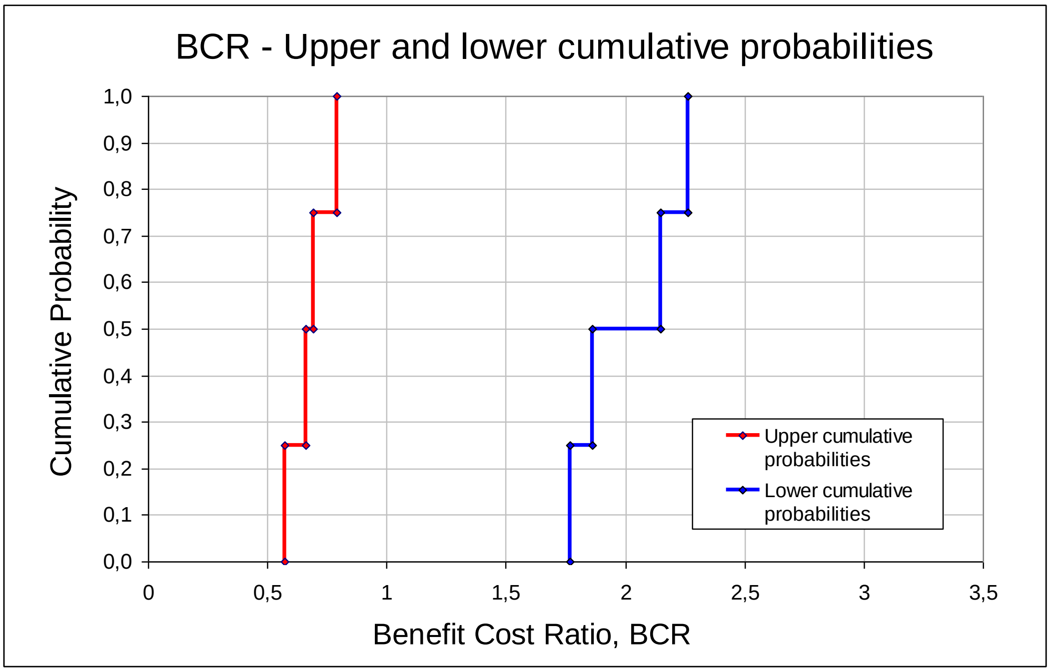


Figure 57: DCF for BCR based on parameter sets as shown in table 11

Due to the reduced input parameter ranges, the variation of the calculated results decreases accordingly, limiting the range of negative values for the NPV to -12,557 million RUR and the minimum value for the BCR to 0.57. Positive values for the NPV are still reaching as high as 40,545 million RUR in conjunction with a BCR of 2.26. A summary of all results calculated by the random set model is presented in section A6 of the appendix.

As illustrated in appendix A6 high discount rates in conjunction with unfavourable tariff scenarios are leading to particularly negative effects on the financial feasibility of the project. One fundamental conclusion resulting from the executed analysis is the deduction that the profitability of the project cannot be demonstrated with discount rates exceeding a maximum value of 12%. Consequently, for further project assessment, discount rates above 12% are not considered any more and the interval ranges of the focal sets are modified accordingly to A_1=[8%;10%] and A_2=[10%;12%].

The still expansive range of results can be further reduced if the sale of power through power purchase agreements is incorporated into the random set model. This modification reduces the range for the projected remuneration that can be obtained for the power generated by the hydropower plant. The effect is more pronounced if a higher percentage of power is sold via PPAs and can theoretically lead to a predefined remuneration based on 100% sale of power based on contractually guaranteed future conditions. Under these circumstances the uncertainties and projects risks related to remuneration are reduced to zero.

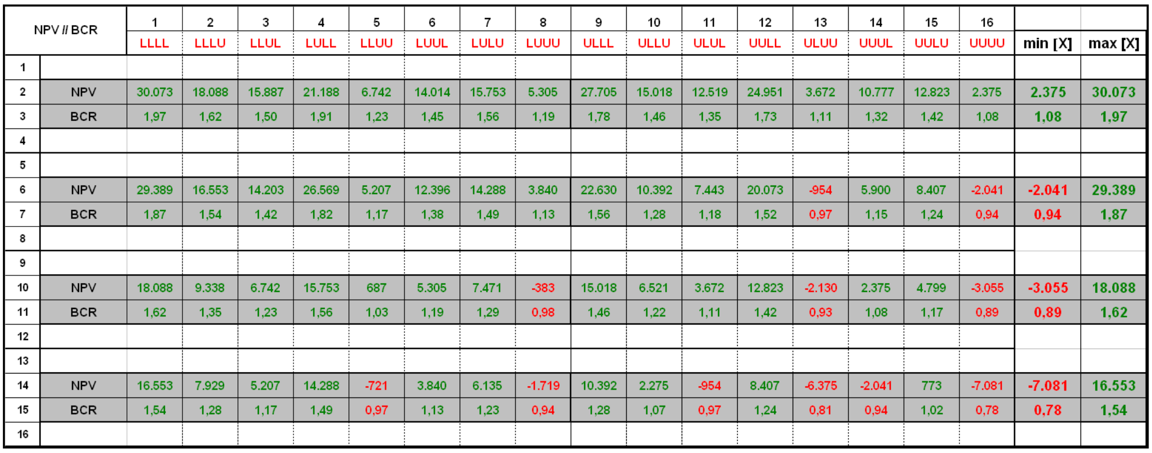
Effects of such scenarios on the financial feasibility of the project are assessed in the following section of the study.

For further project evaluation the random sets defining input parameter ranges and probability weights are selected as illustrated in table 12. The additional modifications compared to the input data of table 11 are affecting the parameter ranges of the focal sets defining possible discount rates.

Parameter	Source	Parameter L	Parameter U	Probability Assignments
CAPEX [Mio. RUR]	A_1	38,000	42,000	0.50
	A_2	40,000	48,000	0.50
Construction Time	A	6 years	7 years	1.00
Tariff Scenario	A	Upside case	Downside case	1.00
Discount Rate [%]	A_1	8	10	0.50
	A_2	10	12	0.50

Table 12: Random sets for 4 input parameters, adjusted ranges for discount rate

The calculated values for NPV and BCR based on the random sets depicted in table 12 and a sale of 50% of the generated power through PPAs (compare figure 54) are summarised in table 13 below.



NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
		LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
1																			
2	NPV	30.073	18.088	15.887	21.188	6.742	14.014	15.753	5.305	27.705	15.018	12.519	24.951	3.672	10.777	12.823	2.375	**2.375**	**30.073**
3	BCR	1,97	1,62	1,50	1,91	1,23	1,45	1,56	1,19	1,78	1,46	1,35	1,73	1,11	1,32	1,42	1,08	**1,08**	**1,97**
4																			
5																			
6	NPV	29.389	16.553	14.203	26.569	5.207	12.396	14.288	3.840	22.630	10.392	7.443	20.073	-954	5.900	8.407	-2.041	**-2.041**	**29.389**
7	BCR	1,87	1,54	1,42	1,82	1,17	1,38	1,49	1,13	1,56	1,28	1,18	1,52	0,97	1,15	1,24	0,94	**0,94**	**1,87**
8																			
9																			
10	NPV	18.088	9.338	6.742	15.753	687	5.305	7.471	-383	15.018	6.521	3.672	12.823	-2.130	2.375	4.799	-3.055	**-3.055**	**18.088**
11	BCR	1,62	1,35	1,23	1,56	1,03	1,19	1,29	0,98	1,46	1,22	1,11	1,42	0,93	1,08	1,17	0,89	**0,89**	**1,62**
12																			
13																			
14	NPV	16.553	7.929	5.207	14.288	-721	3.840	6.135	-1.719	10.392	2.275	-954	8.407	-6.375	-2.041	773	-7.081	**-7.081**	**16.553**
15	BCR	1,54	1,28	1,17	1,49	0,97	1,13	1,23	0,94	1,28	1,07	0,97	1,24	0,81	0,94	1,02	0,78	**0,78**	**1,54**
16																			

Table 13: Results of financial analysis based on 50% power sale through PPAs

The sale of 50% of the generated power through PPAs as illustrated in figure 54 leads to a significant reduction of the input parameter range representing the projected tariff scenarios. The effect of a guaranteed remuneration on the financial project analysis leads to a further decreased variation of results, limiting the range of negative values for the NPV to a minimum of -7,081 million RUR and the minimum value for the BCR to 0.78.

The calculations of the random set model, combining moderate capital expenses and favourable discount rates do in all cases lead to approving values for the financial feasibility indicators (NPV > 0, BCR >1). The results of the analysis can be visualised through graphical result presentation in form of upper and lower cumulative probabilities.

The results of the financial analysis based on a sale of 50% of the generated power through PPAs are illustrated as upper and lower cumulative probabilities in the following figures 58 and 59. As described in chapter 3.4.3 of the study, the left and right envelopes are shifted towards each other reducing the width of the gap, which indicates the extent of calculated parameter ranges.

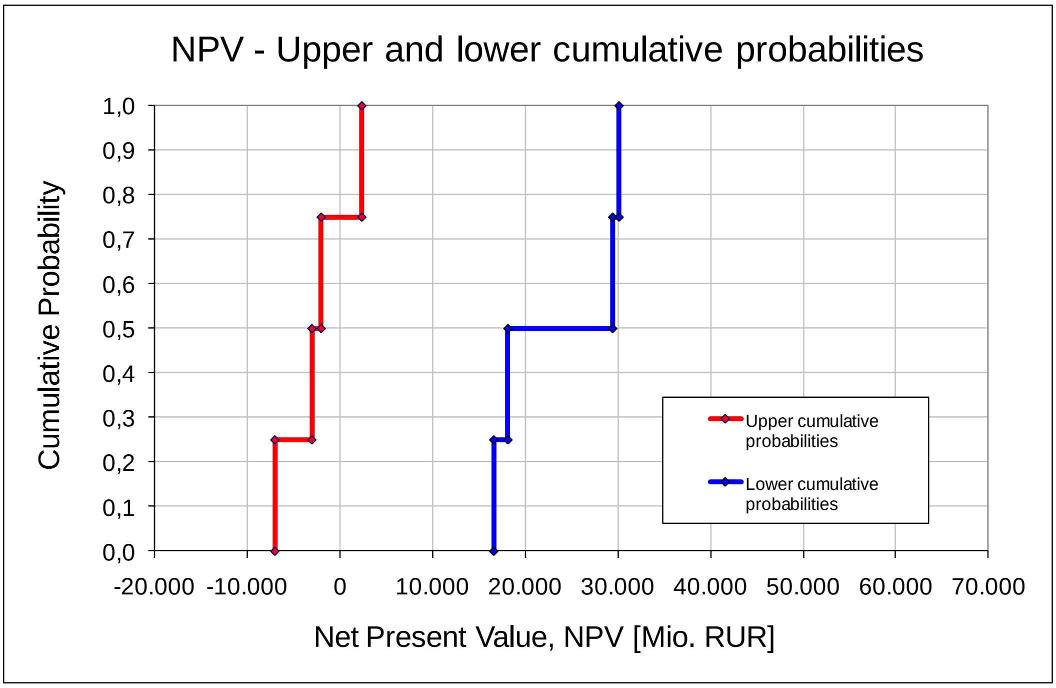


Figure 58: DCF for NPV based on 50% sale of power through PPAs

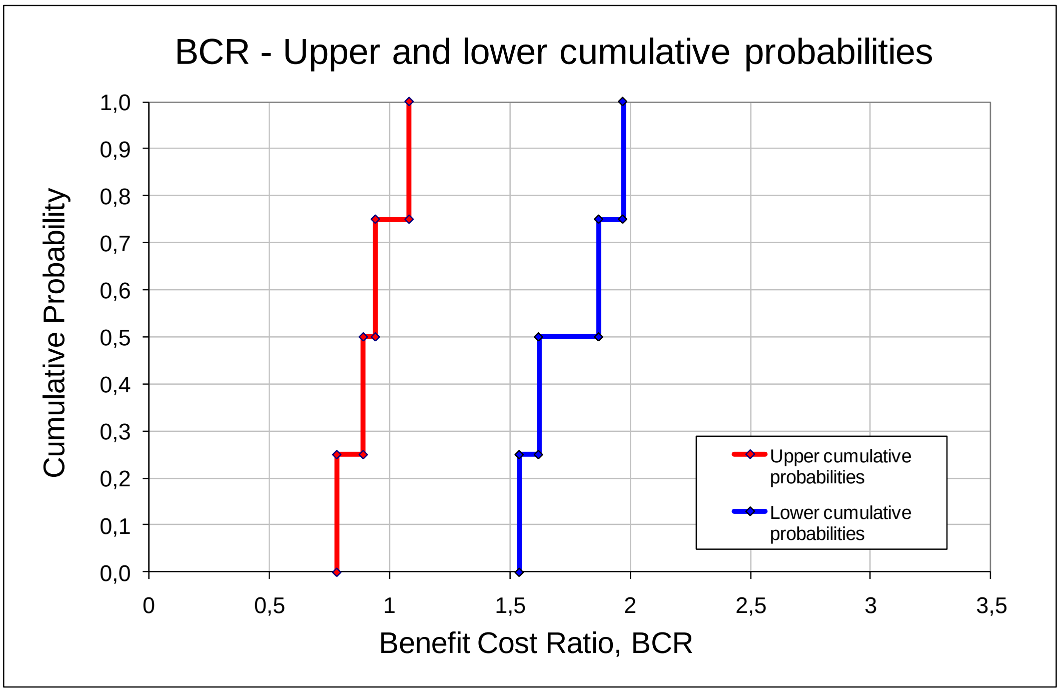


Figure 59: DCF for BCR based on 50% sale of power through PPAs

The analysis is repeated with the same input parameter sets under the assumption that 90% of the generated power is sold through PPAs. The calculated results are summarised in table 14.

NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
		LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	**min [X]**	**max [X]**
1																			
2	NPV	23.496	12.483	20.459	21.035	10.214	18.201	10.526	8.436	20.128	9.413	17.090	17.798	7.144	14.964	7.595	5.506	**5.506**	**23.496**
3	BCR	1,73	1,43	1,64	1,68	1,35	1,59	1,38	1,30	1,57	1,29	1,48	1,52	1,22	1,44	1,25	1,10	**1,10**	**1,73**
4																			
5																			
6	NPV	21.812	10.948	18.774	19.417	8.679	16.582	9.061	6.971	15.052	4.788	12.015	12.921	2.518	10.186	3.180	1.090	**1.090**	**21.812**
7	BCR	1,65	1,36	1,56	1,60	1,28	1,51	1,31	1,24	1,37	1,13	1,30	1,33	1,07	1,26	1,09	1,03	**1,03**	**1,65**
8																			
9																			
10	NPV	12.483	5.107	10.214	10.526	3.377	8.436	3.574	2.003	9.413	2.290	7.144	7.595	560	5.506	902	-668	**-668**	**12.483**
11	BCR	1,43	1,19	1,35	1,38	1,13	1,30	1,14	1,08	1,29	1,08	1,22	1,25	1,02	1,10	1,03	0,98	**0,98**	**1,43**
12																			
13																			
14	NPV	10.948	3.698	8.679	9.061	1.968	6.971	2.238	667	4.788	-1.956	2.518	3.180	-3.686	1.090	-3.124	-4.695	**-4.695**	**10.948**
15	BCR	1,36	1,13	1,28	1,31	1,07	1,24	1,08	1,02	1,13	0,94	1,07	1,09	0,89	1,03	0,90	0,85	**0,85**	**1,36**
16																			

Table 14: Results of financial analysis based on 90% power sale through PPAs

Based on input parameter ranges as specified in table 12 and the assumption that 90% of the generated power is sold through PPAs, the minimum criteria to justify a positive investment decision stipulated for the financial feasibility indicators in (NPV > 0 and BCR > 1) are achieved with a probability of 50%.

The effects, which a higher percentage of guaranteed remuneration in form of contractually confirmed PPAs can have on the results of the financial analysis are illustrated in form of upper and lower cumulative probabilities in figure 60 and figure 61.

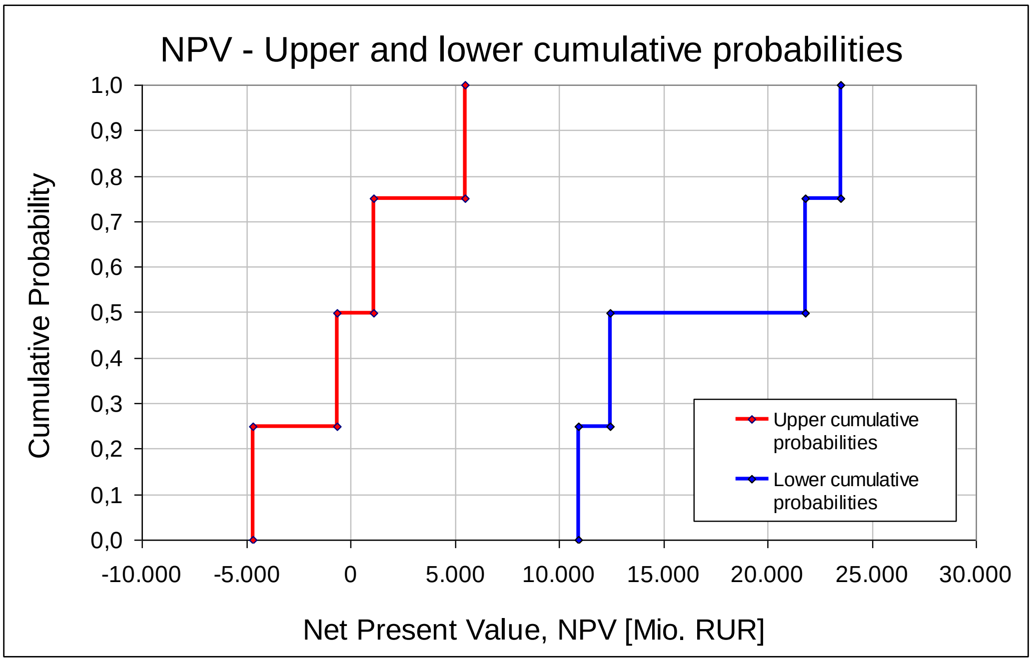


Figure 60: DCF for NPV based on 90% power sale through PPAs

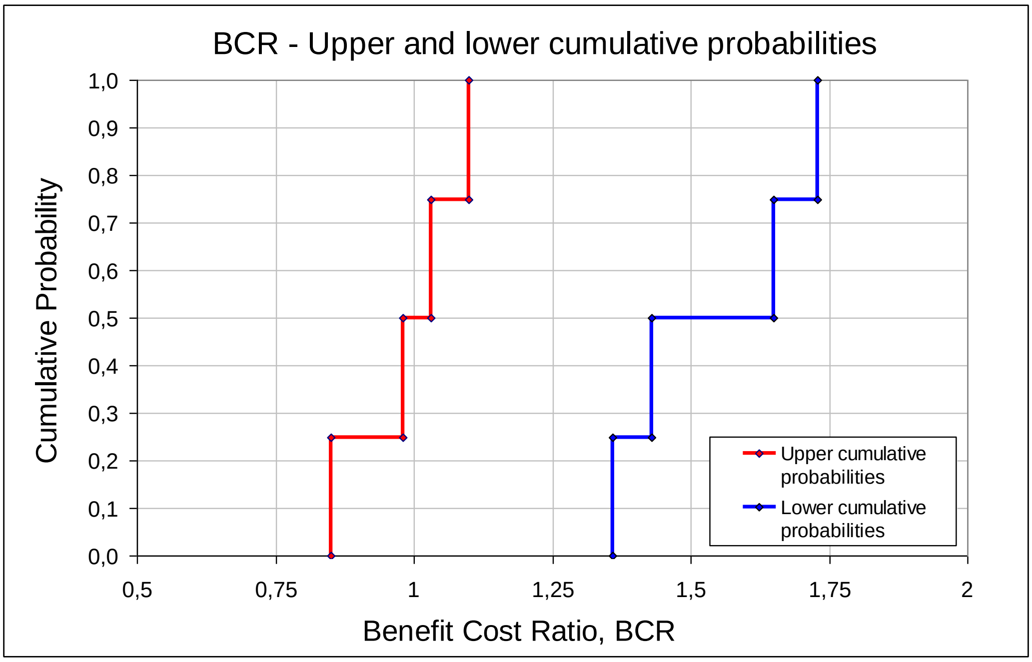


Figure 61: DCF for BCR based on 90% power sale through PPAs

One possible option to achieve the acceptance criteria for the project as specified in chapter 5.1 is a favourable differentiation of information sources through the probability weights assigned to the focal elements.

In case that progressed negotiations with potential investors justify a higher probability weight assigned to the lower and therefore more favourable interval range extending from 8% to 10% for the discount rate, the corresponding value for m_1 can be increased above 0.5. If it can be demonstrated that the probability for obtaining such financing conditions is higher than 80%, the probability weight for the focal element defining a parameter range from 8% to 10% can be selected with 0.8 (or higher) and the probability weight of the focal element defining a parameter range from 10% to 12% can be set to 0.2 (or lower). The modified probability assignments for the two input parameter sets change the result of the analysis accordingly. The minimum criteria that need to be met for the financial feasibility indicators in order to justify a positive investment decision (NPV > 0 and BCR > 1) are now achieved with a probability of 80% or more. Any further increase of the probability weight assigned to the more favourable discount rate leads to an improved prospective for the financial feasibility of the project.

Based on a distribution of probability weights at the ratio of 80 to 20 in favour of the lower parameter interval A_1=[8%;10%] representing the discount rate, the upper and lower bounds of the cumulative probability distribution for NPV and BCR are illustrated in the following figures 62 and 63.

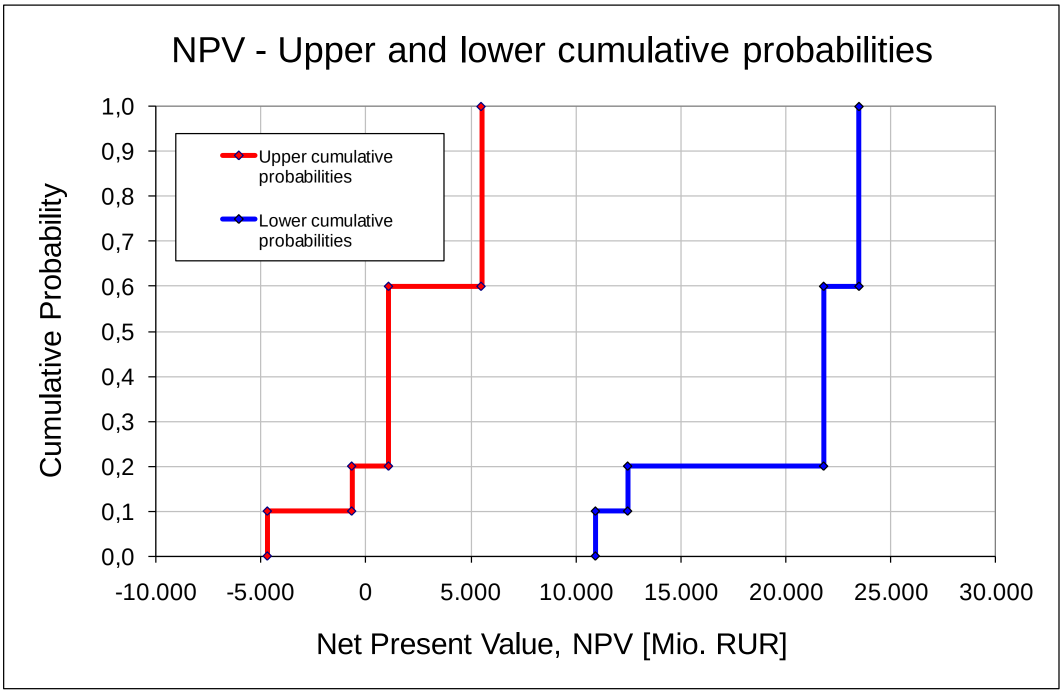


Figure 62: DCF for NPV, differentiated probability weights for discount rate

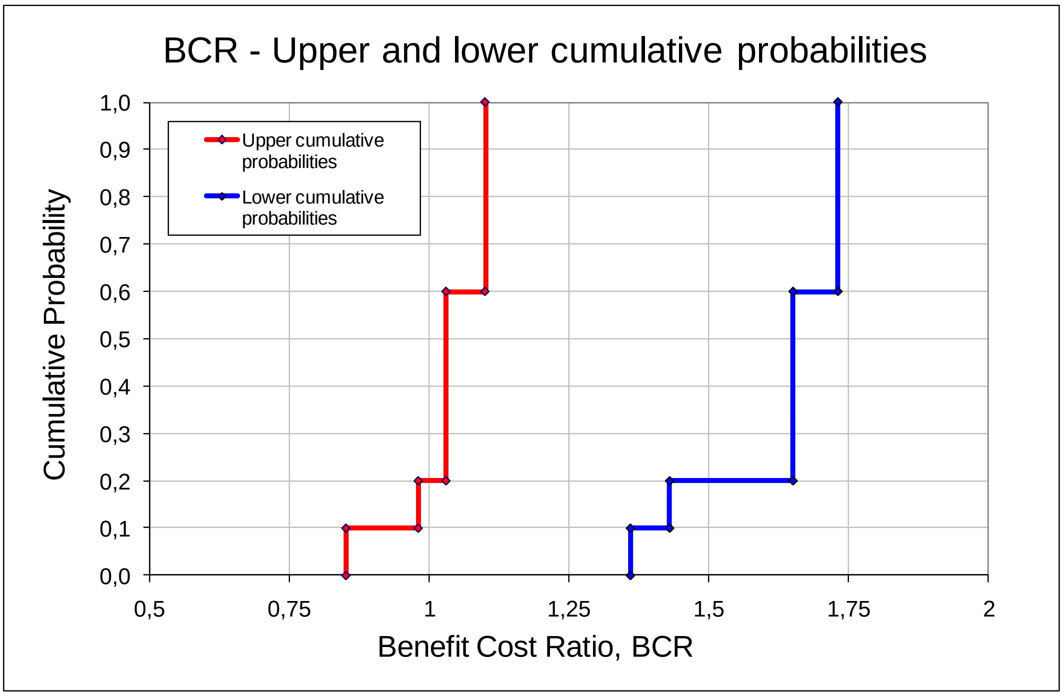
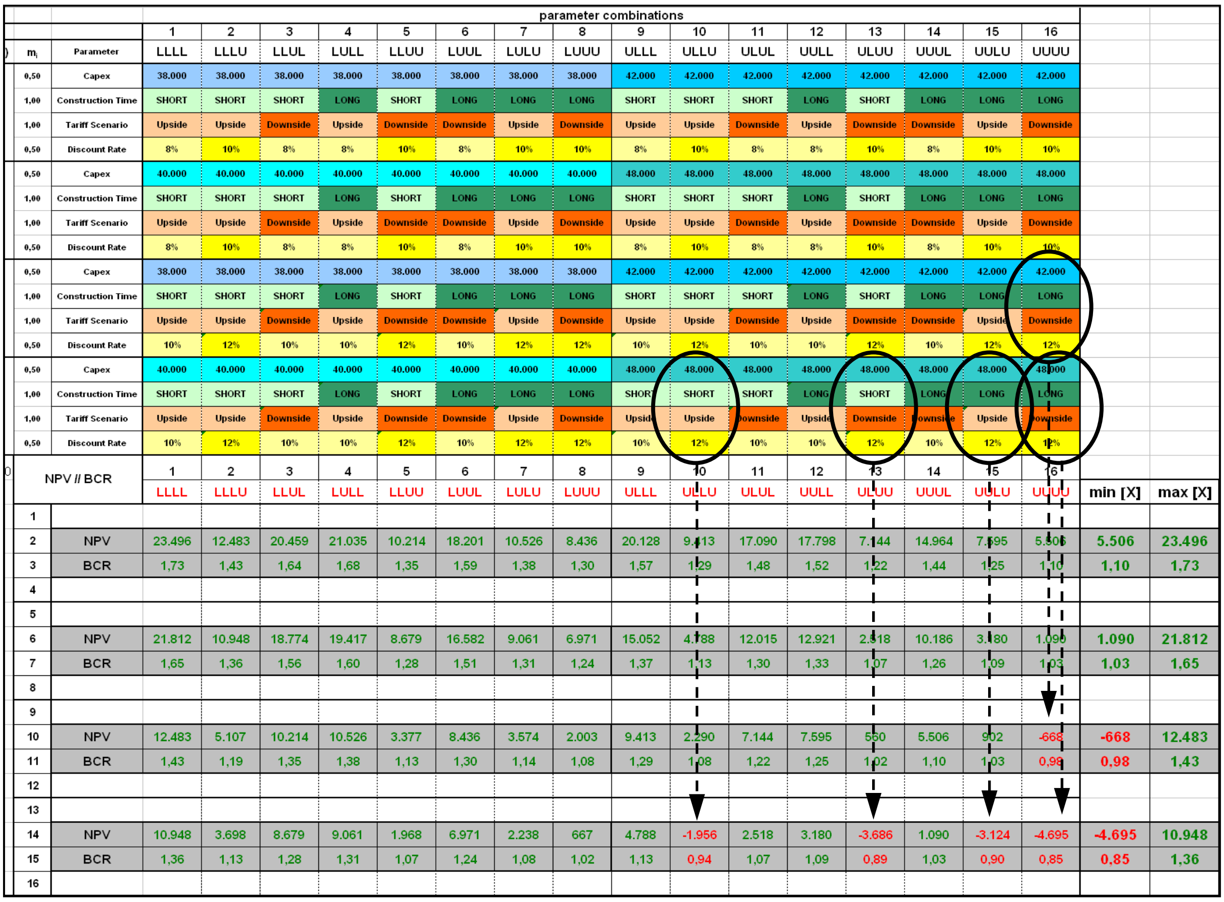


Figure 63: DCF for BCR, differentiated probability weights for discount rate

The scenario illustrated above achieves the criteria stipulated for a positive investment decision but does not represent the only possible constellation of input parameters that can ensure the financial feasibility of the project.

5.4 Detailed assessment of critical parameter combinations

The summary of results for the financial project analysis based on 90% sale of power through PPAs (see table 14) shows that in total 5 particular input parameter combinations lead to a NPV < 0 and a BCR < 1. The focus of subsequent parameter assessments in a further refined approach is consequently placed on the critical parameter combinations, which are depicted in the following figure 64.



		parameter combinations															
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
m_i	Parameter	LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU
0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000
1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG
1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside
0,50	Discount Rate	8%	10%	8%	8%	10%	8%	10%	10%	8%	10%	8%	8%	10%	8%	10%	10%
0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000
1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG
1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside
0,50	Discount Rate	8%	10%	8%	8%	10%	8%	10%	10%	8%	10%	8%	8%	10%	8%	10%	10%
0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000
1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG
1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside
0,50	Discount Rate	10%	12%	10%	10%	12%	10%	12%	12%	10%	12%	10%	10%	12%	10%	12%	12%
0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000
1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG
1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside
0,50	Discount Rate	10%	12%	10%	10%	12%	10%	12%	12%	10%	12%	10%	10%	12%	10%	12%	12%

NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
		LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
1																			
2	NPV	23.496	12.483	20.459	21.035	10.214	18.201	10.526	8.436	20.128	9.413	17.090	17.798	7.144	14.964	7.595	5.506	5.506	23.496
3	BCR	1,73	1,43	1,64	1,68	1,35	1,59	1,38	1,30	1,57	1,29	1,48	1,52	1,22	1,44	1,25	1,10	1,10	1,73
4																			
5																			
6	NPV	21.812	10.948	18.774	19.417	8.679	16.582	9.061	6.971	15.052	4.788	12.015	12.921	2.518	10.186	3.180	1.090	1.090	21.812
7	BCR	1,65	1,36	1,56	1,60	1,28	1,51	1,31	1,24	1,37	1,13	1,30	1,33	1,07	1,26	1,09	1,03	1,03	1,65
8																			
9																			
10	NPV	12.483	5.107	10.214	10.526	3.377	8.436	3.574	2.003	9.413	2.290	7.144	7.595	560	5.506	902	-668	-668	12.483
11	BCR	1,43	1,19	1,35	1,38	1,13	1,30	1,14	1,08	1,29	1,08	1,22	1,25	1,02	1,10	1,03	0,98	0,98	1,43
12																			
13																			
14	NPV	10.948	3.698	8.679	9.061	1.968	6.971	2.238	667	4.788	-1.956	2.518	3.180	-3.686	1.090	-3.124	-4.695	-4.695	10.948
15	BCR	1,36	1,13	1,28	1,31	1,07	1,24	1,08	1,02	1,13	0,94	1,07	1,09	0,89	1,03	0,90	0,85	0,85	1,36
16																			

Figure 64: Critical combinations of input parameters

For reasons explained in chapter 5.3.1 it does not seem appropriate to alter the assumptions for the construction time. Consequently a variation of the corresponding parameters that enter into the financial analysis is not foreseen and the scenarios developed to cover this parameter are maintained.

The remaining options for further parameter assessment are represented by the upper interval bounds defining the input parameters capital expenses and discount rate in conjunction with possible tariff scenarios. The subsequent analysis consists of a variation and combination of these three input parameters in order to assess the consequences for the calculation of the financial feasibility indicators. The results are calculated for discount rates of 11.0%, 11.5% and 12.0%, an alternative maximum value for CAPEX of 45,000 million RUR and tariff scenarios for the sale of generated power based on 90%, 95% and 100% remuneration through PPAs.

The effects for the calculation of feasibility indicators caused by a variation of discount rate and PPA percentage are depicted in table 15. The assessed scenario is based on a maximum value for the CAPEX interval range of 48,000 million RUR, an unfavourable long construction time of 6+1 years and a pessimistic tariff projection.

CAPEX 48,000 Mio. RUR, construction time of 6+1 years, tariff scenario downside case		**Financial Feasibility Indicators Scenario A**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-4,695	0.85	n.a.
	95%	-4,397	0.86	n.a.
	100%	-4,099	0.87	n.a.
11.5 %	90%	-3,480	0.89	n.a.
	95%	-3,161	0.90	n.a.
	100%	-2,842	0.91	n.a.
11.0 %	90%	-2,121	0,94	n.a.
	95%	-1,781	0,95	n.a.
	100%	-1,440	0.96	n.a.

Table 15: Results of a refined financial analysis, scenario A

The results of the refined financial analysis indicate that the project must be rated as not profitable for any of the above parameter combinations.

An alternative scenario based on a maximum upper range for CAPEX of 45,000 million RUR is depicted in table 16 below. Parameter combinations indicating a profitable project are shaded in green colour and include a calculation of the IRR.

CAPEX 45,000 Mio. RUR, construction time of 6+1 years, tariff scenario downside case		**Financial Feasibility Indicators Scenario B**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-2,672	0.91	n.a.
	95%	-2,374	0.92	n.a.
	100%	-2,076	0.93	n.a.
11.5 %	90%	-1,411	0.95	n.a.
	95%	-1,092	0.96	n.a.
	100%	-774	0.97	n.a.
11.0 %	90%	-5	1.00	11.00%
	95%	336	1.01	11.11%
	100%	677	1,02	11.23%

Table 16: Results of a refined financial analysis, scenario B

The profitability of the project can be demonstrated if the discount rate does not exceed 11.0%. A higher percentage of guaranteed remuneration positively contributes to the financial feasibility of the project.

The financial analysis is repeated with an upper interval range for CAPEX of 48,000 million RUR and a more optimistic tariff projection represented by the ‘upside case’.

CAPEX 48,000 Mio. RUR, **construction time of 6+1 years,** **tariff scenario upside case**		**Financial Feasibility Indicators** **Scenario C**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-3,124	0.90	n.a.
	95%	-3,611	0.89	n.a.
	100%	-4,099	0.87	n.a.
11.5 %	90%	-1,796	0.95	n.a.
	95%	-2,319	0.93	n.a.
	100%	-2,842	0.91	n.a.
11.0 %	90%	-314	0.99	n.a.
	95%	-877	0.97	n.a.
	100%	-1,440	0.96	n.a.

Table 17: Results of a refined financial analysis, scenario C

The results of the financial analysis confirm that, based on CAPEX of 48,000 million RUR, the profitability of the project cannot be demonstrated, even under the assumption of a more optimistic tariff projection. If the guaranteed remuneration through PPAs reaches 100% the calculated results are identical with the pessimistic ‘downside’ case scenario, since the entire amount of generated power is sold at the predetermined rate, which entirely eliminates any variation of revenues. Under utilisation of the optimistic tariff projection, the higher percentage of guaranteed remuneration reduces the financial feasibility of the project, since potential higher earnings are not accounted.

By reducing the upper interval range for CAPEX to 45,000 million RUR the prospects for the financial feasibility of the project can be improved as illustrated in the table 18.

CAPEX 45,000 Mio. RUR, **construction time of 6+1 years,** **tariff scenario upside case**		**Financial Feasibility Indicators** **Scenario D**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-1,102	0.96	n.a.
	95%	-1,589	0.95	n.a.
	100%	-2,076	0.93	n.a.
11.5 %	90%	273	1.01	11.60
	95%	-250	0.99	n.a.
	100%	-774	0.97	n.a.
11.0 %	90%	1,803	1.05	11.60
	95%	1,240	1.04	11.41
	100%	677	1.02	11.23

Table 18: Results of a refined financial analysis, scenario D

Based on a maximum interval range for CAPEX of 48,000 million RUR and assuming a shorter construction period of 5+1 years, the financial analysis is performed two more times reflecting optimistic and pessimistic tariff projections.

The results of the analysis are summarised in the following tables 19 and 20.

CAPEX 48,000 Mio. RUR, construction time of 5+1 years, tariff scenario downside case		**Financial Feasibility Indicators Scenario E**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-3,686	0.89	n.a.
	95%	-3,350	0.95	n.a.
	100%	-3,014	0.91	n.a.
11.5 %	90%	-2,373	0.93	n.a.
	95%	-2,015	0.94	n.a.
	100%	-1,657	0.95	n.a.
11.0 %	90%	-912	0.97	n.a.
	95%	-531	0.98	n.a.
	100%	-150	1,00	10.95%

Table 19: Results of a refined financial analysis, scenario E

CAPEX 48,000 Mio. RUR, construction time of 5+1 years, tariff scenario upside case		**Financial Feasibility Indicators Scenario F**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-1,956	0.94	n.a.
	95%	-2,485	0.93	n.a.
	100%	-3,014	0.91	n.a.
11.5 %	90%	-524	0.98	n.a.
	95%	-1,091	0.97	n.a.
	100%	-1,657	0.95	n.a.
11.0 %	90%	1,065	1.03	11.33%
	95%	457	1.01	11.14%
	100%	-150	1.00	10.95%

Table 20: Results of a refined financial analysis, scenario F

The calculation indicates that compared to the input parameters CAPEX and discount rate, the construction time has a limited effect on the feasibility of the project. Negative impacts on the profitability of the project caused by high capital expenses cannot be fully compensated through a shorter construction time. In combination with an optimistic tariff scenario the profitability of the project can be demonstrated indisputably for two parameter combinations.

A final calculation is performed assuming the same project conditions as for the previous scenarios E and F in conjunction with a reduced upper interval range for capital expenses of 45,000 million RUR.

The calculation of the financial feasibility indicators exhibits that, under the above conditions, an increased number of parameter combinations is leading to values for NPV, BCR and IRR that indicate a profitable project. The results of the analysis are summarised in tables 21 and 22.

CAPEX 45,000 Mio. RUR, **construction time of 5+1 years,** **tariff scenario downside case**		**Financial Feasibility Indicators** **Scenario G**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	-1,553	0.95	n.a.
	95%	-1,217	0.96	n.a.
	100%	-881	0.97	n.a.
11.5 %	90%	-195	0.99	n.a.
	95%	163	1.01	11.56%
	100%	521	1.02	11.68%
11.0 %	90%	1,312	1.04	11.43%
	95%	1,694	1.05	11.56%
	100%	2,075	1.06	11.68%

Table 21: Results of a refined financial analysis, scenario G

CAPEX 45,000 Mio. RUR, **construction time of 5+1 years,** **tariff scenario upside case**		**Financial Feasibility Indicators** **Scenario H**		
Discount Rate	**Percentage PPA**	**NPV**	**BCR**	**IRR**
12.0 %	90%	177	1.01	12.06%
	95%	-352	0.99	n.a.
	100%	-881	0.97	n.a.
11.5 %	90%	1,653	1.05	12.06%
	95%	1,087	1,03	11.87%
	100%	521	1.02	11.68%
11.0 %	90%	3,289	1.10	12.06%
	95%	2,682	1.08	11.87%
	100%	2,075	1.06	11.68%

Table 22: Results of a refined financial analysis, scenario H

5.5 Evaluation and interpretation of results

The financial project analysis based on RST indicates that the feasibility of the project can only be demonstrated if certain key requirements are accomplished for the project. These fundamental conclusions are summarised as follows:

- The remuneration risks for the project cannot be controlled to a satisfactory extent without the provision of power purchase agreements for the project, which guarantee the sale of the generated power at a predetermined tariff. In order to sufficiently eliminate risks related to uncertain future tariff projections, the amount of power that is sold on the basis of PPAs should reach at least 90% of the power generated by the plant annually.
  Higher percentages for guaranteed remuneration further reduce the risk related to revenue generation but also prevent the project from generating additional revenues should optimistic tariff scenarios become applicable.
- The financial feasibility of the project cannot be established for discount rates exceeding 12%. If financial feasibility indicators have to be calculated based on discount rates above 12% the project must be rated as unprofitable, leading to a negative investment decision.
  Discount rates below 12% considerably increase the financial attractiveness of the project and provide a higher acceptable tolerance level for possible variations of other input parameters as demonstrated in chapter 5.4.
- In order to ensure the financial feasibility of the project, the total construction time required for the project must not exceed 6+1 years. Longer construction times are likely to lead to a rejection of the project investment, unless additional information gained during the planning process justifies more favourable assumptions with regard to other project parameters of relevance for the financial analysis. Shorter construction times increase the prospects of the project being profitable.
- The amount of capital expenses that have to be expected for the project must not exceed a total of 48.000 million RUR. In order to predict the project profitability with an appropriate margin of safety, further planning activities must aim to demonstrate, that a budget of 45.000 million RUR can cover the capital expenses required for project implementation.

In this context it needs to be highlighted that for the investment decision making it is neither required nor appropriate to completely eliminate all identified uncertainties since a worst case risk management approach does not apply. Founded on the findings provided by the RST based project analysis, the main areas of uncertainty for the project evaluation can be identified and an assessment of their possible effects on the project profitability is carried out. The acceptable uncertainty level for the utilised input parameters can now be defined by decision makers depending on their specific project requirements and risk tolerance. It has to be ensured that the overall risk rating for the project, which is a result of existing parameter uncertainties, can be reduced to an acceptable level. As illustrated in chapter 5.4 various possible parameter constellations may present suitable options to achieve the acceptance criteria stipulated for the project.

If the financial analysis indicates that the minimum criteria for a positive investment decision cannot be met by the project, two possible conclusions may be drawn:

1. The investigated project does not represent an attractive investment opportunity and must be rejected.
2. A definite judgement with regard to the profitability of the project cannot be made due to an unacceptable extent of uncertainties related to the available input parameters. Based on the conclusions of the RST based analysis it is then possible to clearly stipulate the level of accuracy required for specific input parameters that allows for a responsible and well supported investment decision.

RST can efficiently support the financial project analysis through a methodical assessment of the effects, which uncertain input parameters and their possible combinations may have on the financial project feasibility. The methodology therefore provides a valuable instrument to support the investment decision. Under assistance of the described approach, the responsibility for the investment decision must be assumed by the deciding parties (e.g., owner, investor, project developer etc.) based on the acceptance criteria that have been stipulated for the project.

The described method can also be employed should an unacceptably expansive range of results obtained from the financial analysis prevent a definite demonstration of the profitability of the project. Based on the conclusions provided by the RST based analysis, it can be evaluated to what extent additional planning activities are required in order to reduce the input parameter range to an acceptable level, that can provide sufficiently accurate results.

If a definite decision for the acceptance of the project as an investment opportunity is not possible based on the primary feasibility indicators, which have been analysed by means of the financial model, secondary investment criteria as described in chapter 2.2.5 of the study may provide the required additional information. In addition to the investment criteria mentioned above it can also become necessary to consider aspects for the decision making that are not quantifiable in monetary terms (e.g., internal management targets, portfolio strategies, desired company image etc.).

5.6 Uncertainty quantification and risk-informed decision making

Uncertainty and risk are two different but interrelated concepts since many aspects of a project that may be uncertain do not necessarily represent a major risk for the project. However, risks arising from parameter uncertainties which could affect key areas of planning activities and the overall feasibility of the project require proactive management. In order to ensure that the additional information provided through the RST based simulation can be used as a suitable support for investment decision making, the uncertainty exposure of the project should be visualised in a matrix format.

The process of managing uncertainties and their corresponding project risks can be briefly described as follows:

- Uncertainty identification and description
- Uncertainty analysis
- Uncertainty evaluation
- Prioritisation of uncertainties in terms of their significance for the project
- Risk mitigation
- Monitoring, reporting and documentation

A visualisation of uncertainties in matrix format identifies project relevant areas of uncertainty within the assessed project and illustrates the magnitude of potential consequences. The provision of such a risk ranking instrument for the decision making process can be described as risk-informed decision making. The symbols used for the uncertainty matrix and their denotations are explained in figure 65.

Legend for two-dimensional uncertainty matrix:

	Criticality	**Response**
🟩	Very low	Status acceptable, no action required
🟨	Low to moderate	Monitoring, reporting and documentation
🟧	Medium	Research, development of mitigation measures
🟥	High	Status unacceptable, mitigation compulsory

Figure 65: Legend for uncertainty matrix

The matrix presented in figure 65 illustrates the uncertainty status applicable for the evaluated hydropower project based on the information available at pre-feasibility stage, without considering the existence of power purchase agreements.

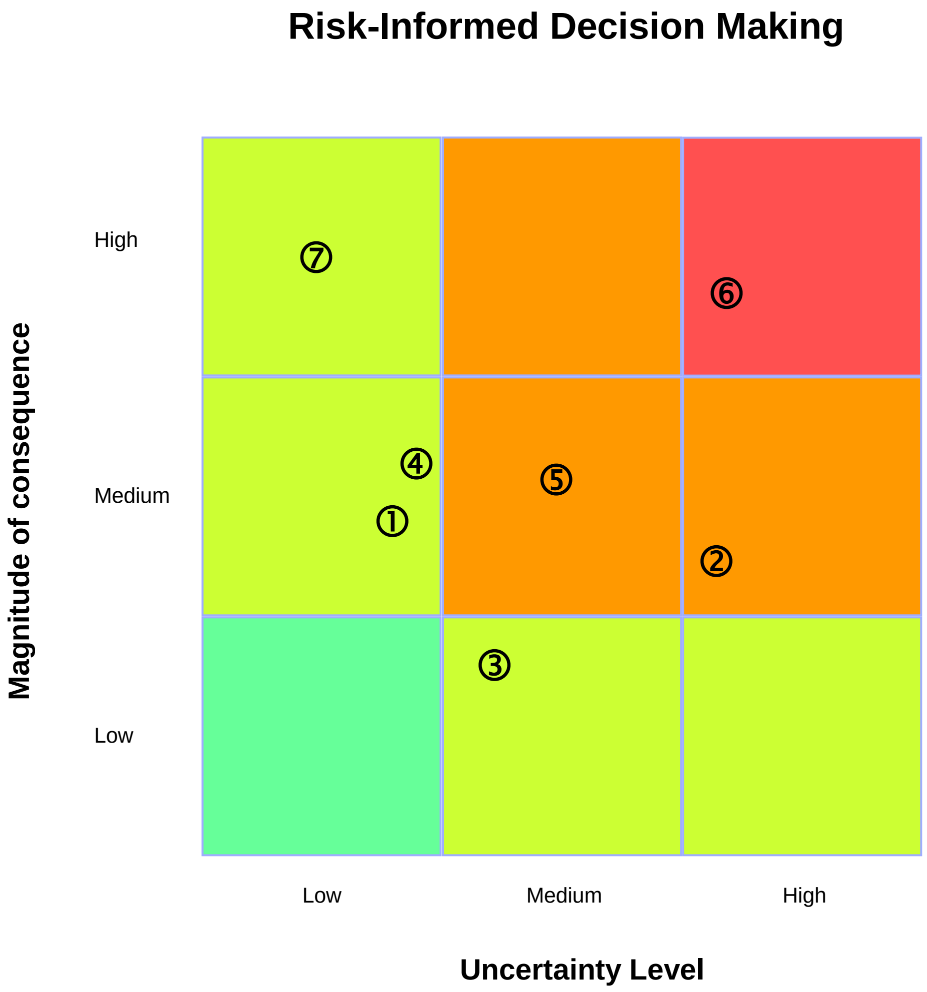


Figure 66: Matrix for risk-informed decision making based on hydropower example

① Risk No. 1	**Exchange rate, inflation and interest risk**
② Risk No. 2	**Construction cost overrun and delay of completion**
③ Risk No. 3	**O&M cost overrun, interruption of operation**
④ Risk No. 4	**Hydrology**
⑤ Risk No. 5	**Site conditions**
⑥ Risk No. 6	**Future energy demand and energy pricing**
⑦ Risk No. 7	**Force majeure**

The result of the project evaluation at feasibility or final design level in conjunction with established power purchase agreements can be depicted in a modified uncertainty matrix as follows:

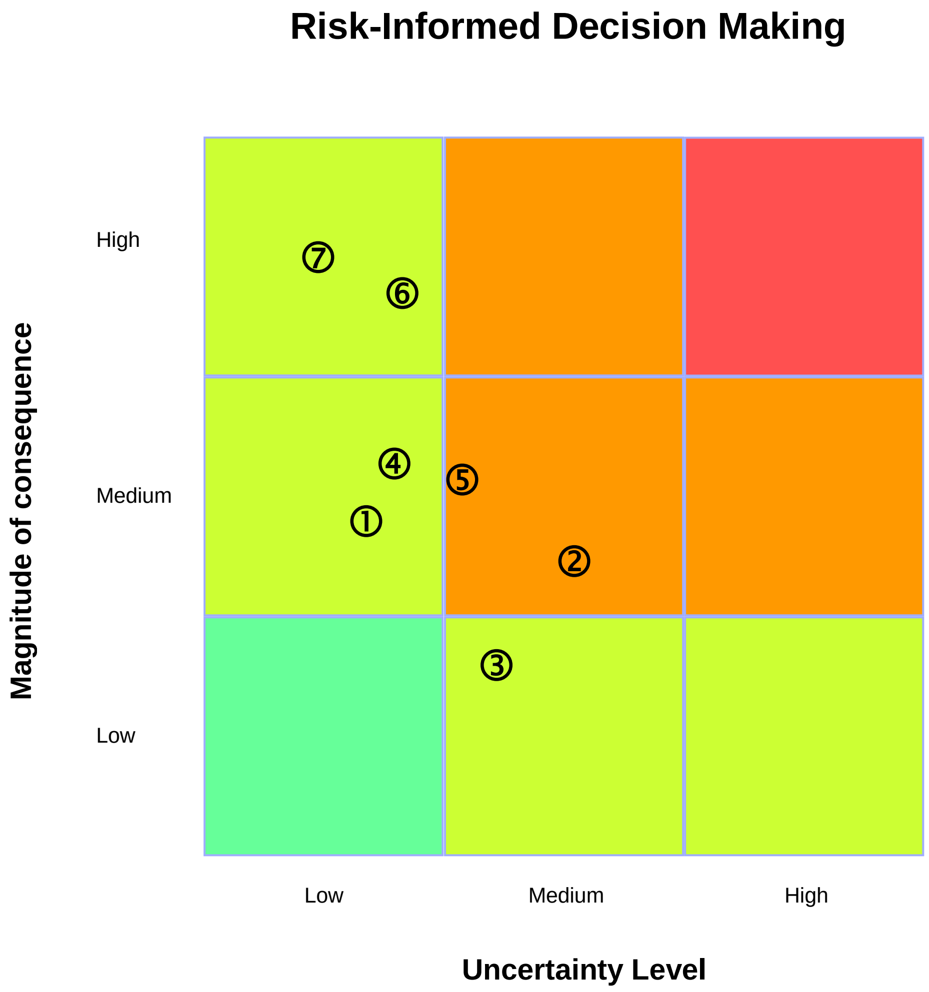


Figure 67: Uncertainty matrix at advanced planning stage

① Risk No. 1	**Exchange rate, inflation and interest risk**
② Risk No. 2	**Construction cost overrun and delay of completion**
③ Risk No. 3	**O&M cost overrun, interruption of operation**
④ Risk No. 4	**Hydrology**
⑤ Risk No. 5	**Site conditions**
⑥ Risk No. 6	**Future energy demand and energy pricing**
⑦ Risk No. 7	**Force majeure**

The successful mitigation of uncertainties and their related project risks can be observed through a comparison of the diagrams presented in figure 66 and 67. Project risks number 2, 5 and 6 are of particular importance for the investment decision since their impact on the financial feasibility of the project must be rated as very high.

The uncertainties leading to risk number 6, which represents the future energy demand and energy pricing, must be treated with the highest priority, since they are characterised by a high uncertainty level in conjunction with a high magnitude of consequences for the investment decision making. The possible consequences of an unpredictable future energy demand and uncertain tariff projections lead to a high remuneration risk. Although the magnitude of possible negative effects for the project profitability cannot be reduced, it is possible to decrease their likelihood of occurrence. The financial analysis supported by the RSM demonstrates that effective risk mitigation is possible by establishing power purchase agreements for the project. The uncertainties related to uncertain future remuneration for the power generated by the plant can be reduced successfully through predetermined prices that guarantee a predictable revenue generation.

Risk number 2 corresponding to construction cost overrun and delay of completion, can be mitigated by reducing the information deficit inherent to the project at initial stages of the planning process. Uncertainties resulting from uncompleted field investigations, the lack of accurate quantities and unit prices, uncertainties related to the ongoing selection of construction methods etc. should be systematically reduced within each stage of the planning process. Risk mitigation in this case consists of completing all related planning activities to an extent that the uncertainties leading to a possible cost overrun or delay of completion are reduced to an acceptable level. The level of accuracy required to ensure an appropriate amount of planning security allowing for a defendable investment decision must be specified by the decision makers.

Similar conclusions can be drawn with regard to risk number 5 representing site conditions. The risk is reduced through the gain of additional project information during the progress of planning activities, through the execution of field investigations, environmental data collection etc. in order to replace literature research and expert opinions with factual information.

The purpose of the risk mitigation concept in the context of risk-informed decision making is to shift all critical risks to an acceptable uncertainty level, which can be tolerated for the investment decision.

For more comprehensive information the International Organisation of Standardization (ISO 31000:2009) provides principles and generic guidelines on risk management. In order to ensure a uniform risk management terminology in processes and frameworks dealing with the management of risk, definitions of generic terms related to risk management are provided by ISO Guide 73:2009 (ISO Guide 73:2009).

6 SUMMARY OF CONCLUSIONS AND FURTHER RESEARCH

6.1 Summary and discussion of main results

The study highlighted the major significance, which appropriate and dependable economic decisions for large water projects represent to the public and how the ignorance of existing input parameter uncertainties at planning stage impends to produce serious misapprehensions for the financial project appraisal. A methodology based on random set theory was introduced and tested for its suitability to provide a mathematical formalisation, describing the effects inherent parameter uncertainties may have on the financial feasibility of a project under investigation.

Based on the planning activities for an existing run-of-river hydropower project the procedures for hydropower optimisation and financial project appraisal were explained including a detailed description of the input parameters required, possible data sources and their related uncertainties. The deficits observed under utilisation of commonly used methods for project assessment were summarised in chapter 2 of the study.

A formalised alternative approach based on random set theory addressed and incorporated inherent parameter uncertainties into the modelling process making them accessible to responsible assessment by all project stakeholders. Basic concepts and definitions of uncertainty models, with particular emphasis on random set theory were outlined in chapter 3, including an illustration of existing engineering applications. The financial project assessment supported by the utilisation of imprecise probabilities allows and also forces the engineer to address existing uncertainties and enables planers to recognise and judge the possible range of outputs predicted by the probabilistic model. Further to an objective formalisation of vague data, the methodology facilitates the utilisation of additional sources of information by formalising expert knowledge, information provided by technical literature or experience gained from comparable previous projects. The general sequence of the analysis is depicted in chapter 4, as well as the selection of key input parameter sets under consideration of all information sources available to the project.

The overall risk and profit potential of the project was assessed in chapter 5 through an initial financial analysis. The range of results obtained from this analysis demonstrated the potential profitability of the hydropower development but also indicated that the propagation of data uncertainty through the model prevented a positive investment decision due to an unacceptable amount of risk involved. The same conclusion could be drawn from the calculation of the financial feasibility indicators as upper and lower cumulative probabilities. This analysis was carried out based on a mathematical formalisation of input parameter uncertainties in form of random sets. The assignment of different probability weights to individual information sources was also described in chapter 5 and the effects caused by the variation of probability assignments on the result of the analysis were demonstrated. Since the profitability of the project could not be clearly established on the basis of existing input parameter ranges the study described possible options for uncertainty reduction available to the planer. The effects of reduced input parameter ranges and the important function of power purchase agreements for the effective reduction of remuneration risks were illustrated in chapter 5 through further analysis based on a refined random set model, characterised by adjusted parameter ranges and modified probability assignments for individual focal elements. The financial analysis based on a refined random set model provided much more accurate indications with regard to the financial project feasibility. In combination with a subsequent project assessment focused on critical parameter combinations, the methodology allowed the definition of key requirements for the project with regard to tariff projections (in conjunction with PPAs) and the input parameters discount rate, construction time and capital expenses. Additional information that could be obtained from the analysis are conclusions regarding the sensitivity of the output related to the input. Input parameters characterised by high output sensitivity such as tariff projections and discount rate denote a high influence on the result. Consequently, these parameters must be investigated more intensively and their values must be determined with the highest possible accuracy. The financial analysis based on random set theory highlighted main areas of uncertainty for the project evaluation and automatically provided best and worst cases, which significantly contributed to an increased validity of results.

Based on the findings provided by the RST based analysis it is possible to clearly stipulate the level of accuracy required for specific input parameters, which allows for a responsible and well supported investment decision. The acceptable uncertainty level for selected input parameters can be defined by decision makers depending on their specific project requirements and risk tolerance, which allows evaluating the additional planning activities and possible expenditures required for reducing the input parameter range to an acceptable level. The use of RST does not replace engineering judgement but can effectively support the financial project analysis through a methodical assessment of the influence, which uncertain input parameters and their possible combinations may have on the financial project feasibility. The responsibility to adequately interpret the uncertainty of the results in view of the specific project conditions will always remain with the engineer. The methodology provides a valuable instrument to support the investment decision even though the decision itself must remain with the project owner (developer, investor etc.) based on his individual decision criteria.

The uncertainty exposure of the project could be visualised in matrix format. In order to support risk-informed decision making, the uncertainty matrix identifies project relevant areas of uncertainty within the assessed project and illustrates the magnitude of potential consequences. Successful mitigation of uncertainties and their related project risks can be supported and initiated under assistance of this instrument. The study confirms that the random set method provides a consistent framework for dealing with uncertainties in the context of financial project appraisal throughout the design and construction of a project. Similarly to geotechnical applications the model can be refined by adding more information when available, depending on the project status (feasibility stage, conceptual design, construction etc.) without changing the underlying concept of analysis.

6.2 Conclusions for practical application and further research

The proposed approach has proven its suitability for modelling of parameter uncertainties and result verification in the context of investment decision making. As highlighted in the study, care has to be exercised with the selection of parameter sets described through interval ranges in order to maintain a transparent linkage between model input and output to make the dependencies between input parameters and the results of the financial analysis accessible to decision makers.

Based on the findings of the study, the practical application of the methodology should be further tested for different types of hydropower developments, such as high pressure and low pressure schemes, hydropower developments with and without storage reservoir, pumped storage plants etc.

It is recommended to planning engineers to put more emphasis on the identification and monitoring of parameter uncertainties during the design and implementation of hydropower schemes in order to establish a database indicating the observed factual parameter variations. If it is possible to establish parameter distributions for selected input parameters under assistance of such a database, a combination of different concepts for uncertainty analysis can be pictured for future project analysis. In this context Monte Carlo simulation may represent a viable tool to provide numerical estimations that adequately represent the stochastic features of the system as illustrated by Tung and Yen (Tung, Yen 2005).

The modelling of alternative scenarios for remuneration is another field of ongoing research and investigation. Newly developed tariff models and remuneration concepts (e.g., in conjunction with carbon dioxide trading) must be incorporated into the financial analysis in order to adequately simulate the future benefits generated by the plant.

Since financial resources are limited due to the recent downturn of financial markets and an aggressive competition for funding between large infrastructure projects can be observed, a high demand for instruments that effectively support the investment decision such as the described methodology must be expected.

7 GLOSSARY OF TERMS

Hydropower Engineering Terms

Design head[I]	The head at which the turbine is designed to operate at maximum efficiency
Generator[I]	A machine powered by a turbine which produces electric current.
Gross head[I]	The difference between headwater level and tailwater level at the powerhouse.
Headrace[I]	That portion of the power canal which extends from the intake works to the powerhouse.
Headwater[I]	The water upstream from the powerhouse, or generally, the water upstream from any hydraulic structure creating a head.
Headwater elevation; headwater level[I]	The height of the headwater in the reservoir.
Hydroelectric efficiency[I]	An efficiency component of the turbine, expressing exclusively the power decrement due to hydraulic losses (friction, separation, impact), including the losses in the scroll case and draft tube.
Hydroelectric power[I]	The electric current produced from water power.
Hydropower plant; hydropower development[I]	The comprehensive term for all structures (powerhouse and pertaining installations) necessary for utilising a selected power site.
Hydropower station[I]	A term sometimes equivalent to the powerhouse, sometimes including the structures situated nearby.
Hydropower system[I]	Two or more power plants (and therefore two or more powerhouses) which are cooperating electrically through a common network.
Mechanical efficiency[I]	An efficiency component of the turbine, expressing exclusively the power losses of the revolving parts, due to mechanical friction
Net head[I]	That part of the gross head which is directly available for the turbines.
Powerhouse[I]	The main structure of a water power plant, housing the generator units and the pertaining installations.
Tailrace[I]	That portion of the power canal which extends from the powerhouse to the recipient watercourse.
Tailwater[I]	The water downstream from the powerhouse. In general, the water downstream from any hydraulic structure creating a head.

Turbine efficiency[I]	The entire efficiency of the turbine, i.e., the product of hydraulic mechanical and volumetric efficiencies.

Power System Terms

Availability[II]	The fraction of time (usually hrs/year) for which a power plant is in operational service.
Base load[I]	Typically, the minimum load over a given period of time.
Base load (demand)[II]	The maximum continuous load (demand) experienced over a given period of time (usually for 1 year).
Capacity[I]	The greatest load a piece of equipment can safely serve.
Capacity factor[II]	The ratio of average output to installed capacity from a generating unit over a given period of time (usually 1 year).
Dispatching[II]	Allocation of power plant output to specific elements of load coverage.
Energy[I]	The power of doing work, for a given period. Usually measures in kilowatt-hours.
Firm energy[II]	Energy which is available at least 95% of the time.
Load allocation[II]	Proportion (or tranche) of the system demand assigned to a given power plant.
Load demand[I]	A sudden electrical load upon the generating units, inducing the rapid opening of the turbines.
Load curve[II]	Diagram showing the variation of load (or demand) over a given period of time.
Load duration[II]	The duration of given increments of demand throughout the year.
Load factor[I]	The ratio of the annually produced kilowatt-hours and of the energy theoretically producible at installed capacity during the whole year.
Load factor[II]	The ratio of average to peak load over a given period of time (usually 1 year).
No-firm energy; secondary energy[II]	Energy which is available for less than 95% of the time.
Peak load[I]	The greatest amount of power given out or taken in by a machine or power distribution system in a given time.
Peak load (demand)[II]	The maximum load (demand) experienced during a given period of time (usually for 1/2 to 1 hr).

Plant factor [II]	The ratio of average output to peak output from a generating unit over a given period of time (usually 1 year).
Power [I]	The rate at which work is done by an electric current or mechanical force, generally measured in watts or horsepower.
Power factor [II]	The ratio of useful power dissipated in a circuit to the product of voltage and current applied to this circuit.
Water power [I]	A general term used for characterising both power (kW) and energy (kWh) of watercourses, lakes, reservoirs and seas.

Economic and Financial Terms

ADSCR [IV]	Annual Debt Service Cover Ratio, the ratio between operating cash flow and debt service over any one year of the project.
All Risks insurance [IV]	Insurance against physical damage to the project during operation.
Annual cost [II]	Annually recurring expenditure in operations.
Annuity [II]	The annual repayment tranches for a capital loan.
Annuity repayment [IV]	A debt repayment schedule that produces level debt service payments.
Asset [II]	A physical component having a capital value.
Asset life [II]	The physical life with which an asset can be credited up to the time it becomes no longer serviceable and is considered to be obsolete.
Availability charge [IV]	The fixed charge element of a tariff, payable whether or not the product or service is required.
Base Case [IV]	The lenders' projections of project cash flow at or shortly before Financial Close.
Capacity Charge [IV]	*See* Availability Charge.
Capital cost [II]	Expenditure for the purchase of an asset.
Cash flow [II]	Total annual income and outgoings on an asset, including capital and annual revenue expenditure.
Cash flow cascade [IV]	The order of priorities under the financing documentation for the application of the Project Company's cash flow.
CEAR insurance [IV]	Construction & Erection All Risks insurance, covering physical damage to the project during construction.

COD [IV]	Commercial Operation Date, the date on which the project is complete and the Project Company is ready to begin operations.
Commercial banks [IV]	Private-sector banks, the main providers of debt to the project finance markets.
Commercial risks [IV]	Project finance risks inherent in the project itself or the market for its product or service; cf. completion, operating, revenue, input supply, and environmental risks.
Completion risks [IV]	Commercial risks relating to the completion of the project.
Concession Agreement [IV]	A Project Agreement under which the Project Company provides a service to the Contracting Authority, or directly to the general public.
Construction risks [IV]	*See* completion risks.
Contingency [IV]	Unallocated reserve in the project cost budget, covered by contingency funding.
Country risk [IV]	*See* political risks.
Cover ratios [IV]	Ratios of the cash flows from the project against debt service, i.e., ADSCR, LLCR, PLCR, or Reserve Cover Ratio.
CPI [IV]	Consumer Price Index, in index of inflation.
Debt [IV]	Finance provided by the lenders.
Debt capital [II]	Capital raised from loans or borrowings, generally for a fixed period of time (to the ‘maturity date’) and at a fixed interest rate.
Debt service [IV]	Payment of interest and debt principal installments.
Debt : equity ratio [IV]	Ratio of debt to equity.
Degradation [IV]	The decline in operating efficiency of a project caused by usage.
Delay LDs [IV]	LDs payable by the EPC Contractor for failure to complete the project by the agreed date.
Depreciation [II]	The writing-down of an asset value through regular payments or through allowances set against the original asset value.
Depreciation [IV]	Writing down the capital cost of the project.
Developers [IV]	*See* Sponsors.
Development Agreement [IV]	An agreement between Sponsors relating to the development of the project.
Development costs [IV]	Costs incurred by the Sponsors before Financial Close.

Discounting [II]	Establishing the initial sum (the present worth) which with interest compounded, will pay for the cash flow accumulated over a given period of time.
Discount rate [II]	The interest rate –usually per annum- at which the discounting process is carried out.
Discount rate [IV]	The rate used to reduce a future cash flow to a current value, and calculate its NPV.
Distributions [IV]	Net cash flow paid to the investors as dividends, subordinated debt interest or principal, or repayment of equity.
Economic life [II]	The life-span of an asset over which it achieves the economic performance expected from it.
EPC Contract [IV]	Engineering, Procurement, and Construction Contract, a fixed-price, date-certain, turnkey contract under which the project is designed and engineered, equipment procured or manufactured, and the project constructed and erected.
EPC Contractor [IV]	The contractor under the EPC contract.
Equity [IV]	The portion of the project’s capital costs contributed by the investors, which may be provided as share capital or subordinated debt.
Equity capital [II]	Investments from shareholders or participants in the enterprise with no fixed redemption date or fixed interest rate.
Equity IRR [IV]	The IRR on the equity paid in by the investors, derived from distributions.
Financial Adviser [IV]	The sponsor’s adviser on arranging finance for the Project Company.
Financial Close [IV]	The date on which all Project Contracts and financing documentation are signed, and conditions precedent to initial drawing of the debt have been fulfilled.
Financial Model [IV]	The financial model used by lenders to review and monitor the project.
Fixed Charge [IV]	*See* Availability Charge.
Floating interest rate [IV]	An interest rate revised at regular intervals to the current market rate; cf. LIBOR, rate-fixing date.
Government Support Agreement [IV]	A Project Contract that establishes the legal basis for the project, or under which the government agrees to provide various kinds of support or guarantees.
ICB [IV]	International competitive bidding procedures of the World Bank; *See* public procurement.

IDC [IV]	Interest during construction, which is capitalized and forms part of the project cost budget.
Interest [II]	Recurring service charges attached to borrowings of any kind and usually payable throughout the period during which these borrowings are outstanding (i.e. until they have been fully repaid).
Independent Engineer [IV]	*See* Lenders' Engineer.
Inflation risks [IV]	Macroeconomic risks resulting from changes in the rate of price inflation.
Interest rate cap [IV]	A hedging contract that sets a maximum interest rate for the Project Company's debt.
Interest rate risks [IV]	Macroeconomic risks resulting from increases in interest rates.
Interest rate swap [IV]	A hedging contract to convert a floating interest rate into a fixed rate.
Investment risks [IV]	Political risks relating to currency convertibility and transfer, expropriation, and political force majeure.
Investors [IV]	Sponsors and other parties investing equity into the Project Company.
IRR [IV]	Internal rate of return, the rate of return on an investment derived from future cash flows.
LDs [IV]	Liquidated damages, i.e., the agreed level of loss when a party does not perform under a contract.
Lenders [IV]	Banks or bond investors.
Lenders' advisers [IV]	External advisers employed by the lenders.
Lenders Engineer [IV]	An engineering firm advising the lenders.
Levellised rates [II]	Repayment of a loan, or depreciation of an asset, in equal annual tranches throughout the life period of the loan or asset.
LIBOR [IV]	London interbank offered rate, one of the leading floating interest rates.
LLCR [IV]	Loan Life Cover Ratio, the ratio of the NPV of operating cash flow during the remaining term of the debt and the debt principal amount.
Loans [II]	Borrowings of capital which have to be repaid over a period of time and usually incur interest rates.
Loan redemption [II]	Repayment of a loan throughout the loan life on whatever terms the loan was originally granted.
LOI [IV]	Letter of Intent, heads of terms for a Project Agreement or other Project Contract.

Macroeconomic risks[IV]	Project finance risks related to inflation, interest rates, or currency exchange rates.
Maintenance Reserve Account[IV]	A Reserve Account that builds up a cash balance sufficient to cover the major maintenance of the project.
Marginal rate[II]	The rate appropriate to an increment of consumption or expenditure.
Merchant power plant[IV]	A power project that does not have a PPA, but relies on selling its power into a competitive market.
MIRR[IV]	Modified IRR, an IRR calculation with a reduced reinvestment rate for cash taken out of the project.
Net revenue[II]	Income from operations after accounting for costs (≠ ‘profit’).
NPV[IV]	Net Present Value, the discounted present value of a stream of future cash flows.
O&M[IV]	Operation and maintenance.
Offtake Contract[IV]	A Project Agreement under which the Project Company produces a product and sells it to the Offtaker.
Offtaker[IV]	The purchaser of the product under an Offtake Contract.
Operating cost budget[IV]	The budget for the operating costs (where these are under the Project Company’s control).
Operating risks[IV]	Commercial risks relating to the operation of the project.
Owner’s Engineer[IV]	The engineer supervising the EPC Contractor on behalf of the Project Company.
Payback period[IV]	The period of time in which distributions to investors equal their original investment.
Penalties[IV]	LDs payable under the Project Agreement.
Performance risks[IV]	Completion risks relating to the performance of the project.
PLCR[IV]	Project Life Cover Ratio, the ratio of the NPV of operating cash flow and debt service during the remaining life of the project.
Political risks[IV]	Project finance risks related to political force majeure and other investment risks, change of law, and quasi-political risks.
PPA[IV]	Power Purchase Agreement, a type of Offtake Contract.
PPP[IV]	Public-private partnership, all contracts under which a private-sector party provides a service to or on behalf of the public sector.

Profit [II]	Income after deduction of all costs and charges.
Project Agreement [IV]	A contract that provides the Project Company with revenues over the project’s life, usually in the form of an Offtake Contract or Concession Agreement.
Project Company [IV]	The SPV created to construct and operate the project.
Project Company costs [IV]	Costs of running the Project Company itself.
Project cost budget [IV]	The budget for construction, finance, and other capital costs of the project.
Project finance [IV]	A method for raising long-term debt financing for major projects through “financial engineering”, based on lending against the cash flow generated by the project alone; it depends on a detailed evaluation of a project’s construction, operating and revenue risks, and their allocation between investors, lenders, and other parties through contractual and other arrangements.
Project finance risks [IV]	*See* commercial risks, macroeconomic risks and political risks.
Project IRR [IV]	The IRR of the Project Company’s cash flow before allowing for debt service and distributions.
Project risks [IV]	*See* commercial risks.
Promoters [IV]	*See* Sponsors.
Public procurement [IV]	Competitive bidding for a Project Agreement.
Purchasing Power Parity [IV]	The assumption that the future exchange rate between two currencies will reflect their inflation rate differentials.
Real interest rate [IV]	The interest rate excluding inflation.
Real return [IV]	The return on a project or investment excluding inflation (cf. nominal return).
Redemption [II]	Recovery or pay-back of loans, borrowings or capital expenditure.
Refinancing [IV]	Prepayment of the debt and substitution of new debt on more attractive terms.
Revenue [II]	Income from operations (usually total income or ‘gross revenue’).
Revenue risks [IV]	Commercial risks relating to generation of revenue by the Project Company, derived from volume and price of product sales, or level of usage of the project.

RFP ^{IV}	Request for Proposals, an invitation to bid in a public procurement.
Risk matrix ^{IV}	Schedule of project finance risks and mitigations.
Specific cost ^{II}	The cost per unit of capacity, usually per kW or MW installed.
Sponsors ^{IV}	The investors who develop and lead the project through their investment in the Project Company.
SPV ^{IV}	Special Purpose Vehicle, a separate legal entity with no activity other than those connected with its borrowing.
Subordinated debt ^{IV}	Debt whose debt service comes after amounts due to senior lenders, but before distributions of dividends to investors; cf. mezzanine debt.
Tariff ^{IV}	Payments under a Project Agreement; see Availability Charge and Variable Charge, or Unitary Charge.
Term ^{IV}	Duration of a Project Contract or the period until the final repayment date of the debt.
Unity Charge ^{IV}	A combined Availability and Variable Charge under a Concession Agreement.
Variable Charge ^{IV}	The element of a Tariff intended to cover a project’s variable costs.
VAT ^{IV}	Value added tax.
Working capital ^{IV}	The amount of funding required for inventories and other costs incurred before receipt of sales revenues.

Theories of Uncertainty

Aleatory uncertainty ^{V}	The kind of uncertainty resulting from randomness or unpredictability due to stochasticity. Aleatory uncertainty is also known as variability, stochastic uncertainty, Type I or Type A uncertainty, irreducible uncertainty, objective uncertainty.
Best possible ^{V}	An upper bound is best possible if it is the smallest such bound possible. A lower bound is best possible if it is the largest lower bound possible.
Bound ^{V}	An upper bound of a set of real numbers is a real number that is greater than or equal to every number in the set. A lower bound is a number less than or equal to every number in the set. In this report, we also consider bounds on functions. These are not bounds on the range of the function, but rather bounds on the function for every function input. For instance, an upper bound on a function $F(x)$ is another function $B(x)$ such that $B(x) \geq F(x)$ for all values of x. $B(x)$ is a lower bound on the function if the inequality is reversed. If an upper bound cannot be any smaller, or a

	lower bound cannot be any larger, it is called a best possible bound.
Cumulative distribution function ^{V}	For a random variable *X,* the probability *F*(*x*) that will take on a value not greater than *x*. If the random variable takes on only a finite set of values, then *F*(*x*) is the sum of the probabilities of the values less than or equal to *x*. Also known as a distribution function.
Dempster-Shafer structure ^{V}	A kind of uncertain number representing indistinguishability within bodies of evidence. In this report, a Dempster-Shafer structure is a finite set of closed intervals of the real line, each of which is associated with a nonnegative value *m*, such that the sum of all such *m*’s is one.
Distribution function ^{V}	For a random variable *X,* the probability *F*(*x*) that *X* will take on a value not greater than *x*. If the random variable takes on only a finite set of values, then *F*(*x*) is the sum of the probabilities of the values less than or equal to *x*. Also known as a cumulative distribution function.
Epistemic uncertainty ^{V}	The kind of uncertainty arising from imperfect knowledge. Epistemic uncertainty is also known as incertitude, ignorance, subjective uncertainty, Type II or Type B uncertainty, reducible uncertainty, and state-of-knowledge uncertainty.
Focal element ^{V}	A set (in this report, a closed interval of the real line) associated with a nonzero mass as a part of a Dempster-Shafer structure.
Imprecise probabilities ^{V}	Any of several theories involving models of uncertainty that do not assume a unique underlying probability distribution, but instead correspond to a set of probability distributions (Couso et al. 2000). An imprecise probability arises when one’s lower probability for an event is strictly smaller than one’s upper probability for the same event (Walley 1991). Theories of imprecise probabilities are often expressed in terms of a lower probability measure giving the lower probability for every possible event from some universal set, or in terms of closed convex sets of probability distributions (which are generally much more complicated structures than either probability boxes or Dempster-Shafer structures).
Interval ^{V}	A kind of uncertain number consisting of the set of all real numbers lying between two fixed numbers called the endpoints of the interval. In this report, intervals are always closed so that the endpoints are always considered part of the set.
Lower probability ^{V}	The maximum rate for an event *A* one would be willing to pay for the gamble that pays 1 unit of utility if *A* occurs and nothing otherwise.

Measurement error ^{V}	The difference between a measured quantity and its actual or true value is called measurement error. The term is also used to refer to the imprecision or uncertainty about a measurement, although the term measurement uncertainty is now preferable for this meaning.
Measurement uncertainty ^{V}	The uncertainty (incertitude) about the accuracy of a measurement.
Monte Carlo simulation ^{V}	A method of calculating functions (often convolutions) of probability distributions by repeatedly sampling random values from those distributions and forming an empirical distribution function of the results.
Precision ^{V}	A measure of the reproducibility of a measured value under a given set of conditions.
Probability box ^{V}	A kind of uncertain number representing both incertitude and variability. A probability box can be specified by a pair of functions serving as bounds about an imprecisely known cumulative distribution function. The probability box is identified with the class of distribution functions that would be consistent with (i.e., bounded by) these distributions.
Quantile ^{V}	A number that divides the range of a set of data or a distribution such that a specified fraction of the data or distribution lies below this number.
Random variable ^{V}	A variable quantity whose values are distributed according to a probability distribution. If the potential values of the random variable are a finite or countable set, the random variable is said to be discrete. For a discrete random variable, each potential value has an associated probability between zero and one, and the sum of all of these probabilities is one. If the random variable can take on any value in some interval of the real line (or any rational value within some interval), it is called a continuous random variable.
Rigorous ^{V}	Exact or sure, as opposed to merely approximate.
Sampling uncertainty ^{V}	The incertitude about a statistic or a probability distribution arising from incomplete sampling of the population characterized by the statistic or distribution.
Uncertain number ^{V}	A numerical quantity or distribution about which there is uncertainty. Uncertain numbers include intervals, probability distributions, probability boxes, Dempster-Shafer structures as special cases. Uncertain numbers also include scalars (real numbers) as degenerate special cases.

Uncertainty[V]	The absence of perfectly detailed knowledge. Uncertainty includes incertitude (the exact value is not known) and variability (the value is changing). Uncertainty may also include other forms such as vagueness, ambiguity and fuzziness (in the sense of border-line cases).
Upper probability[V]	The minimum rate for an event *A* one would be willing to pay for the gamble that pays 1 unit of utility if *A* does not occur and nothing otherwise.
Variability[V]	The fluctuation or variation due to randomness or stochasticity. Variability is also associated with aleatory uncertainty, stochastic uncertainty, Type I or Type A uncertainty, irreducible uncertainty, objective uncertainty.

Sources:

I : (Gulliver, Arndt 1991)

II : (Goldsmith 1993)

III : (Ravn 1992)

IV : (Yescombe 2006)

V: (Ferson et al. 2003)

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APPENDIX

A1 Table of natural monthly discharge in m^3/s at the proposed HPP project site

Month	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	Mean
Year	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s	m^3/s
1951	2936	3155	3126	3190	8940	3996	3451	5057	4536	3220	2925	2772	3942
1952	2912	3112	3068	3129	6360	5410	6034	5610	6325	5136	2971	2958	4419
1953	2935	3159	3081	4093	6540	3364	5061	5019	3273	3226	2937	2924	3801
1954	2896	3122	3049	3118	5520	3457	4871	3371	3360	3273	2942	2889	3489
1955	2910	3154	3142	3257	5790	4982	4252	3305	3352	3266	2928	2895	3603
1956	2951	3145	3126	3234	7500	3686	3866	3325	3282	3278	2925	2827	3595
1957	2852	3106	3089	3153	4840	3593	3230	3304	3232	3220	2904	2582	3259
1958	2853	3073	3025	3115	5630	4074	3270	3405	3248	3181	2917	3083	3406
1959	3049	3230	3060	3525	7780	8270	4485	4677	3338	3272	2926	2882	4208
1960	2859	3070	3104	3211	5720	3864	3437	3344	3521	3327	2971	2933	3447
1961	2939	3197	3148	3536	6240	4053	4395	3319	4008	3285	2984	2944	3671
1962	2967	3167	3087	3220	6870	4617	6293	5713	5335	3269	2938	2938	4201
1963	2934	3179	3130	3155	5680	5619	5169	3662	5034	3391	3102	2977	3919
1964	2981	3190	3080	3177	5620	3711	3982	3286	5110	3222	2941	2923	3602
1965	2914	3185	3062	3118	6220	3537	3313	3305	3463	3326	2889	2878	3434
1966	2877	3118	3065	3108	7770	4381	4843	5404	5199	3234	2883	2919	4067
1967	2872	3119	3058	3984	5470	3465	3288	5018	6284	3592	2952	2907	3834
1968	2914	3076	3065	3765	3996	3355	3608	5128	3286	3231	2903	2886	3434
1969	2884	3068	3045	3099	6930	4750	3302	3265	3259	3215	2802	2775	3533
1970	2816	3118	3028	3220	5050	4302	3904	3309	3238	3195	2843	2831	3405
1971	2860	3081	3035	3320	5650	3477	5695	5610	6355	3569	3005	2941	4050
1972	2884	3120	3067	3610	6180	3702	3655	3266	3278	3223	2856	2838	3473
1973	2820	3134	3095	3199	6120	6033	4277	5644	6093	5245	2946	2899	4292
1974	2889	3163	3085	3285	5240	4490	3311	3266	3464	3431	2995	2920	3462
1975	2947	3142	3116	3348	9930	4287	3345	4915	4729	3642	3065	2967	4119
1976	2947	3141	3094	3233	5550	3632	3292	3162	3141	3381	2894	2836	3359
1977	2827	3059	3063	2874	7560	4590	3556	3323	3462	3024	2492	3131	3580
1978	2786	2920	2903	2839	6360	3895	3143	3123	3310	3540	2535	3154	3376
1979	3400	2868	2842	3086	7060	4057	3152	3311	3338	3070	2424	3207	3485
1980	2929	2872	2886	2358	5680	4111	3161	3206	3125	4081	2894	3275	3382
1981	3251	3115	2656	2667	5960	3578	3468	3239	3242	3257	3399	3459	3441
1982	2977	1707	1562	1321	5960	3924	3269	3409	3098	2877	1684	2133	2827
1983	1890	2202	1632	2376	7370	6510	3209	3405	3254	2850	2085	2586	3281
1984	3216	3770	3494	3420	6940	3717	3174	3121	3351	3608	3495	3670	3748
1985	4127	4114	4079	3491	7350	4112	3461	4732	5474	3866	3764	3439	4334
1986	3875	4001	3869	3821	6230	4293	3617	3746	3706	3307	3447	3337	3937
1987	3724	3613	3681	3322	4670	4141	3996	3470	3977	3343	3300	3231	3706
1988	3258	3563	3331	3624	6690	4050	3517	3856	5351	4215	4171	3336	4080
1989	3522	3971	4413	4471	7650	4399	4199	3905	3821	4049	3545	3793	4312
1990	3945	3925	3230	3048	5620	3454	3396	3395	3603	3020	3001	3416	3588
1991	3510	3569	3445	2954	6090	3900	3653	3522	3497	3579	2937	3248	3659
1992	3319	3904	3845	3581	6180	3571	3357	3387	3268	2996	2972	3181	3630
1993	3439	3875	3648	3351	6003	3819	3246	3430	3658	3830	2748	3188	3686
1994	3023	3281	3390	3385	7500	4339	3426	3319	3292	4473	3435	3639	3875
1995	3653	3818	3723	4781	8100	4951	4924	5535	4494	3779	3124	3198	4507
1996	3584	4073	3847	3241	6680	3883	3507	3650	3725	3324	3117	3110	3812
Average	3084	3255	3167	3270	6408	4248	3871	3908	3974	3477	2976	3040	3723
Maximum	4127	4114	4413	4781	9930	8270	6293	5713	6355	5245	4171	3793	9930
Minimum	1890	1707	1562	1321	3996	3355	3143	3121	3098	2850	1684	2133	1321

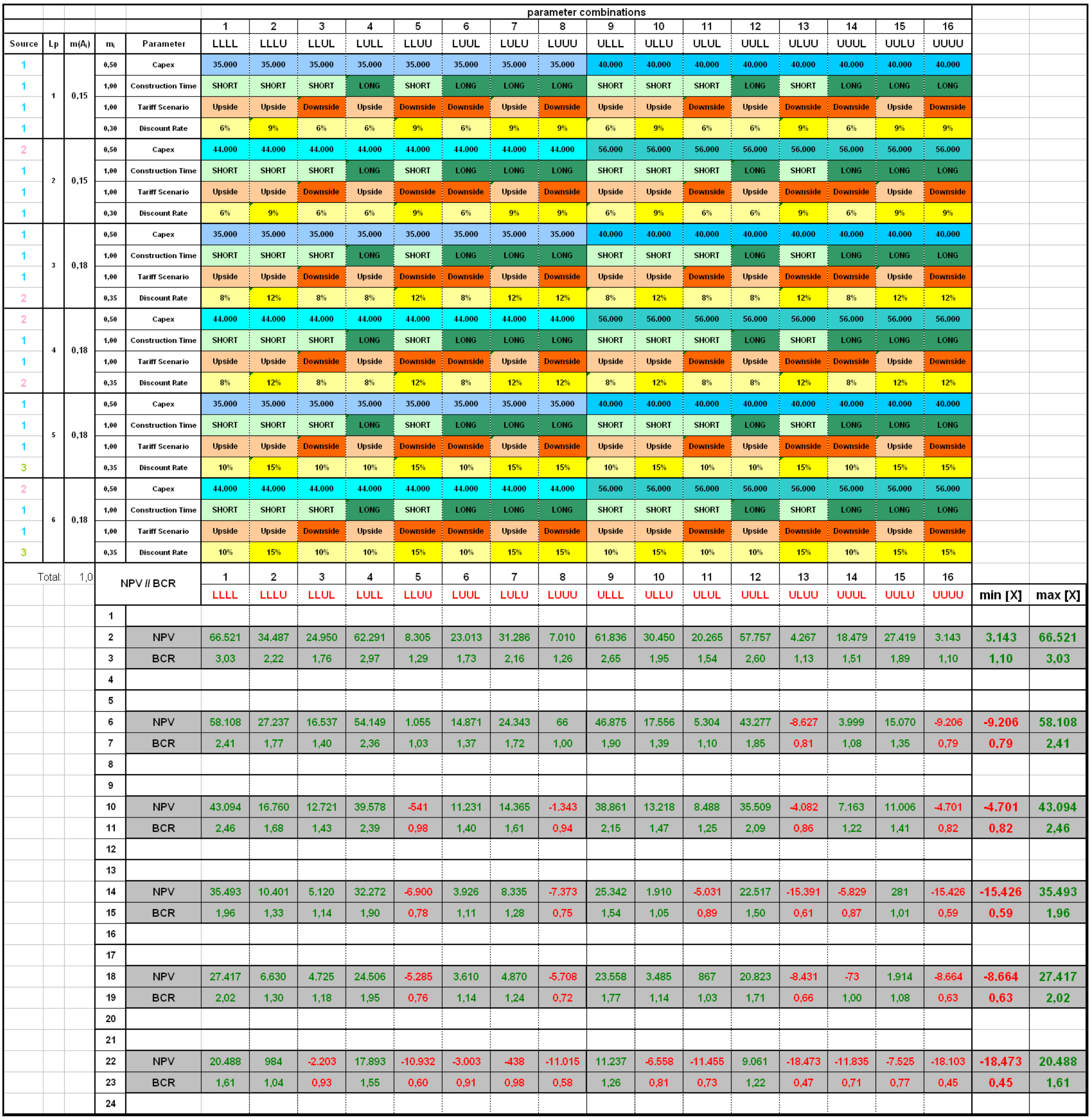
A2 Calculation of NPV, IRR and BCR for all input parameter combinations

	Capex				Total Construction Time		Tarif Scenario		Discount Rate						NPV	IRR	B/C	Interval Ranges			
	Source No. 1		Source No.2														Ratio	NPV	IRR	B/C Ratio	
	Min.	Max.	Min.	Max.	Min. SHORT	Max. LONG	Upside	Downside	6,00%	8,00%	9,00%	10,00%	12,00%	15,00%							
	35.000	40.000	44.000	56.000	6 Years	7 Years															
1	35.000				6 Years		Upside		6,00%						66.521	18,49%	3,03	3.999	6,70%	1,08	Min.
2	35.000				6 Years			Downside	6,00%						24.950	11,75%	1,76				
3	35.000					7 Years	Upside		6,00%						62.291	17,60%	2,97				
4	35.000					7 Years		Downside	6,00%						23.013	11,37%	1,73				
5		40.000			6 Years		Upside		6,00%						61.836	16,67%	2,65				
6		40.000			6 Years			Downside	6,00%						20.265	10,29%	1,54				
7		40.000				7 Years	Upside		6,00%						57.757	15,93%	2,60				
8		40.000				7 Years		Downside	6,00%						18.479	9,97%	1,51				
9			44.000		6 Years		Upside		6,00%						58.108	15,44%	2,41				
10			44.000		6 Years			Downside	6,00%						16.537	9,30%	1,40				
11			44.000			7 Years	Upside		6,00%						54.149	14,80%	2,36				
12			44.000			7 Years		Downside	6,00%						14.871	9,02%	1,37				
13				56.000	6 Years		Upside		6,00%						46.875	12,53%	1,90				
14				56.000	6 Years			Downside	6,00%						5.304	6,91%	1,10				
15				56.000		7 Years	Upside		6,00%						43.277	12,08%	1,85				
16				56.000		7 Years		Downside	6,00%						3.999	6,70%	1,08	66.521	18,49%	3,03	Max.
17	35.000				6 Years		Upside			8,00%					43.094	18,49%	2,46	-5.829	6,70%	0,87	Min.
18	35.000				6 Years			Downside		8,00%					12.721	11,75%	1,43				
19	35.000					7 Years	Upside			8,00%					39.578	17,60%	2,39				
20	35.000					7 Years		Downside		8,00%					11.231	11,37%	1,40				
21		40.000			6 Years		Upside			8,00%					38.861	16,67%	2,15				
22		40.000			6 Years			Downside		8,00%					8.488	10,29%	1,25				
23		40.000				7 Years	Upside			8,00%					35.509	15,93%	2,09				
24		40.000				7 Years		Downside		8,00%					7.163	9,97%	1,22				
25			44.000		6 Years		Upside			8,00%					35.493	15,44%	1,96				
26			44.000		6 Years			Downside		8,00%					5.120	9,30%	1,14				
27			44.000			7 Years	Upside			8,00%					32.272	14,80%	1,90				
28			44.000			7 Years		Downside		8,00%					3.926	9,02%	1,11				
29				56.000	6 Years		Upside			8,00%					25.342	12,53%	1,54				
30				56.000	6 Years			Downside		8,00%					-5.031	6,91%	0,89				
31				56.000		7 Years	Upside			8,00%					22.517	12,08%	1,50				
32				56.000		7 Years		Downside		8,00%					-5.829	6,70%	0,87	43.094	18,49%	2,46	Max.
33	35.000				6 Years		Upside				9,00%				34.487	18,49%	2,22	-9.206	6,70%	0,79	
34	35.000				6 Years			Downside			9,00%				8.305	11,75%	1,29				
35	35.000					7 Years	Upside				9,00%				31.286	17,60%	2,16				
36	35.000					7 Years		Downside			9,00%				7.010	11,37%	1,26				
37		40.000			6 Years		Upside				9,00%				30.450	16,67%	1,95				
38		40.000			6 Years			Downside			9,00%				4.267	10,29%	1,13				
39		40.000				7 Years	Upside				9,00%				27.419	15,93%	1,89				
40		40.000				7 Years		Downside			9,00%				3.143	9,97%	1,10				
41			44.000		6 Years		Upside				9,00%				27.237	15,44%	1,77				
42			44.000		6 Years			Downside			9,00%				1.055	9,30%	1,03				
43			44.000			7 Years	Upside				9,00%				24.343	14,80%	1,72				
44			44.000			7 Years		Downside			9,00%				66	9,02%	1,00				
45				56.000	6 Years		Upside				9,00%				17.556	12,53%	1,39				
46				56.000	6 Years			Downside			9,00%				-8.627	6,91%	0,81				
47				56.000		7 Years	Upside				9,00%				15.070	12,08%	1,35				
48				56.000		7 Years		Downside			9,00%				-9.206	6,70%	0,79	34.487	18,49%	2,22	
49	35.000				6 Years		Upside					10,00%			27.417	18,49%	2,02	-11.835	6,70%	0,71	Min.
50	35.000				6 Years			Downside				10,00%			4.725	11,75%	1,18				
51	35.000					7 Years	Upside					10,00%			24.506	17,60%	1,95				
52	35.000					7 Years		Downside				10,00%			3.610	11,37%	1,14				
53		40.000			6 Years		Upside					10,00%			23.558	16,67%	1,77				
54		40.000			6 Years			Downside				10,00%			867	10,29%	1,03				
55		40.000				7 Years	Upside					10,00%			20.823	15,93%	1,71				
56		40.000				7 Years		Downside				10,00%			-73	9,97%	1,00				
57			44.000		6 Years		Upside					10,00%			20.488	15,44%	1,61				
58			44.000		6 Years			Downside				10,00%			-2.203	9,30%	0,93				
59			44.000			7 Years	Upside					10,00%			17.893	14,80%	1,55				
60			44.000			7 Years		Downside				10,00%			-3.003	9,02%	0,91				
61				56.000	6 Years		Upside					10,00%			11.237	12,53%	1,26				
62				56.000	6 Years			Downside				10,00%			-11.455	6,91%	0,73				
63				56.000		7 Years	Upside					10,00%			9.061	12,08%	1,22				
64				56.000		7 Years		Downside				10,00%			-11.835	6,70%	0,71	27.417	18,49%	2,02	Max.
65	35.000				6 Years		Upside						12,00%		16.760	18,49%	1,68	-15.426	6,70%	0,59	Min.
66	35.000				6 Years			Downside					12,00%		-541	11,75%	0,98				
67	35.000					7 Years	Upside						12,00%		14.365	17,60%	1,61				
68	35.000					7 Years		Downside					12,00%		-1.343	11,37%	0,94				
69		40.000			6 Years		Upside						12,00%		13.218	16,67%	1,47				
70		40.000			6 Years			Downside					12,00%		-4.082	10,29%	0,86				
71		40.000				7 Years	Upside						12,00%		11.006	15,93%	1,41				
72		40.000				7 Years		Downside					12,00%		-4.701	9,97%	0,82				
73			44.000		6 Years		Upside						12,00%		10.401	15,44%	1,33				
74			44.000		6 Years			Downside					12,00%		-6.900	9,30%	0,78				
75			44.000			7 Years	Upside						12,00%		8.335	14,80%	1,28				
76			44.000			7 Years		Downside					12,00%		-7.373	9,02%	0,75				
77				56.000	6 Years		Upside						12,00%		1.910	12,53%	1,05				
78				56.000	6 Years			Downside					12,00%		-15.391	6,91%	0,61				
79				56.000		7 Years	Upside						12,00%		281	12,08%	1,01				
80				56.000		7 Years		Downside					12,00%		-15.426	6,70%	0,59	16.760	18,49%	1,68	Max.
81	35.000				6 Years		Upside							15,00%	6.630	18,49%	1,30	-18.473	6,70%	0,45	Min.
82	35.000				6 Years			Downside						15,00%	-5.285	11,75%	0,76				
83	35.000					7 Years	Upside							15,00%	4.870	17,60%	1,24				
84	35.000					7 Years		Downside						15,00%	-5.708	11,37%	0,72				
85		40.000			6 Years		Upside							15,00%	3.485	16,67%	1,14				
86		40.000			6 Years			Downside						15,00%	-8.431	10,29%	0,66				
87		40.000				7 Years	Upside							15,00%	1.914	15,93%	1,08				
88		40.000				7 Years		Downside						15,00%	-8.664	9,97%	0,63				
89			44.000		6 Years		Upside							15,00%	984	15,44%	1,04				
90			44.000		6 Years			Downside						15,00%	-10.932	9,30%	0,60				
91			44.000			7 Years	Upside							15,00%	-438	14,80%	0,98				
92			44.000			7 Years		Downside						15,00%	-11.015	9,02%	0,58				
93				56.000	6 Years		Upside							15,00%	-6.558	12,53%	0,81				
94				56.000	6 Years			Downside						15,00%	-18.473	6,91%	0,47				
95				56.000		7 Years	Upside							15,00%	-7.525	12,08%	0,77				
96				56.000		7 Years		Downside						15,00%	-18.103	6,70%	0,45	6.630	18,49%	1,30	Max.

A3 Calculation of NPV, IRR and BCR using reduced interval ranges

	Capex				Total Construction Time		Tarif Scenario		Discount Rate				NPV	IRR	B/C	Interval Ranges			
	Min.		Max.												Ratio	NPV	IRR	B/C Ratio	
	Min.1	Min.2	Max.1	Max.2	Min. SHORT	Max. LONG	Upside	Downside	8,00%	10,00%	12,00%	14,00%							
	38.000	40.000	42.000	48.000	6 Years	7 Years													
1	38.000				6 Years		Upside		8,00%				40.545	17,35%	2,26	667	8,16%	1,02	Min.
2	38.000				6 Years			Downside	8,00%				10.172	10,84%	1,32				
3	38.000					7 Years	Upside		8,00%				37.128	16,56%	2,20				
4	38.000					7 Years		Downside	8,00%				8.781	10,50%	1,28				
5		40.000			6 Years		Upside		8,00%				38.861	16,67%	2,15				
6		40.000			6 Years			Downside	8,00%				8.488	10,29%	1,25				
7		40.000				7 Years	Upside		8,00%				35.509	15,93%	2,09				
8		40.000				7 Years		Downside	8,00%				7.163	9,97%	1,22				
9			42.000		6 Years		Upside		8,00%				37.177	16,03%	2,05				
10			42.000		6 Years			Downside	8,00%				6.804	9,78%	1,19				
11			42.000			7 Years	Upside		8,00%				33.891	15,35%	1,99				
12			42.000			7 Years		Downside	8,00%				5.544	9,48%	1,16				
13				48.000	6 Years		Upside		8,00%				32.102	14,35%	1,79				
14				48.000	6 Years			Downside	8,00%				1.729	8,41%	1,04				
15				48.000		7 Years	Upside		8,00%				29.013	13,79%	1,74				
16				48.000		7 Years		Downside	8,00%				667	8,16%	1,02	40.545	17,35%	2,26	Max.
17	38.000				6 Years		Upside			10,00%			25.093	17,35%	1,86	-5.954	8,16%	0,83	Min.
18	38.000				6 Years			Downside		10,00%			2.402	10,84%	1,08				
19	38.000					7 Years	Upside			10,00%			22.288	16,56%	1,80				
20	38.000					7 Years		Downside		10,00%			1.392	10,50%	1,05				
21		40.000			6 Years		Upside			10,00%			23.558	16,67%	1,77				
22		40.000			6 Years			Downside		10,00%			867	10,29%	1,03				
23		40.000				7 Years	Upside			10,00%			20.823	15,93%	1,71				
24		40.000				7 Years		Downside		10,00%			-73	9,97%	1,00				
25			42.000		6 Years		Upside			10,00%			22.023	16,03%	1,68				
26			42.000		6 Years			Downside		10,00%			-668	9,78%	0,98				
27			42.000			7 Years	Upside			10,00%			19.358	15,35%	1,63				
28			42.000			7 Years		Downside		10,00%			-1.538	9,48%	0,95				
29				48.000	6 Years		Upside			10,00%			17.397	14,35%	1,47				
30				48.000	6 Years			Downside		10,00%			-5.294	8,41%	0,86				
31				48.000		7 Years	Upside			10,00%			14.942	13,79%	1,42				
32				48.000		7 Years		Downside		10,00%			-5.954	8,16%	0,83	25.093	17,35%	1,86	Max.
33	38.000				6 Years		Upside				12,00%		14.627	17,35%	1,54	-10.064	8,16%	0,69	Min.
34	38.000				6 Years			Downside			12,00%		-2.674	10,84%	0,90				
35	38.000					7 Years	Upside				12,00%		12.342	16,56%	1,48				
36	38.000					7 Years		Downside			12,00%		-3.365	10,50%	0,87				
37		40.000			6 Years		Upside				12,00%		13.218	16,67%	1,47				
38		40.000			6 Years			Downside			12,00%		-4.082	10,29%	0,86				
39		40.000				7 Years	Upside				12,00%		11.006	15,93%	1,41				
40		40.000				7 Years		Downside			12,00%		-4.701	9,97%	0,82				
41			42.000		6 Years		Upside				12,00%		11.810	16,03%	1,40				
42			42.000		6 Years			Downside			12,00%		-5.491	9,78%	0,81				
43			42.000			7 Years	Upside				12,00%		9.670	15,35%	1,34				
44			42.000			7 Years		Downside			12,00%		-6.037	9,48%	0,79				
45				48.000	6 Years		Upside				12,00%		7.564	14,35%	1,22				
46				48.000	6 Years			Downside			12,00%		-9.737	8,41%	0,71				
47				48.000		7 Years	Upside				12,00%		5.644	13,79%	1,18				
48				48.000		7 Years		Downside			12,00%		-10.064	8,16%	0,69	14.627	17,35%	1,54	Max.
49	38.000				6 Years		Upside					14,00%	7.448	17,35%	1,30	-12.557	8,16%	0,57	Min.
50	38.000				6 Years			Downside				14,00%	-5.988	10,84%	0,76				
51	38.000					7 Years	Upside					14,00%	5.605	16,56%	1,24				
52	38.000					7 Years		Downside				14,00%	-6.413	10,50%	0,73				
53		40.000			6 Years		Upside					14,00%	6.148	16,67%	1,24				
54		40.000			6 Years			Downside				14,00%	-7.288	10,29%	0,72				
55		40.000				7 Years	Upside					14,00%	4.380	15,93%	1,18				
56		40.000				7 Years		Downside				14,00%	-7.639	9,97%	0,69				
57			42.000		6 Years		Upside					14,00%	4.848	16,03%	1,18				
58			42.000		6 Years			Downside				14,00%	-8.588	9,78%	0,69				
59			42.000			7 Years	Upside					14,00%	3.155	15,35%	1,12				
60			42.000			7 Years		Downside				14,00%	-8.864	9,48%	0,66				
61				48.000	6 Years		Upside					14,00%	930	14,35%	1,03				
62				48.000	6 Years			Downside				14,00%	-12.506	8,41%	0,60				
63				48.000		7 Years	Upside					14,00%	-538	13,79%	0,98				
64				48.000		7 Years		Downside				14,00%	-12.557	8,16%	0,57	7.448	17,35%	1,30	Max.

A4 Calculation of NPV and BCR as upper and lower bounds of the CDF based on random set input parameter ranges (balanced probability weights)

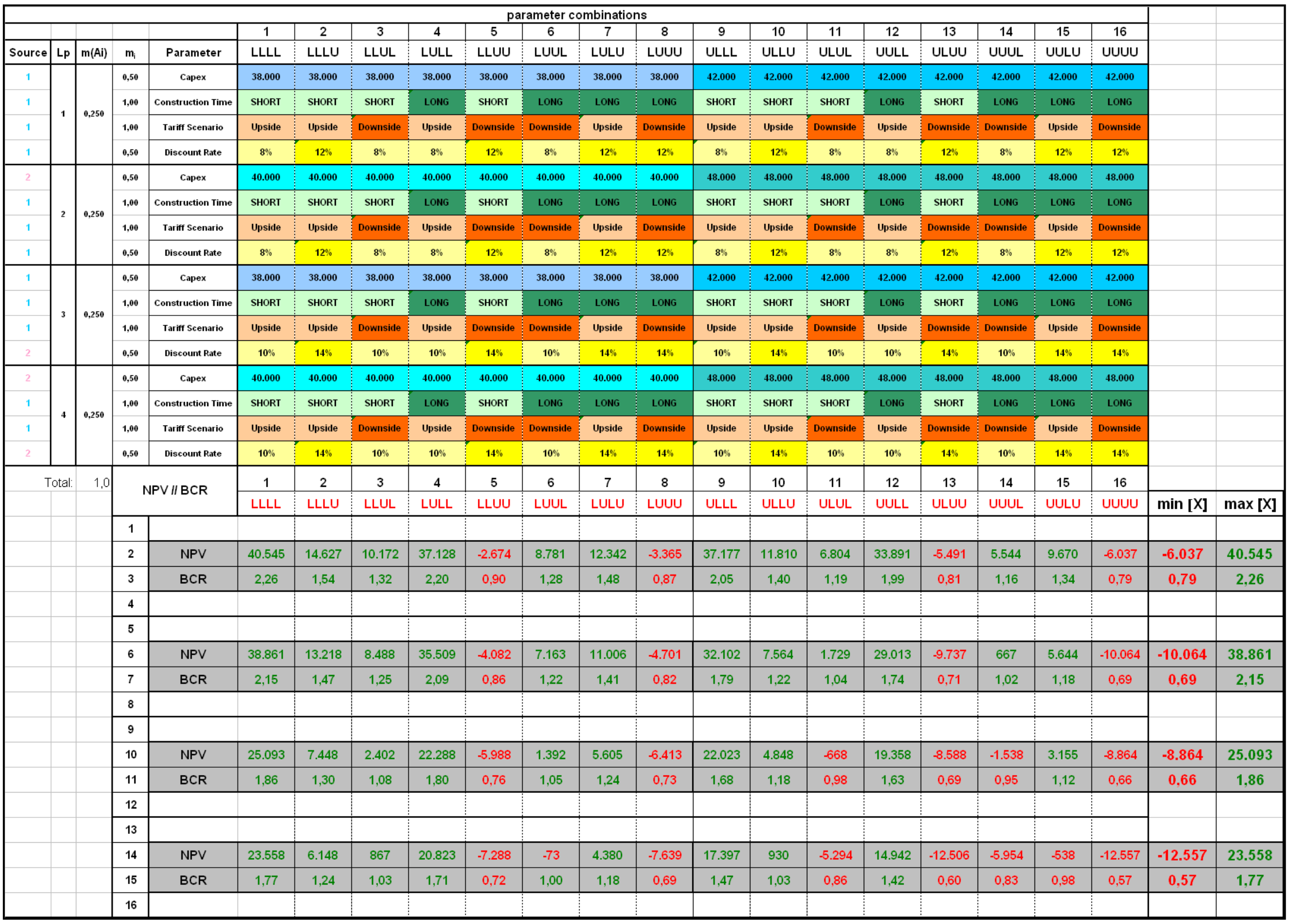


					parameter combinations																	
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Source	Lp	m(A$_j$)	m$_i$	Parameter	LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU		
1	1	0,15	0,50	Capex	35.000	35.000	35.000	35.000	35.000	35.000	35.000	35.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,30	Discount Rate	6%	9%	6%	6%	9%	6%	9%	9%	6%	9%	6%	6%	9%	6%	9%	9%		
2	2	0,15	0,50	Capex	44.000	44.000	44.000	44.000	44.000	44.000	44.000	44.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,30	Discount Rate	6%	9%	6%	6%	9%	6%	9%	9%	6%	9%	6%	6%	9%	6%	9%	9%		
1	3	0,18	0,50	Capex	35.000	35.000	35.000	35.000	35.000	35.000	35.000	35.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,35	Discount Rate	8%	12%	8%	8%	12%	8%	12%	12%	8%	12%	8%	8%	12%	8%	12%	12%		
2	4	0,18	0,50	Capex	44.000	44.000	44.000	44.000	44.000	44.000	44.000	44.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,35	Discount Rate	8%	12%	8%	8%	12%	8%	12%	12%	8%	12%	8%	8%	12%	8%	12%	12%		
1	5	0,18	0,50	Capex	35.000	35.000	35.000	35.000	35.000	35.000	35.000	35.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
3			0,35	Discount Rate	10%	15%	10%	10%	15%	10%	15%	15%	10%	15%	10%	10%	15%	10%	15%	15%		
2	6	0,18	0,50	Capex	44.000	44.000	44.000	44.000	44.000	44.000	44.000	44.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
3			0,35	Discount Rate	10%	15%	10%	10%	15%	10%	15%	15%	10%	15%	10%	10%	15%	10%	15%	15%		
Total:		1,0	NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
					LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
			1																			
			2	NPV	66.521	34.487	24.950	62.291	8.305	23.013	31.286	7.010	61.836	30.450	20.265	57.757	4.267	18.479	27.419	3.143	3.143	66.521
			3	BCR	3,03	2,22	1,76	2,97	1,29	1,73	2,16	1,26	2,65	1,95	1,54	2,60	1,13	1,51	1,89	1,10	1,10	3,03
			4																			
			5																			
			6	NPV	58.108	27.237	16.537	54.149	1.055	14.871	24.343	66	46.875	17.556	5.304	43.277	-8.627	3.999	15.070	-9.206	-9.206	58.108
			7	BCR	2,41	1,77	1,40	2,36	1,03	1,37	1,72	1,00	1,90	1,39	1,10	1,85	0,81	1,08	1,35	0,79	0,79	2,41
			8																			
			9																			
			10	NPV	43.094	16.760	12.721	39.578	-541	11.231	14.365	-1.343	38.861	13.218	8.488	35.509	-4.082	7.163	11.006	-4.701	-4.701	43.094
			11	BCR	2,46	1,68	1,43	2,39	0,98	1,40	1,61	0,94	2,15	1,47	1,25	2,09	0,86	1,22	1,41	0,82	0,82	2,46
			12																			
			13																			
			14	NPV	35.493	10.401	5.120	32.272	-6.900	3.926	8.335	-7.373	25.342	1.910	-5.031	22.517	-15.391	-5.829	281	-15.426	-15.426	35.493
			15	BCR	1,96	1,33	1,14	1,90	0,78	1,11	1,28	0,75	1,54	1,05	0,89	1,50	0,61	0,87	1,01	0,59	0,59	1,96
			16																			
			17																			
			18	NPV	27.417	6.630	4.725	24.506	-5.285	3.610	4.870	-5.708	23.558	3.485	867	20.823	-8.431	-73	1.914	-8.664	-8.664	27.417
			19	BCR	2,02	1,30	1,18	1,95	0,76	1,14	1,24	0,72	1,77	1,14	1,03	1,71	0,66	1,00	1,08	0,63	0,63	2,02
			20																			
			21																			
			22	NPV	20.488	984	-2.203	17.893	-10.932	-3.003	-438	-11.015	11.237	-6.558	-11.455	9.061	-18.473	-11.835	-7.525	-18.103	-18.473	20.488
			23	BCR	1,61	1,04	0,93	1,55	0,60	0,91	0,98	0,58	1,26	0,81	0,73	1,22	0,47	0,71	0,77	0,45	0,45	1,61
			24																			

A5 Calculation of NPV and BCR as upper and lower bounds of the CDF based on random set input parameter ranges (differentiated probability weights)

					parameter combinations																	
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Source	Lp	$m(A_i)$	m_i	Parameter	LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU		
1	1	0,06	0,30	Capex	35.000	35.000	35.000	35.000	35.000	35.000	35.000	35.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,20	Discount Rate	6%	9%	6%	6%	9%	6%	9%	9%	6%	9%	6%	6%	9%	6%	9%	9%		
2	2	0,14	0,70	Capex	44.000	44.000	44.000	44.000	44.000	44.000	44.000	44.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,20	Discount Rate	6%	9%	6%	6%	9%	6%	9%	9%	6%	9%	6%	6%	9%	6%	9%	9%		
1	3	0,12	0,30	Capex	35.000	35.000	35.000	35.000	35.000	35.000	35.000	35.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,40	Discount Rate	8%	12%	8%	8%	12%	8%	12%	12%	8%	12%	8%	8%	12%	8%	12%	12%		
2	4	0,28	0,70	Capex	44.000	44.000	44.000	44.000	44.000	44.000	44.000	44.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,40	Discount Rate	8%	12%	8%	8%	12%	8%	12%	12%	8%	12%	8%	8%	12%	8%	12%	12%		
1	5	0,12	0,30	Capex	35.000	35.000	35.000	35.000	35.000	35.000	35.000	35.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
3			0,40	Discount Rate	10%	15%	10%	10%	15%	10%	15%	15%	10%	15%	10%	10%	15%	10%	15%	15%		
2	6	0,28	0,70	Capex	44.000	44.000	44.000	44.000	44.000	44.000	44.000	44.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000	56.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
3			0,40	Discount Rate	10%	15%	10%	10%	15%	10%	15%	15%	10%	15%	10%	10%	15%	10%	15%	15%		
	Total:	1,0	NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
					LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
			1																			
			2	NPV	66.521	34.487	24.950	62.291	8.305	23.013	31.286	7.010	61.836	30.450	20.265	57.757	4.267	18.479	27.419	3.143	3.143	66.521
			3	BCR	3,03	2,22	1,76	2,97	1,29	1,73	2,16	1,26	2,65	1,95	1,54	2,60	1,13	1,51	1,89	1,10	1,10	3,03
			4																			
			5																			
			6	NPV	58.108	27.237	16.537	54.149	1.055	14.871	24.343	66	46.875	17.556	5.304	43.277	-8.627	3.999	15.070	-9.206	-9.206	58.108
			7	BCR	2,41	1,77	1,40	2,36	1,03	1,37	1,72	1,00	1,90	1,39	1,10	1,85	0,81	1,08	1,35	0,79	0,79	2,41
			8																			
			9																			
			10	NPV	43.094	16.760	12.721	39.578	-541	11.231	14.365	-1.343	38.861	13.218	8.488	35.509	-4.082	7.163	11.006	-4.701	-4.701	43.094
			11	BCR	2,46	1,68	1,43	2,39	0,98	1,40	1,61	0,94	2,15	1,47	1,25	2,09	0,86	1,22	1,41	0,82	0,82	2,46
			12																			
			13																			
			14	NPV	35.493	10.401	5.120	32.272	-6.900	3.926	8.335	-7.373	25.342	1.910	-5.031	22.517	-15.391	-5.829	281	-15.426	-15.426	35.493
			15	BCR	1,96	1,33	1,14	1,90	0,78	1,11	1,28	0,75	1,54	1,05	0,89	1,50	0,61	0,87	1,01	0,59	0,59	1,96
			16																			
			17																			
			18	NPV	27.417	6.630	4.725	24.506	-5.285	3.610	4.870	-5.708	23.558	3.485	867	20.823	-8.431	-73	1.914	-8.664	-8.664	27.417
			19	BCR	2,02	1,30	1,18	1,95	0,76	1,14	1,24	0,72	1,77	1,14	1,03	1,71	0,66	1,00	1,08	0,63	0,63	2,02
			20																			
			21																			
			22	NPV	20.488	984	-2.203	17.893	-10.932	-3.003	-438	-11.015	11.237	-6.558	-11.455	9.061	-18.473	-11.835	-7.525	-18.103	-18.473	20.488
			23	BCR	1,61	1,04	0,93	1,55	0,60	0,91	0,98	0,58	1,26	0,81	0,73	1,22	0,47	0,71	0,77	0,45	0,45	1,61
			24																			

A6 Refined calculation of NPV and BCR as upper and lower bounds of the CDF based on random set input parameter ranges (equal probability weights for all information sources)

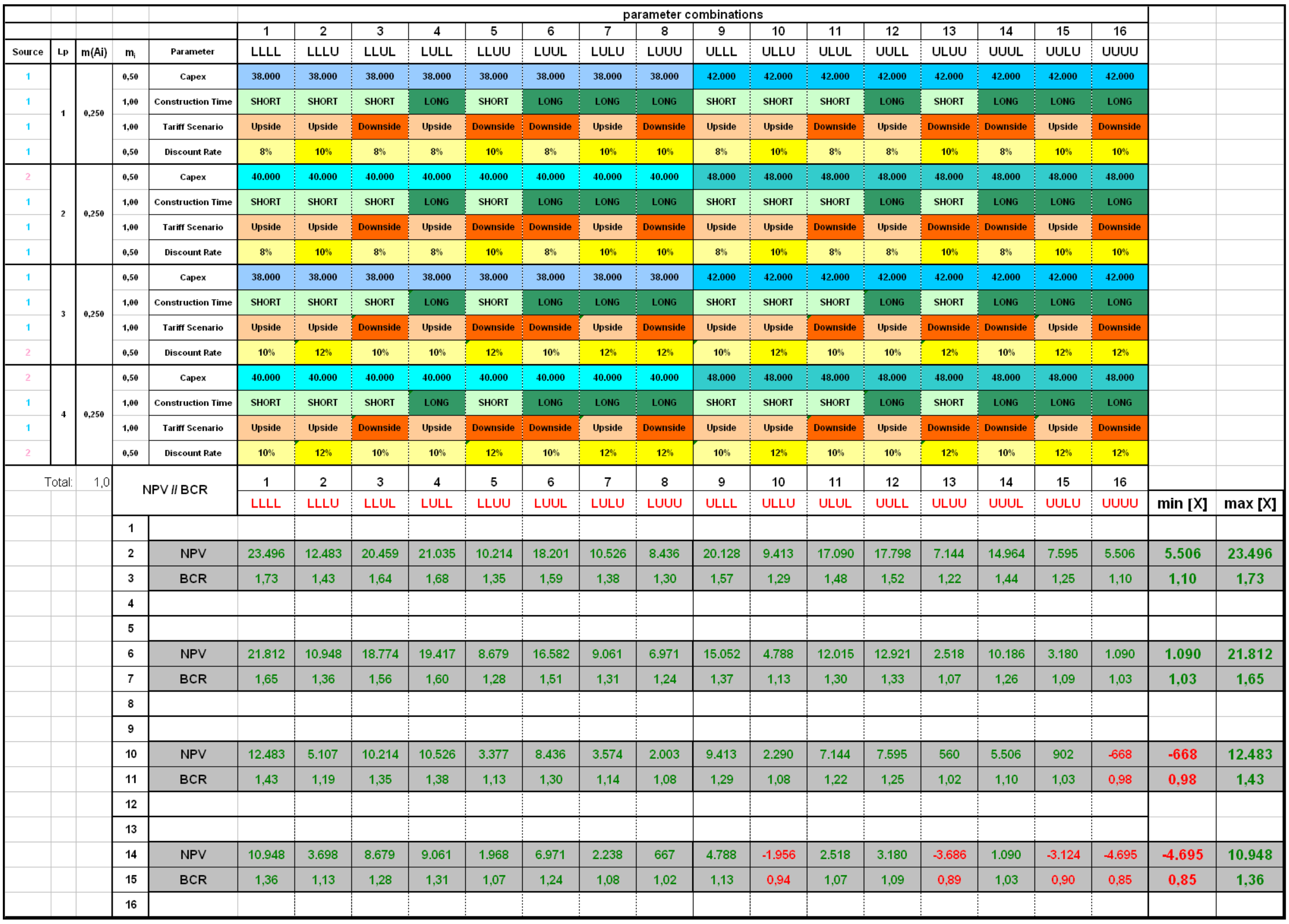


					parameter combinations																	
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Source	Lp	m(Ai)	m_i	Parameter	LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU		
1	1	0,250	0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,50	Discount Rate	8%	12%	8%	8%	12%	8%	12%	12%	8%	12%	8%	8%	12%	8%	12%	12%		
2	2	0,250	0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,50	Discount Rate	8%	12%	8%	8%	12%	8%	12%	12%	8%	12%	8%	8%	12%	8%	12%	12%		
1	3	0,250	0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,50	Discount Rate	10%	14%	10%	10%	14%	10%	14%	14%	10%	14%	10%	10%	14%	10%	14%	14%		
2	4	0,250	0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,50	Discount Rate	10%	14%	10%	10%	14%	10%	14%	14%	10%	14%	10%	10%	14%	10%	14%	14%		
	Total:	1,0	NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
					LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
			1																			
			2	NPV	40.545	14.627	10.172	37.128	-2.674	8.781	12.342	-3.365	37.177	11.810	6.804	33.891	-5.491	5.544	9.670	-6.037	-6.037	40.545
			3	BCR	2,26	1,54	1,32	2,20	0,90	1,28	1,48	0,87	2,05	1,40	1,19	1,99	0,81	1,16	1,34	0,79	0,79	2,26
			4																			
			5																			
			6	NPV	38.861	13.218	8.488	35.509	-4.082	7.163	11.006	-4.701	32.102	7.564	1.729	29.013	-9.737	667	5.644	-10.064	-10.064	38.861
			7	BCR	2,15	1,47	1,25	2,09	0,86	1,22	1,41	0,82	1,79	1,22	1,04	1,74	0,71	1,02	1,18	0,69	0,69	2,15
			8																			
			9																			
			10	NPV	25.093	7.448	2.402	22.288	-5.988	1.392	5.605	-6.413	22.023	4.848	-668	19.358	-8.588	-1.538	3.155	-8.864	-8.864	25.093
			11	BCR	1,86	1,30	1,08	1,80	0,76	1,05	1,24	0,73	1,68	1,18	0,98	1,63	0,69	0,95	1,12	0,66	0,66	1,86
			12																			
			13																			
			14	NPV	23.558	6.148	867	20.823	-7.288	-73	4.380	-7.639	17.397	930	-5.294	14.942	-12.506	-5.954	-538	-12.557	-12.557	23.558
			15	BCR	1,77	1,24	1,03	1,71	0,72	1,00	1,18	0,69	1,47	1,03	0,86	1,42	0,60	0,83	0,98	0,57	0,57	1,77
			16																			

A7 Refined calculation of NPV and BCR based on a discount rate of max. 12% and sale of 50% of the generated power through PPAs

					parameter combinations																		
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Source	Lp	m(Ai)	m_i	Parameter	LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU		
1	1	0,250	0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,50	Discount Rate	8%	10%	8%	8%	10%	8%	10%	10%	8%	10%	8%	8%	10%	8%	10%	10%		
2	2	0,250	0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,50	Discount Rate	8%	10%	8%	8%	10%	8%	10%	10%	8%	10%	8%	8%	10%	8%	10%	10%		
1	3	0,250	0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,50	Discount Rate	10%	12%	10%	10%	12%	10%	12%	12%	10%	12%	10%	10%	12%	10%	12%	12%		
2	4	0,250	0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,50	Discount Rate	10%	12%	10%	10%	12%	10%	12%	12%	10%	12%	10%	10%	12%	10%	12%	12%		
	Total:	1,0	NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
					LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
			1																			
			2	NPV	30.073	18.088	15.887	21.188	6.742	14.014	15.753	5.305	27.705	15.018	12.519	24.951	3.672	10.777	12.823	2.375	2.375	30.073
			3	BCR	1,97	1,62	1,50	1,91	1,23	1,45	1,56	1,19	1,78	1,46	1,35	1,73	1,11	1,32	1,42	1,08	1,08	1,97
			4																			
			5																			
			6	NPV	29.389	16.553	14.203	26.569	5.207	12.396	14.288	3.840	22.630	10.392	7.443	20.073	-954	5.900	8.407	-2.041	-2.041	29.389
			7	BCR	1,87	1,54	1,42	1,82	1,17	1,38	1,49	1,13	1,56	1,28	1,18	1,52	0,97	1,15	1,24	0,94	0,94	1,87
			8																			
			9																			
			10	NPV	18.088	9.338	6.742	15.753	687	5.305	7.471	-383	15.018	6.521	3.672	12.823	-2.130	2.375	4.799	-3.055	-3.055	18.088
			11	BCR	1,62	1,35	1,23	1,56	1,03	1,19	1,29	0,98	1,46	1,22	1,11	1,42	0,93	1,08	1,17	0,89	0,89	1,62
			12																			
			13																			
			14	NPV	16.553	7.929	5.207	14.288	-721	3.840	6.135	-1.719	10.392	2.275	-954	8.407	-6.375	-2.041	773	-7.081	-7.081	16.553
			15	BCR	1,54	1,28	1,17	1,49	0,97	1,13	1,23	0,94	1,28	1,07	0,97	1,24	0,81	0,94	1,02	0,78	0,78	1,54
			16																			

A8 Refined calculation of NPV and BCR based on a discount rate of max. 12% and sale of 90% of the generated power through PPAs



					parameter combinations																	
					1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
Source	Lp	m(Ai)	m_i	Parameter	LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU		
1	1	0,250	0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,50	Discount Rate	8%	10%	8%	8%	10%	8%	10%	10%	8%	10%	8%	8%	10%	8%	10%	10%		
2	2	0,250	0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
1			0,50	Discount Rate	8%	10%	8%	8%	10%	8%	10%	10%	8%	10%	8%	8%	10%	8%	10%	10%		
1	3	0,250	0,50	Capex	38.000	38.000	38.000	38.000	38.000	38.000	38.000	38.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000	42.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,50	Discount Rate	10%	12%	10%	10%	12%	10%	12%	12%	10%	12%	10%	10%	12%	10%	12%	12%		
2	4	0,250	0,50	Capex	40.000	40.000	40.000	40.000	40.000	40.000	40.000	40.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000	48.000		
1			1,00	Construction Time	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG	SHORT	SHORT	SHORT	LONG	SHORT	LONG	LONG	LONG		
1			1,00	Tariff Scenario	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside	Upside	Upside	Downside	Upside	Downside	Downside	Upside	Downside		
2			0,50	Discount Rate	10%	12%	10%	10%	12%	10%	12%	12%	10%	12%	10%	10%	12%	10%	12%	12%		
Total:		1,0	NPV // BCR		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16		
					LLLL	LLLU	LLUL	LULL	LLUU	LUUL	LULU	LUUU	ULLL	ULLU	ULUL	UULL	ULUU	UUUL	UULU	UUUU	min [X]	max [X]
			1																			
			2	NPV	23.496	12.483	20.459	21.035	10.214	18.201	10.526	8.436	20.128	9.413	17.090	17.798	7.144	14.964	7.595	5.506	5.506	23.496
			3	BCR	1,73	1,43	1,64	1,68	1,35	1,59	1,38	1,30	1,57	1,29	1,48	1,52	1,22	1,44	1,25	1,10	1,10	1,73
			4																			
			5																			
			6	NPV	21.812	10.948	18.774	19.417	8.679	16.582	9.061	6.971	15.052	4.788	12.015	12.921	2.518	10.186	3.180	1.090	1.090	21.812
			7	BCR	1,65	1,36	1,56	1,60	1,28	1,51	1,31	1,24	1,37	1,13	1,30	1,33	1,07	1,26	1,09	1,03	1,03	1,65
			8																			
			9																			
			10	NPV	12.483	5.107	10.214	10.526	3.377	8.436	3.574	2.003	9.413	2.290	7.144	7.595	560	5.506	902	-668	-668	12.483
			11	BCR	1,43	1,19	1,35	1,38	1,13	1,30	1,14	1,08	1,29	1,08	1,22	1,25	1,02	1,10	1,03	0,98	0,98	1,43
			12																			
			13																			
			14	NPV	10.948	3.698	8.679	9.061	1.968	6.971	2.238	667	4.788	-1.956	2.518	3.180	-3.686	1.090	-3.124	-4.695	-4.695	10.948
			15	BCR	1,36	1,13	1,28	1,31	1,07	1,24	1,08	1,02	1,13	0,94	1,07	1,09	0,89	1,03	0,90	0,85	0,85	1,36
			16																			