IMPLEMENTING A REAL OPTION VALUATION METHOD TO ANALYSE ELECTRICITY NETWORK INFRASTUCTURE INVESTMENTS WITH UNCERTAINTIES IN FINLAND

Lappeenranta–Lahti University of Technology LUT

Master's Programme in Business Analytics, Master's thesis

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Examiners: Associate Professor, Jan Stoklasa, Ph.D.

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ABSTRACT

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Supervisor: Osmo Siirto Ph.D.

Keywords: investment analysis, real options, fuzzy pay-off method, electricity distribution.

The clean energy transition increases the need for electricity distribution network investments. At the same time distribution system operators face more uncertainties regarding these investments. Traditional investment calculation methods are weak to cover uncertainties related to investments. Using real options theory, the effect of managerial decisions to investment profitability can be considered.

This thesis studies how real options theory can be used to analyse electricity distribution investments with uncertainties. The fully possibilistic pay-off method was chosen to be implemented into the case company's current practices, due to the use of fuzzy numbers which suit uncertainties that are hard to assign probabilities and easy implementation in excel.

The possibilistic pay-off method is implemented to analyse a distribution capacity reinforcement investment with the option to defer a cable reinforcement investment. Initial calculations with the company's current practices show that the cable reinforcement is not profitable. However, the possibilistic pay-off method is used to demonstrate that investing first in electricity flow control device and deferring the cable reinforcement investment creates value. Using the pay-off method is suitable for the case company in initial planning and its methodology is used in this study for sensitivity analysis where applicable.

TIIVISTELMÄ

Lappeenrannan–Lahden teknillinen yliopisto LUT

LUT-kauppakorkeakoulu

Kauppatieteet

Esa Äärynen

REAALIOPTIO TEORIAN SOVELTAMINEN EPÄVARMUUKSIA SISÄLTÄVIEN SÄHKÖVERKKO INVESTOINTIEN ANALYSOINTIIN SUOMESSA

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Avainsanat: reaalioptiot, sumea tuottojakauma, sähkönjakeluverkko, investointien analyysi

Puhtaan energian siirtymä kasvattaa investointitarpeita sähkönjakeluverkkoihin. Samanaikaisesti sähköverkkoyhtiöt kohtaavat lisääntyviä epävarmuuksia näitä investointitarpeita koskien. Perinteiset investointien kannattavuuslaskenta menetelmät huomioivat epävarmuudet heikosti. Reaalioptio teoriaa hyödyntämällä voidaan huomioida yrityksen päätöksen teon vaikutukset investointien kannattavuuteen.

Tässä työssä tutkitaan reaalioptio teorian hyödyntämistä epävarmuuksia sisältävien sähköverkkoinvestointien kannattavuuden arvioinnissa. Reaalioption arvostusmetodologiaksi valikoitui sumeaa tuottojakaumaa hyödyntävä menetelmä, koska sumean logiikan hyödyntäminen sopii epävarmuuksille, joille on vaikea asettaa epävarmuuksia. Sumean tuottojakauman implementointi Exceliin on myös suoraviivaista.

Sumean tuottojakauman metodologiaa sovelletaan sähkönjakeluverkon kapasiteetinvahvistusinvestoinnin analysoinnissa, jossa optiona kaapelivahvistuksen viivästyttäminen. Sumean tuottojakauma menetelmän avulla osoitettiin, että investoimalla ensin sähkövirran ohjauslaitteeseen ja odottamalla kaapelivahvistuksen tarpeen varmistumista, voidaan projektille luoda lisäarvoa. Työssä osoitetaan myös kuinka sumean tuottojakauman menetelmää voi soveltuvin osin hyödyntää yksittäisen investoinnin herkkyysanalyysiin valaisemaan epävarmuuksia projektin kannattavuudessa.

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This thesis is the end of an inspiring journey to broaden my knowledge in Business Analytic. The idea for this education raised to me when I was working as an analyst in electricity network asset management: “many of these problems could be solved way more fluently”. After starting my studies in the fall 2019, I managed to change my job twice, there was the covid guarantees and to top these an addition to the family. So yes, it took a while longer than I initially thought. But now the journey that has taught me so many new things and so much about myself and my limits has come to an end.

I want to thank Helen Electricity Network for providing me the subject for my thesis and opportunity to combine it to my day-to-day work.

Biggest thanks go to my loving wife Maiju, who supported me true out the whole process. Yor support was crucial for me to be able to finish my studies.

Esa Äärynen

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SYMBOLS AND ABBREVIATIONS

ATOTEX	Allowed Operational Expenditure
CAPEX	Capita expenditure
CAP	Capital Asset Pricing
CF	Cashflow
COC	Customer outage cost
CoG	Center of Gravity
DCF	Discounted Cashflow
DSO	Distribution System Operator
EA	Energy Authority
GMB	Geometric Brownian Motion
IRR	Internal rate of return
IEA	International Energy Agency
JHA	Adjusted replacement value of network
JHATP	Adjusted straight-line depreciations
KAH	Regulatory outage costs
NKA	Adjusted net present value of network
NPV	Net present value
OPEX	Operational Expenditure
PI	Profitability Index
ROV	Real Option Value
StoNED	Stochastic Non-smooth Envelopment of Data

TCO	Total Cost of Ownership
TOTEX	Total Operational Expenditure
WACC	Weighted Average Cost of Capital
ykv	Corporate tax rate

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Abstract

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Symbols and abbreviations

Appendix 1. Cashflows in present values for real option valuation with the fully possibilistic pay-off method.

Appendix 2. Cashflows in present values for sensitivity analysis with the fully possibilistic pay-off method.

1. Introduction

Electricity networks are facing new challenges with the energy transition from fossil fuels to renewables. Renewable energy sources, in particular solar and wind will gain most ground from any energy source by accounting 43% of electricity generation worldwide by 2030, from what is up from todays 28% share. (IEA 2022) There is high pressure to develop electricity networks to meet the needs of the energy transition. The International Energy Agency (IEA) states in their World Energy Outlook (IEA 2022), that in their scenarios 13-14 million km of distribution networks and 1,6-1,8 million km of transmission network will be constructed worldwide.

Modern electricity networks enable the success of clean energy transition, and therefore the development of electricity networks requires long-term vision and planning (IEA 2022). Lifetime of electricity distribution infrastructure investments can vary from 20 to 65 years (EA 2022). Planning, permitting and construction of electricity distribution investments can take years and large projects in electricity transmission system can often take a decade or longer to complete. Annual grid investments are projected to rise in IEA’s scenarios between USD 550 billion and 630 billion by 2030, compared to USD 300 billion per year from 2012-2021 (IEA 2022). As the need for electricity investments grows substantially all over the world, managers in Electricity Distribution System Operator companies will have increased amount of investment decisions to make. Increasing investments to the electricity network and changes in the operating environment for example by the clean energy transition, make it important to take uncertainties into consideration when performing investment analysis to the electricity distribution network.

Traditional capital investment valuation methods based on discounted-cash-flow (DCF) make implicit assumptions on expected cashflows (CF) and presume managements passive commitment on operating strategy. This said, in the real world, which in its nature has uncertainties and changes, realized cash flows will probably differ from expert estimations used in decision making. The traditional DCF approach methods as the net-present-value (NPV) or internal rate of return (IRR), have their limits to capture managerial flexibility to adapt and respond to unexpected market developments. (Trigeorgis, 1996, p.1)

Real option valuation methods can be used to address the disadvantages of the traditional capital investment valuation methods. (Trigeorgis, 1996) Using real options theory and decision-making framework in investment analysis has the potential to improve managerial decision making by calculating value on the decisions managers have a right to make to actively manage investments. (Lander, Pinches 1998)

According to Wijnia and Herder (2005) some investment alternatives that contain uncertainties are ignored by managers because there are problems assigning proper value to them. Therefore, real option theory seems to be a suitable method to analyse investment opportunities in electricity distribution network. Electricity network investments need a great deal of capital expenditure and have a long lifetime. Size of the investments, their lifetime and the changing operational environment caused by the energy transition makes it interesting to study the real options that lye in electricity network investment projects.

1.1. Research question and main objectives

Objective of this study is to examine how real option valuation can be applied in electricity distribution business in Finland. Furthermore, the objective is to provide a way to analyse investments with uncertainties whose effects can be influenced with managerial decisions. Also, analyse uncertainties that effect investment profitability in electricity infrastructure investments in Finland. To fulfil the objectives of the thesis one main research question and three sub-questions were determined as follows.

Main research question of this study is:

How can real option methodology be used to analyse electricity distribution infrastructure investments in Finland?

There are three sub-questions to complement the main research question:

1. *Can uncertainties in electricity distribution infrastructure investments be analysed using real option valuation methodology?*

2. *Is it feasible to implement real option valuation methodology to Helen Electricity Networks investment analysis tool?*

3. *Is the selected real option valuation method valid for Helen Electricity Network?*

Research questions are answered in scope of electricity distribution in Finland and in more detail concerning Helen Electricity Network. This can limit the broader application of the results, as different countries have their own regulatory models in the electricity distribution business, which can cause differences in the value creation of electricity network investments. The purpose of the main research question is to introduce how to use real options in electricity distribution network investment and introduce real options thinking to electricity distribution companies. Answers for the main research question are found trough literature and a case study. The case study is based on a real-life investment need. However, cost information is modified from real-life to keep business sensitive information nondisclosed.

The sub question 1. aims to find help in analysing uncertainties in electricity distribution investments. Understanding uncertainties in the outcome of a project can help make better investment decisions. Sub questions 2. and 3. are focused on the case company and practical implementation of real options methodology in its operations.

1.2. Scope of the study and method research

This thesis is limited to electricity distribution network investments in Finland and analysing investment profitability with uncertainties using real option methodology. Conventional capital budgeting methods and their limitation compared to real options theory. This thesis takes into consideration economical regulation of electricity distribution business and how the regulation determines investment profitability. Figure 1.1 illustrates the focus area of this study in a simple way.

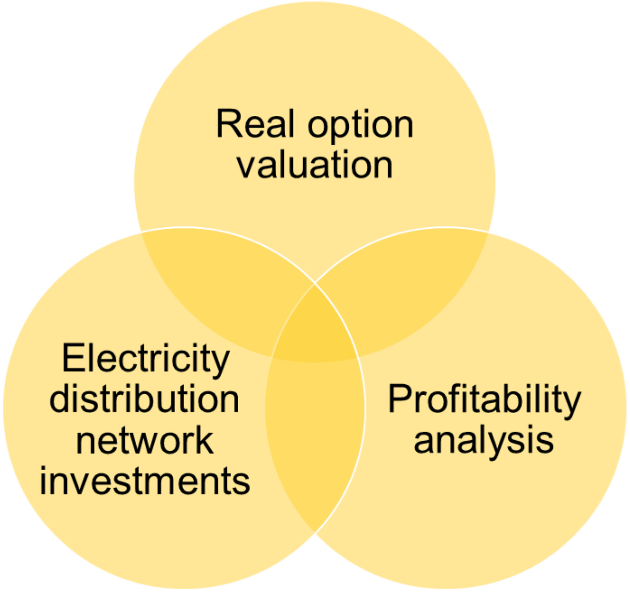


Figure 1.1 Focus area of the study simplified.

The three focus areas shown in figure 1.1, real option valuation, electricity distribution network investments and profitability analysis form the basis for this thesis. For profitability analysis the conventional methods and current practices of the case company are presented. Electricity distribution network investment focus on the Finnish regulation and operative environment especially in Helsinki where the case company operates. Methods for real option valuation are presented and discussed. As the aim for this thesis is to examine how real options can be applied for electricity distribution investment analysis, each of these areas are studied separately and combined to get a comprehensive overview of the topic.

This study is performed using case study approach as the research problem is somewhat experimental and illustrative. According to Yin (2009) case studies are preferred in situations where how or why questions are asked, when the researcher has little control over events or when the focus in on a contemporary phenomenon. This study has a “how” in the research question and it requires both quantitative and qualitative aspects. Numerical calculations and analysis are used for profitability analysis and the qualitative side comes from discussing possibilities, advantages, disadvantages, and feasibility of the chosen real option valuation method. This study is conducted in cooperation and partly funded by Helen Electricity Network Ltd.

2. Theoretical background

This section of theoretical background presents different investment profitability analysis methods firstly starting with the conventional methods including NPV, IRR, and payback period. Secondly introducing different real option valuation methods. Finally, taking a general look and discussion at real option valuation methods used in the electricity distribution industry.

2.1. Conventional investment budgeting methods

Capital budgeting decisions should fulfil two fundamental criteria. First all the projects' cash flows must be considered and secondly it must consider the "Time Value of Money". (Goel, 2015, 47)

Net present value is often the most appropriate method to use in most cases when analysing projects. (Dayananda, 2002, 96) NPV of an investment or project is basically the present cash inflows subtracted with present value of cash outflows. Net present value can be calculated using the following mathematical equation:

$$NPV = \left(\frac{C_1}{(1+r)} + \frac{C_2}{(1+r)^2} + \cdots \frac{C_T}{(1+r)^T} - C_0\right) = -C_0 + \sum_{i=1}^{T} \frac{C_i}{(1+r)^i}, \qquad (1)$$

where C_0 is the initial investment, C_i is cash flow at time i, and r is the discount rate which in other words is the appropriate interest rate for to accommodate the company's objectives. (Goel, 2015, 70) Helbæk, Lindest and McLellan (2010) state in their book that NPV is the best way to analyse the profitability of a project. Calculating percentage yield using internal rate of return can also be used to evaluate investment profitability. The internal rate of return is the discount rate that returns a zero net present value. IRR can be found by solving discount rate r from the following equation (Helbæk et.al. 2010, 26-27):

$$-C_0 + \left(\frac{C_1}{(1+r)} + \frac{C_2}{(1+r)^2} + \cdots \frac{C_T}{(1+r)^T}\right) = 0 \qquad (2)$$

Discount rates lower than the IRR will give a positive NPV and discount rates higher than the IRR will give a negative NPV. If a project is evaluated by using IRR, there need to be an idea of how high the IRR should be for the project to be profitable. In other words, IRR needs to be higher than required rate of return. (Helbæk et.al. 2010, 30):

Payback period is widely used and considered to be one of the simplest methods for valuating capital budgeting decisions. Payback period is defined as the time period needed to recover the initial investment of a project. Payback period can be calculated by dividing the initial investment with average annual cash inflow. (Goel, 2015, 64)

Profitability index (PI) the ratio of present value cash inflows and the present value of cash outflows at the required rate of return. Profitability index is suitable in evaluating projects involving capital expenditure as relative measure. PI can be calculated by the following equation:

$$PI = \frac{Present\ value\ of\ cash\ inflows}{Present\ value\ of\ cash\ outflows} \tag{3}$$

If PI is above 1 project can be accepted. (Goel, 2015, 74-76)

2.2. Real options

Myers (1977) was the first one to introduce the term real option and pointing out the similarity between real options and financial options. In Meyers (1977) article “Determinants of corporate borrowing” growth opportunity of assets is compared to a call option. The article also states that real option value depends on future discretionary investments by the company. Future research on real options to find more applications was encouraged by Meyers and there have been found more applications of real options in addition to the growth opportunity Myers presented in the article. (Meyers, 1977) Real option theory starts by creating a link between real options and financial options. Black, Merton and Scholes pioneered a formula for valuating financial options which paved way for the development of real options theory. (Reuer, Tong 2007)

Kodukula and Papudesu (2006, p. 5) determined real options in their book as follows: “A real option is a right - not an obligation - to take action on an underlying nonfinancial asset, real asset.” As option is a right but not an obligation to act, hereby the yield of an option cannot be less than zero. Traditionally, there are two main types of options, the right to buy (call) and the right to sell (put). Options can also be categorized as American or European options. The American option can be exercised on or before a predetermined expiration date and the European option can be exercised on a fixed date only. The real assets may include real estate, projects, intellectual property, infrastructure, most of which are not usually traded. Actions on these real assets may involve e.g. abandoning, expanding, contracting a project, deferring the decision to a later time or otherwise alter the project at different stages during its useful lifetime. (Kodukula, Papudesu 2006, p. 5; Trigeorgis, 1993; Black, Scholes 1973)

Mathews, Datar and Johnson (2007) state in their study that much of the value of real option comes from real options thinking. Real options thinking allows companies to find and exploit real options that can be exploited via managerial decision making. For this it is necessary to understand the types of real options. There are several types of real options which can be classified into different groups. Most common types of real options are option to expand, option to abandon, option to wait, option to switch, and option to contract are shown in figure 2.1. (CFI, 2023)

Figure 2.1 Most common types of real options (CFI, 2023)

Option to expand refers to the ability to make an investment or undertake a project in the future to expand business. **Option to abandon** means that the project or an asset can be ceased to realise salvageable value of the project or an asset. In **Option to wait**, a business decision can be deferred to the future to gain more information. **Option to Contract** is the option to shut down a project in the future if conditions turn unfavourable. In **Option to switch** it is possible to shut down a project in the future if conditions turn unfavourable and resume it if conditions turn back to favourable. (CFI, 2023)

Real option valuation comes to consideration after the real options associated with the projects are recognized. Real option valuation methods can be used to address the disadvantages of the traditional capital investment valuation methods. (Trigeorgis, 1996) It is broadly recognised by academics and practitioners that the NPV rule and other DCF approaches to capital investment budgeting are inadequate to properly capture managerial decisions at a later stage and flexibility to adapt in when there are unexpected market developments. The conventional NPV makes implicit assumptions about the expected cash flows and presumes managements passive involvement to operating strategy. Managers are often able to adapt their actions based on different market developments. This managerial flexibility can expand on investment opportunity’s value by limiting the downside losses and improving its upside potential. (Trigeorgis, 1993; Trigeorgis, 1996) Therefore, conventional NPV should be developed to an option based expanded NPV analysis as the following formula presented by Trigeorgis (1993):

$$Expanded\ NPV = static\ NPV\ of\ expected\ cash\ flows + value\ of\ options\ from\ active\ management \tag{4}$$

The value of options that arises from active management can be conceptualized and their value even quantified using an options approach to complement traditional capital budgeting. (Trigeorgis, 1993)

Trigeorgis and Reuer (2017) summarised the process of using real options in organizations in three phases to help classify research and uncover gaps in understanding and research paths: 1. Problem structuring, 2. Valuation and modelling and 3. Implementation planning. First phase, problem structuring incorporates qualitative, strategic description of the problem structure indicating various managerial decisions or options, timing and linkages of these options, also the main uncertainties and the key value drivers. Second phase, valuation and modelling, is an analysis which incorporates data collection of primary input data to enable a conventional DCF estimation and determination of a base-case NPV to be used as benchmark. After the base-case determination, additional option driven inputs are estimated. With the base case and option driven inputs estimated, the analysis proceeds to choosing most suitable option valuation model. e.g binominal trees, simulation etc. to estimate the expanded NPV of an investment. This way the value of active management, represented by the set of embedded options, can be captured. Third phase, Implementation planning, contains the development of a contingent decision plan which specifies the conditions when major options are exercised in different circumstances. An operating policy and decision milestones over investment stages is also developed. (Trigeorgis, Reuer, 2017)

There are three major components of modelling real option value. First modelling how the future value distribution is created, secondly the calculation of the expected value of the future value distribution while ignoring negative values of the distribution, and thirdly modelling the calculation of the present value of the expected value. (Collan, 2011)

As mentioned in the second phase of real option process different models have been developed for valuating real options. Collan (2011) presents four main fields of modelling methodology for real options. These methodologies are differential equation solutions, discrete event and decision models, simulation-based models and fuzzy-logic-based models as presented in figure 2.2:

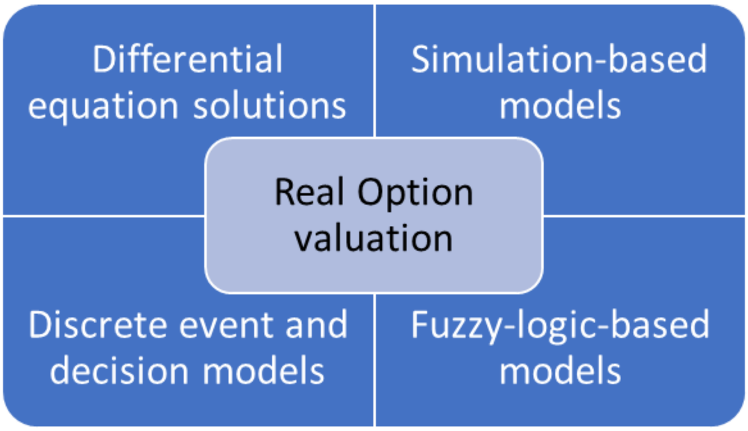


Figure 2.2 Real option valuation methodologies (Collan, 2011)

The first three methodologies use probability distributions of the future value of a project as the fourth methodology uses fuzzy numbers to describe future value of a project. The differential equation based, and discrete event and decision models use continuous or compounded discounting together with risk-free interest rate. Simulation- and fuzzy-logic based models are more flexible and user selectable. (Collan, 2011) Next an overview of commonly known real option valuation methods is presented.

2.2.1. Black and Scholes option pricing model

Real option theory originates from the pricing of financial options, which comes from the work of Black Merton and Scholes. (Reuer et. al. 2007) The original formula is designed to value a European call options contract based on the price of an underlying stock (Black, Scholes, 1973)

$$C = S\,N(d_1) - Xe^{-r(t)}N(d_2), \tag{5}$$

$$d_1 = \frac{ln\frac{S}{X} + (r + \frac{1}{2}\sigma^2)t}{\sigma\sqrt{t}}, \tag{6}$$

$$d_2 = d_1 - \sigma\sqrt{t}, \tag{7}$$

where *C* is the European Call option price, *S* presents the stock price, *N(d)* is the cumulative normal density function, *X* exercise price, *t* is the time to maturity, *r* is the risk-free rate of return and *σ* is the volatility representing uncertainty.

The Black and Scholes formula for valuating an option has seven assumptions for ideal conditions in the market for the stock and the option.

- The risk-free interest rate is known and stays constant through time to maturity.
- Stock price follows a random walk which allows the use of a stochastic process such as Geometric Brownian Motion (GBM) when variance and growth rate stays constant.
- No dividends or other distributions are paid.
- The option is European and can be exercised only at a specific time.

- There are no transaction costs nor taxes.
- Borrowing any fraction of the price of a security to buy or hold it at the risk-free interest rate is possible.
- There are no penalties for selling short.

(Black, Scholes 1973)

The original Black and Scholes formula was defined for financial markets, Leslie and Michaels (1997, p. 9) introduced real-market equivalents for the factors in the formula which can be used for real options analysis as follows:

“*The* ***stock price*** *(S) - the present value of cashflows expected from the investment opportunity on which the option is purchased.*

The ***exercise price*** *(X) - the present value of all the fixed costs expected over the lifetime of the investment opportunity.*

Uncertainty *(σ) - unpredictability of the cashflows associated with the asset. more precisely, the standard deviation of the growth rate of the value of future cash inflows associated with asset.*

Time to expiry *(t) - the period for which the investment opportunity is valid. This will depend on technology (a product’s life cycle), competitive advantage (intensity of competition), and contracts (patents, leases, licences).*

Dividends *(δ) - the value that drains away over the duration of the option. This could be the costs incurred to preserve the option (by staving off competition or keeping the opportunity alive), or the cashflows lost to competitors that go ahead and invest in an opportunity, depriving later entrants of cashflows.*

The risk-free interest rate *(r) - the yield of a riskless security with the same maturity as the duration of the option.*”

According to Collan (2011) the construct of the Black and Scholes method is clever, as assumptions, modelling and the replication argument are chosen in a way that allows a closed form solution which returns a single number value for the call option.

2.2.2. The binomial option pricing model

The binominal option pricing model developed by Cox, Ross, and Rubinstein (1979) estimates the variation of an underlying asset's price based on a "discrete time" binomial tree. It is widely used for valuating standard options, it is straightforward to use, and it usually converges rather fast to the continuous time limit as in the Black and Scholes model. (Tian, 1999) The binomial model option pricing model is one of the simplest option pricing models. (Elton, Gruber, 2003) Binomial option pricing model allows to check the option price throughout its whole lifetime. The binomial option pricing model is not dependent on probabilities of any individual outcome, which means that the model is independent of personal probabilities of different investors related to the movement of asset prices going up or down. Binomial option pricing model is completed in three phases: first the binomial tree is constructed, secondly the option value for each final node is calculated and in the third part option value for all earlier nodes is determined by iterating backwards from the final nodes. (Collan, 2011; Michailidis, Mattas, 2007)

In the Binomial model future values of an underlying asset are assumed to follow multiplicative binomial distribution over a discreet period. The model has an initial value X for the investment project, and it can go up Xu or down Xd. If there are more discrete time periods or branches the next possible values are Xu^2, Xud or Xd^2. Figure 2.3 presents how negative or positive changes in the option value create trails or branches for the development of an investment project. (Bendob, Bentouir 2019; Cox et al. 1979)

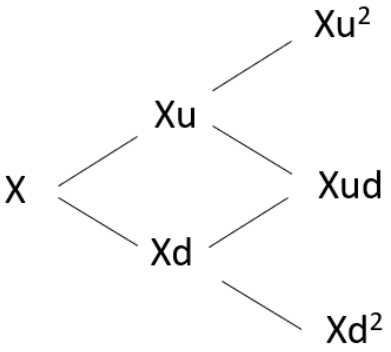


Figure 2.3 Example of a binomial option pricing model

The binomial model does not predict future values for the underlying asset that is being invested as the values are assumed to follow the multiplicative binomial distribution. The model presumes that the volatility of the underlaying asset and the positive up (u) and negative down (d) parameters are assumed to be known and constant. In addition to the previous, the binomial option pricing model uses risk free probabilities (p and $1- p$) with the risk-free interest rate being known and constant. Calculation of the parameters u, d and p is needed in order to value a binomial model. When X is the value of an investment at time 0, Xu is the value multiplied with the positive up parameter u, Xd is the value multiplied with the negative down parameter d and r_f is the risk-free interest rate, then: (Lander, Pinches, 1998)

$$u = \frac{X_u}{X} \tag{8}$$

$$d = \frac{X_d}{X} \tag{9}$$

$$p = \frac{(1+r_f)-d}{u-d} \tag{10}$$

Other required restrictions for the binomial option pricing model are that $u > (1+ r_f) > d$ and $d=1/u$. Once the parameters u, d and p are obtained they can be inserted to the equation (11) to find out expected return e^r for each discrete period.

$$e^r = \frac{pX_u+(1-p)X_d}{X} \tag{11}$$

The e^r from equation (11) is calculated as many times as there are possible values for the investment. The equation (11) is used to step backwards through the binomial tree calculating the expected return for each node until the option value at time zero is calculated. (Higham, 2004)

Binomial option pricing model is the most suitable when there is only one fundamental source of uncertainty. There can be many branches in the binomial model and increased number of branches makes the option value more accurate, but at the same time increases the number of calculations needed, which can grow fiercely. The discrete future value distribution approaches the continuous distribution used in Black and Sholes model, when the discrete- time approximation and stochastic processes have the same mean and variance. (Collan, 2011; Lander & Pinches, 1998)

2.2.3. Monte Carlo simulation

Monte Carlo methods are stochastic methods that involve sampling random values from probability distributions to a certain problem. (Robert, Casella 1999) To apply Monte Carlo simulation a mathematical model that simulates the real system is constructed. Then the model is run many times as in random sampling. For each sample selected input variables are generated with random variates. Computations with the randomly variating input variables are run through the model resulting in a distribution of random outcomes. (Thomopoulos, 2013) Monte Carlo simulation is applied in simulation-based RO valuation methods like the Datar-Mathews model presented next.

2.2.4. Datar-Mathews model

The Datar-Mathews model developed at year 2004 for real option valuation is based on modelling by simulation. (Datar, Mathews 2004) The model uses conventional DCF analysis as a basis when modelling the value of a real option. The Datar-Mathews model aims to model the value of a real option in a simple way but at the same time take into account dynamics and uncertainties of the real market that are not present in the conventional DCF method. (Mathews, Datar, Johnson, 2007)

The valuation algorithm is based on operational cash flow scenarios, created by experts and managers, that are used as an input for a Monte Carlo simulation. The simulation creates a probability distribution, also called as pay-off distribution, of the expected net present value for the project or real option that is being analysed. The Datar-Mathews model uses different discount rates for profits and losses as they have a different amount of risk associated with them. The real option value can be determined using the pay-off distribution by finding out the values for negative outcomes and the positive outcomes. The negative outcomes are then set to be zero, and the option value is calculated as a weighted average from the positive outcomes of the pay-off distribution. (Datar, Mathews 2004; Collan 2011; Kozlova, Collan and Luukka 2016)

Mathews et. al. (2007) provided an intuitive approach to the method by the following formula:

$$Real\ option\ value = \ Risk\ adjusted\ succes\ probability\ \cdot (Benefits - Costs) \quad (12)$$

If the Datar-Mathews uses the same assumptions as the Black and Shcoles formula and simulations are run a sufficient number of times, it will converge with the results of the Black and Scholes method. (Mathews et. al. 2007) The Datar -Mathews method is very flexible and available in spread-sheet applications where the discounting of future value distribution can be automated. The flexibility allows also non-lognormal CF distributions to be quite easily used, which is better in line with the reality of real options. (Collan, 2011)

2.2.5. Fuzzy pay-off method

Collan, Fuller and Mezei (2009) developed the Fuzzy pay-off method for real option valuation. The model is based on fuzzy numbers, it is developed to be easily understandable and a lot simpler than any other previously developed real option valuation method. Valuation of possible future outcomes is not based on probability distributions as the fuzzy pay-off method uses a simple pay-off distribution which is treated as a fuzzy number. A fuzzy number A is defined as a fuzzy set of the real line R with different membership functions of limited support. Fuzzy numbers contain objects that belong to the fuzzy number A with a varying membership degree between zero and one. (Carlsson, Fuller, 2001)

Fuzzy pay-off is based on cashflow calculations of an investment project. There can be three different cashflow scenarios in the fuzzy pay-off method, which corresponds to the triangular number. Using the triangular fuzzy number management may want to define the following cashflow scenarios: best guess, minimum and maximum scenario. With these three scenarios a full range of possible net present values can be constructed in a way that managers estimating the scenarios also understand them. (Collan et al. 2009; Collan, 2012)

The pay-off distribution A can be constructed from these scenarios the following way (Collan, 2012):

1. The best guess scenario where the most likely numbers are estimated, is given a full membership in the set of possible outcomes.

2. The minimum possible cashflow scenario, where the minimum cash-flows are separately estimated from operations and for investment cost, is the lower bound of the distribution. The maximum possible cashflow scenario, where the maximum possible cashflows from operations and for investment cost are also separately estimated, is the upper bound of the distribution.

3. the shape of the pay-off distribution is assumed to be triangular.

The pay-off distribution is defined as a triangular fuzzy number of NPV by denoting the best guess NPV scenario as (a), the minimum NPV scenario as (a-α) and the maximum NPV scenario as (a+β). Further denotations are the distance between the best guess and the maximum net present value (β), the distance between best guess and minimum is (α). For each value in the set of possible values for the investment project NPV, a membership degree can be denoted from where the possible NPV intersects the fuzzy pay-off distribution. The pay-off distribution as a fuzzy number A is demonstrated in figure 2.4. (Collan et al. 2009; Collan, 2012)

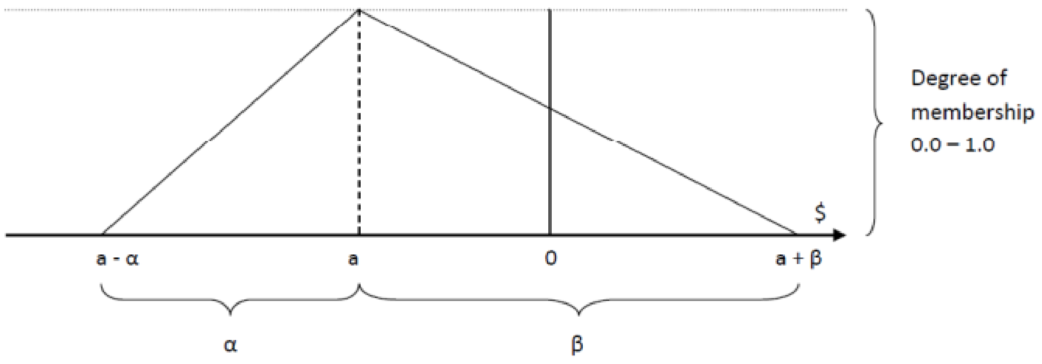


Figure 2.4 Triangular fuzzy number A with definitions for the fuzzy pay-off method. (Collan, 2012)

Calculating a possibilistic mean value of the positive side E(A_+) of the pay-off distribution A can be done in four ways depending on how the triangular fuzzy pay-off distribution locates with zero NPV. The calculation of possibilistic mean was first introduced by Carlson and Fullér (2001). Collan 2012, in his book, presents the following ways to calculate the possibilistic mean:

1. When the whole distribution is above zero 0 ≤ (a-α)

$$E(A_+) = a + \frac{\beta-\alpha}{6} \tag{13}$$

2. When the pay-off distribution is partly above zero, so that minimum possible NPV is below zero and best guess above zero. (a-α < 0 ≤ a).

$$E(A_+) = a + \frac{\beta-\alpha}{6} + \frac{(\alpha-a)^3}{6\alpha^2} \tag{14}$$

3. when the pay-off distribution is partly above zero, with zero equal to the best guess NPV or between best guess and maximum NPV. (a ≤ 0 < a + β)

$$E(A_+) = \frac{(\alpha+\beta)^3}{6\beta^2} \tag{15}$$

4. the whole distribution is below zero

$$E(A_+) = 0 \tag{16}$$

The real option value from the fuzzy NPV can be calculated using the following equation presented by Collan et al. (2009):

$$ROV = \frac{\int_0^\infty A(x)dx}{\int_{-\infty}^\infty A(x)dx} \cdot E(A_+) \tag{17}$$

Where A is the fuzzy NPV, $E(A_+)$ the fuzzy mean value of the positive side of the NPV also called the possibilistic mean value, $\int_{-\infty}^{\infty} A(x)\, dx$ the area of the whole fuzzy number A and $\int_0^\infty A(x)dx$ is the area of the positive side of the fuzzy number A. (Collan et al. 2009)

Success ratio can also be calculated from the fuzzy pay-off distribution. It describes the future possibilities to end up with a profitable investment and it can be used to compare corresponding projects. Success ratio can be calculated by dividing the positive area of the pay-off distribution with the whole area of the pay-off distribution. (Collan, 2012)

The fuzzy pay-off method is a relatively new real option analysis method, and it gives similar results as the Datar-Matthews method. As the Datar-Mathews method uses probability theory the fuzzy pay-off method is a more robust method based on cash-flows represented as fuzzy numbers. (Kozlova et al., 2016)

There has been discussion about the theoretical correctness of the original fuzzy pay-off method. Borges, Dias, Neto and Meier (2018) pointed out issues with the fuzzy pay-off method and real option valuation it presents in certain situations. They proved that the original pay-off method can give theoretically incorrect outcomes. In their example the value of a project without RO was higher than the project with RO. This means that the value of the option would be negative. Borges et al. (2018) approach to the problem uses the Center of Gravity CoG method for defuzzification.

$$CoG(A_+) = \begin{cases} \frac{3a-\alpha+\beta}{3} & , 0 \leq a-\alpha \\ \frac{\alpha(a+\beta)^3 - a^3(a+\beta)}{3[\alpha(a+\beta)^2 - a^2(a+\beta)]} & , a-\alpha \leq 0 \leq a \\ \frac{a+\beta}{3} & , a \leq 0 \leq a+\beta \\ 0 & , a+\beta \leq 0 \end{cases} \tag{18}$$

The value of the project with a real option can be calculated using the CoG approach in the following way (Borges et al. 2018)

$$ROV_{CoG} = \frac{\int_0^{\infty} A(x)dx}{\int_{-\infty}^{\infty} A(x)dx} \cdot CoG(A_+) \tag{19}$$

The value of the project without real option can be calculated with the CoG approach in the following way. (Borges et al. 2018)

$$CoG\ NPV(A) = \frac{3a-\alpha+\beta}{3} \tag{20}$$

Stoklasa, Luukka and Collan (2021) argued that the CoG approach has analogy to a probabilistic approach as using the ratio of the area above zero and the area of the whole distribution has probabilistic variant as it describes the likelihood of NPV being above zero. Stoklasa et al. (2021) introduced a fully possibilistic pay-of method where the $\frac{\int_0^{\infty} A(x)dx}{\int_{-\infty}^{\infty} A(x)dx}$ ratio is not used in real option valuation to make it fully possibilistic. Calculation of real option value in the fully possibilistic pay-off method *ROVposs(A)* can be carried out with the following equations.

$$ROV_{poss}(A) = \begin{cases} a + \frac{\beta-\alpha}{6} & ,0 \leq a - \alpha \\ -\frac{a^3}{6a^2} + \frac{a^2}{2\alpha} + \frac{a}{2} + \frac{\beta}{6} & ,a - \alpha \leq 0 \leq a \\ \frac{a^3}{6\beta^2} + \frac{a^2}{2\beta} + \frac{a}{2} + \frac{\beta}{6} & ,a \ \leq 0 \leq a + \beta \\ 0 & ,a + \beta \leq 0 \end{cases} \tag{21}$$

To establish theoretical correctness of the new possibilistic variant where the value of the project with real option is always higher than the NPV of the project. For the triangular fuzzy NPV a possibilistic crisp NPV as in *Possibilistic NPV(A)* can be calculated in the following way. (Stoklasa et al. 2021)

$$Possibilistic\ NPV(A) = \mathrm{a} + \frac{\beta-\alpha}{6} \tag{22}$$

For real option valuation the fully possibilistic pay-off method *ROVposs(A)* is used in the thesis for further analysis as it is a corrected version of the original method and does not include probabilistic analogy.

2.3. Real options in electricity network investments

Using real option in electricity network investment analysis were examined by a literature review focusing on real options and electricity network investments, including power transmission networks. After getting to know real options theory it is interesting to see how it has been used to analyse electricity network investments in prior literature. This chapter gives a basic overview of the topic and highlights some key findings from the selected articles.

As it is stated in the Winja and Heder (2005) paper, they call real options specialists to show network companies how real options could be of value for them. It can be said that real options theory is not very commonly used within the electricity distribution network -field. For the literature review 15 suitable articles were selected presented in table 2.1. Some of these articles did not focus on real option valuation but rather analysing investment options in an uncertain environment.

Table 2.1 Real options in electricity network literature review

Article Name	Modeling technique/ valuation method	Athors	Year	Note
Designing regulatory frameworks for merchant transmission investments by real options analysis	Least Square Monte Carlo	Pringles, Olsina, Garcés	2014	Power transmission network, option to defer
Valuation of Flexible Transmission Investment Options Under Uncertainty	Multi-stage scenario tree	Konstantelos et al.	2015	Power transmission networks, does not concider the valuation of real options more focused on analyzing different investment options under uncertainty
How much should we pay for interconnecting electricity markets A real otions analysis	Seasonal trend, mean-reverting Gaussian process, and mean-reverting jump process.	Cartea, González-Pedraz	2011	Power transmission network
Options for real options: Dealing with uncertainty in investment decisions for electricity investments	Defining a need for real optoin valuation	Wijnia, Herder	2005	Option to defer and option to switch
Real options valuation applied to transmission expansion planning	Binomial tree	Lumbreras, Bunn, Ramos,	2016	Different investmetn cases whos real option values are comparised
Real Option Valuation of FACTS Investments Based on the Least Square Monte Carlo	Least Square Monte Carlo	Blanco, Olsina, Garcés,Rehtanz	2011	Power transmission network investments, Option to Abandon,
Research and Application of Power Network Investment Decision-making Model based on Fuzzy Real Options	Fuzzy logic	Zeng, Wang, Zhang, Li, Huang	2007	Option to defer / option to expand
What is the value of the option to defer an investment in Transmission Expansion Planning? An estimation using Real Options	Binomial tree, Monte Carlo for estimating parameters	Henao, Sauma, Reyes, Gonzalez	2017	Power transmission network, Option to defer
Transmission Expansion Planning under Uncertainty for Investment Options with Various Lead-Times	Mixed integer linear programming and stochastic programming	Kim W, Park, Yoon, Kim M	2018	Power transmission, Not really real option valuation but analysing investments options under uncertainty.
Real option valuation of power transmission investments by stochastic simulation	Least-Square Monte Carlo valuation algorithm	Pringles, Olsina, Garcés	2015	Power transmission, Option to defer
Expansion planning for transmission network under demand uncertainty: A real options framework	Binomial tree	Kucuksayacigil, Min	2018	Power transmission, Option to expand
Capacity expansion in transmission networks using portfolios of real options	Binomial tree	Loureiro, Claro, Pereira	2015	Power transmission, Option to expand
Analysis of Transmission Investments using Real Options	Binomial tree, Monte Carlo	Ramanathan, Varadan	2006	General illustration how real options could be used in Power transmission investments
Networks Under Uncertainty With Distributed Generation-Part I: Model Formulation	Monte Carlo simulation	Samper, Vargas	2013 a	Real options for deferring, switching, and abandoning
Investment Decisions in Distribution Networks Under Uncertainty With Distributed Generation-Part II: Implementation and results	Monte Carlo simulation	Samper, Vargas	2013 b	Real options for deferring, switching, and abandoning

Five of the articles use binomial tree on some level and seven of the articles are related to using Monte Marlo or other stochastic methods. For example, Samper and Vargas (2013a,2013b) introduced Montecarlo simulation to value real options to analyse electricity network expansion investments in an uncertain environment. Modelled uncertainties were electricity demand growth and wholesale price. Options they recognized were deferring switching and abandoning and the option maturity was determined by tariff periods being maximum of five years. The more uncertain investment environment is there is more value in investments that are flexible and real option value reflects the value of this flexibility. Simulations were time consuming and a full simulation with ten computers i7 (80 cores) can take up to 25 hours to run. (Samper & Vargas, 2013b)

Articles using binomial tree were focused on network expansion planning and often on option to defer or option to expand. Lumbreras et al. (2016) used binomial tree to analyse transmission network expansion investments. They made a conclusion that even if some projects have negative NPVs, but they have real option value, it makes sense to start permitting process as permitting can take a lot of time. They considered that requesting a permit is equivalent to an option to build the transmission line in the future.

Zeng et al. (2007) used fuzzy logic was used to value real options with electricity distribution investments in their study. The extended value of the project was determined by a combination of fuzzy theory and the Black and Sholes real option valuation method. They created fuzzy trapezoidal cashflow scenarios for a two staged power grid investment project. After determining the fuzzy cash flow scenarios NPV of the project scenarios and expected NPV are calculated using fuzzy number theory. For the real option value, they used normal distribution and the Black and Scholes formulas presented in chapter 2.2.1 in equations (5), (6) and (7). The Blac and Scholes real option value and extended project value (eNPV) is calculated for all of the project scenarios. Overall extended expected value of the project is then derived using fuzzy theory for the extended project scenario values.

The most common option under analysis was the option to defer, found in six papers. Option to expand and option to abandon were also analysed in some papers selected to this review. Based on the papers in table 2.1 option to expand and option defer were often linked to each other as the option to defer often considered an expansion investment to the electricity network.

The literature review shows that real options can be found in electricity network investments. Most used ways of analysing real options were based on simulation and they were related to large electricity transmission investments with high costs, when there is usually more time to analyse investments. Only one paper introduced a more straightforward RO valuation method that used fuzzy logic for electricity network investments. It is interesting to study more how fuzzy logic based real option valuation methods can be used in electricity network investment analysis and valuation.

3. Electricity distribution business in Finland

Electricity distribution business is a natural monopoly, as it would be inefficient to build parallel connections for electricity distribution. (Wessman, 2016) Monopoly companies usually operate under regulation in order to ensure reasonable costs for customers. As the case company operates in Finland this chapter focuses on the economic regulation model used in Finland. Following the economic regulation model, the need for electricity network investments and different electricity network renovation strategies under the economic regulation are discussed.

3.1. Economical regulation model for electricity distribution in Finland

As electricity distribution is a natural monopoly, there is no pressure from open competition to keep prices reasonable and operations efficient for the distribution system operators (DSO). Therefore, the Energy authority (EA) is assigned to oversee reasonable prising of electricity distribution operations in Finland. The economic regulation has become a basis for electricity distribution business in Finland. It can be said that the objective of economic regulation is to set limits for DSOs in the electricity distribution business. DSOs are remunerated for improving the quality of electricity distribution for their customers and engouraged to develop their electricity distribution network which value is used to calculate reasonable return. On top of this the regulation sets allowed reasonable operative expenditure and an efficiency incentive to streamline DSOs operational expenditure. (Partanen et al. 2014; Haakana, Lassila, Honkapuro and Partanen, 2012)

The Finnish Energy authority controls the reasonable pricing of DSOs in regulatory periods that last for 4 years. This chapter is based on the regulatory methods (EA, 2021a) that the EA determines. The regulation methods are valid for two periods with certain parameter updates. The current methods are valid for regulatory periods 2016-2019 and 2020-2023. This thesis focuses on the current methods as the methods for the next periods are not yet confirmed. This section presents the key aspects of Finnish economic regulation that effect the profitablity of investments. The framework of the regulatory methods is presented in Figure 3.1.

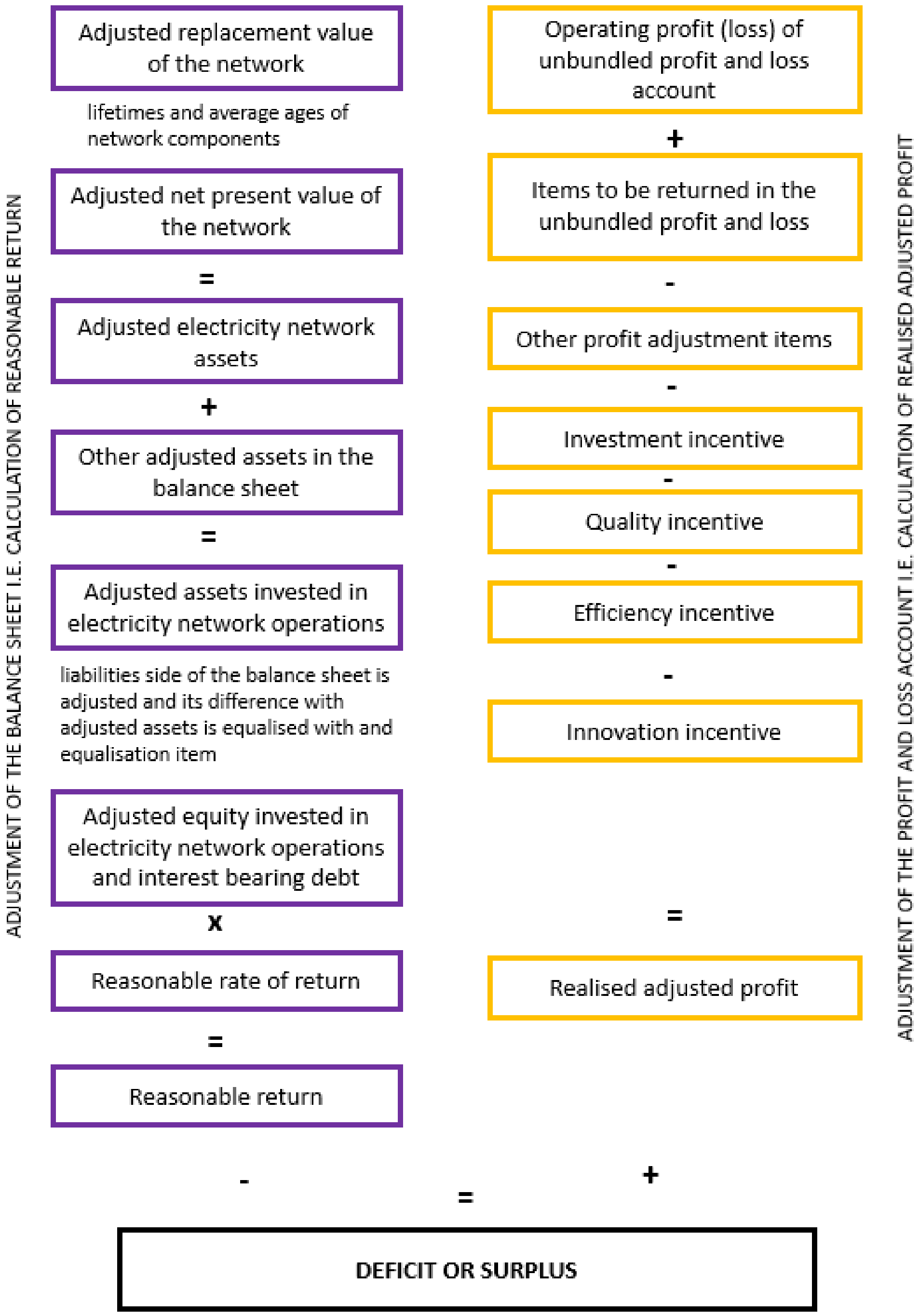


Figure 3.1 Regulatory model in Finland for regulatory periods 2016-2019 and 2020-2023. (EA, 2021a)

In the illustration of the regulatory methods shown in figure 3.1, the left-hand side consists of the components that are used to determine reasonable return for the DSOs. The reasonable return is calculated by adjusting the DSO balance sheet and multiplying it with reasonable rate of return. This reasonable return is the acceptable return for the DSO determined by the EA. The right-hand side shows how the adjusted return for each DSO is calculated in the regulatory model. The realised adjusted return is calculated based on the profit or loss in the DSO income statement which is adjusted with different adjustment items and incentives that are in place for the DSOs to improve their operations. For each fiscal year the EA compares the left-hand side reasonable return to the right-hand side realised adjusted profit, and if the realised adjusted profit is smaller or larger than reasonable return a deficit or a surplus is created for the year. DSO must be in cumulative balance or in deficit in the end of each regulatory period. After the regulatory period the surplus is returned to the customers by lowering tariffs or deficit might be collected back by increasing tariffs.

The regulatory model consists of many components. These components also effect the profitability of investments to the electricity distribution network. Next a more detailed description of the calculation of reasonable return and incentives which are used to adjust the DSO income statement is presented as the regulatory model and parameters in it determine how network investments create value for DSOs.

3.1.1. Reasonable return

This chapter presents the calculation methods for reasonable return and is based on the Finnish regulatory methods (EA, 2021a). The reasonable return is based on adjusted equity invested in electricity network operations, interest bearing dept and reasonable rate of return.

The adjusted electricity network assets are based on the electricity network components DSO has invested in, lifetime of these components and average age of these components. First the adjusted replacement value of these components is calculated by multiplying the amount of network components with a regulatory unit price. These regulatory unit prices are determined by the EA, updated for every period, and can be found from (EA, 2023). Calculation of adjusted replacement is presented in equation 23. (EA, 2021a)

$$JHA_i = unit\ price_i \cdot number_i \tag{23}$$

For the whole electricity network asset the adjusted replacement value can be calculated according to equation 24.

$$JHA = \sum_{i=1}^{n} (JHA_i) \ , \tag{24}$$

where in equations 23 and 24

JHA_i = the total adjusted replacement value of all components of network component *i*

$unit\ price_i$ = regulatory unit price of network component *i*

$number_i$ = number of all components in network component *i*

JHA = DSOs adjusted replacement value of all electricity network assets.

After the replacement value of the network is obtained, the adjusted net present value is calculated in the following way:

$$NKA_i = \left(1 - \frac{average\ age_i}{lifetime_i}\right) \cdot JHA_i \tag{25}$$

and for the whole network

$$NKA = \sum_{i=1}^{n}(NKA_i), \tag{26}$$

where:

NKA_i = adjusted net present value of all components in network component *i*

$lifetime_i$ = lifetime of network component *i*

$average\ age_i$ = average age of components in network component *i*

NKA = DSOs adjusted net present value of all electricity network assets.

Assets that do not have a corresponding regulatory network component but are acceptable for network assets can be added to the equity from balance sheet.

Calculation of reasonable rate of return approved for the capital invested in network operations is based on the Weighted Average Cost of Capital (WACC) model. For the WACC the reasonable cost of equity is determined using the well-known Capital Asset

Pricing model (CAP model). Calculation of the CAP model is presented in equation 27. (EA, 2021a)

$$C_E = R_r + \beta_{equity} \cdot (R_m - R_r) + LP \tag{27}$$

where

C_E = reasonable cost of equity

R_r = risk-free rate

β_{equity} = equity beta coefficient

R_m = average market returns

$Rm\text{-}Rr$ = market risk premium

LP = premium for lack of liquidity

The risk-free rate is determined using the ten-year Finnish government bonds and calculating the average from daily values between April and September from the previous year. Market risk premium is determined to be 5% and the premium for lack of liquidity 0.6%. Beta coefficient for the equity can is calculated using equation 28. (EA, 2021a)

$$\beta_{equity} = \beta_{asset} \cdot \left(1 + (1 - ykv) \cdot \frac{D}{E}\right) \tag{28}$$

where

β_{asset} = the asset beta

yvk = the rate of corporate tax

D/E = the capital structure determined by EA (interest bearing dept / equity)

In the regulation model a fixed capital structure is used. The capital structure describes the weightings between the cost of equity and the cost of dept in the WACC model. The weighting is 40 % for interest-bearing debt and 60 % for equity. (EA, 2021a)

For the WACC model a reasonable cost of dept is also calculated by adding dept premium to the risk-free rate. The reasonable cost of dept C_D is calculated using equation 29. (EA, 2021a)

$$C_D = R_r + DP \tag{29}$$

where DP is the dept premium. The dept premium is determined to be 1.4%.

The reasonable rate of return in the regulatory model can be now calculated after taxes $WACC_{post\text{-}tax}$ using equation 30.

$$WACC_{post-tax} = C_E \cdot \frac{E}{E+D} + C_D \cdot (1 - ykv) \cdot \frac{D}{E+D} \tag{30}$$

where

E = adjusted equity invested in network operations

D = adjusted interest-bearing dept invested in network operations.

Using the fixed capital structure where interest-bearing debt is 40% and equity is 60% applied to the DSO, calculation of pre-tax reasonable rate of return $WACC_{pre\text{-}tax}$ can be carried out using equation 31.

$$WACC_{pre-tax} = \frac{C_E \cdot 0.6}{(1-ykv)} + C_D \cdot 0.40 \tag{31}$$

An overview of the parameters used to calculate the reasonable return is presented in table 3.1.

Table 3.1 Parameter for the regulatory WACC calculation (EA, 2021a)

Parameter	**Value applied in the regulatory WACC model**
Risk free rate R_r	Average daily values of the interest of 10-year Finnish government bonds for previous year's April–September
Asset beta β_{asset}	0.54
Equity beta β_{equity}	0.828
Market risk premium R_m	5.0 %
Premium for lack of liquidity *LP*	0.6 %
Capital structure (interest-bearing dept / equity) *(D/E)*	40 % / 60 %
Debt premium *DP*	1.4 %
Corporate tax rate *ykv*	20.0 %

Finally, the reasonable return before taxes $R_{k,pre\text{-}tax}$ can be calculated by multiplying $WACC_{pre\text{-}tax}$ with the adjusted equity invested in network operations and interest-bearing debt invested in network operations, presented in equation 32. (EA, 2021a)

$$R_{k,pre-tax} = WACC_{pre-tax} \cdot (E + D) \tag{32}$$

3.1.2. Investment incentive

The investment incentive is intended to encourage the DSOs to make cost efficient investments on average between the DSOs and to enable replacement investments. The investment incentives impact comes from the unit prices and the straight-line depreciation calculated from the adjusted replacement value of the network. According to the Energy authority's regulatory methods (EA, 2021a) the investment incentive guides the DSOs to make more efficient investments than the average of all DSOs. The impact arises from difference between the investments calculated with the regulatory unit prices and the realised investments. When DSO makes more efficient investment compared to the unit prices (adjusted replacement) they will get a higher value for their investment, and if the investment costs more than the value calculated with the regulatory unit prices the investment loses value. (EA, 2021a)

The adjusted straight-line depreciations $JHATP_k$ are calculated for all of the network components as presented in equation 33.

$$JHATP_k = \sum_{i=1}^{n}\left(\frac{JHA_i}{lifetime_i}\right)\cdot\left(\frac{KHI_k}{KHI_{2022}}\right) \tag{33}$$

where KHI_k is the consumer price index at year k and KHI_{2022} is the consumer price index at year 2022. The consumer price index is updated to the year when unit prices were last updated. (EA, 2021a)

3.1.3. Other incentives

In the regulation methods there are also other incentives, Quality incentive, efficiency incentive and innovation incentive. Considering the case study and case company which are presented in chapter 4, the mathematical background of these incentives is not thoroughly introduced, but the main idea is presented as their effects to the case company's investments are minimal. The quality incentive's objective is to improve the quality of distributed electricity, efficiency incentive's objective is to encourage DSO to operate in an efficient way and innovation incentive aims to encourage development and innovation of new technology and operational solutions for the DSO in its network. (EA, 2021a)

The quality incentive aims to improve the quality of electricity distribution by setting a price for different kind of outages with energy and power dimensions. The customer outage prices are presented in table 3.2. (EA, 2021a)

Table 3.2 Regulatory prices for different kind of electricity distribution outages. (EA, 2021a)

Unexpected outage		**Planned outage**		**Time-delayed autorecloser**	**High-speed autorecloser**
$h_{E,unexp}$	$h_{W,unexp}$	$h_{E,plan}$	$h_{W,plan}$	h_{AJK}	h_{PJK}
€ / kWh	€ / kW	€ / kWh	€ / kW	€ / kWh	€ / kWh
11.0	1.1	6.8	0.5	1.1	0.55

The quality incentive is determined by calculating a reference level of regulatory outage costs from past years KAH_{ref} and comparing it to the realised regulatory outage cost $KAH_{t,k}$, using the regulatory customer prices for outages presented in table 3.2 with corresponding realised outages. The impact of quality incentive is deducted when calculating realised adjusted profit and its effect can be positive or negative depending on if the KAH_{ref} deducted with $KAH_{t,k}$ is above or less than zero. The effect of the quality incentive is limited to be 15 % of reasonable return at its maximum on both ways. (EA, 2021a)

Efficiency targets are defined by the EA for the distribution industry and for every DSO. There is a general efficiency target which is set to 0% as there’s a lot of new expectations to DSOs that increase their costs. Company specific efficiency targets steer DSOs to improve their own efficiency. In the regulatory model efficiency benchmarking uses a very complicated Stochastic Non-smooth Envelopment of Data model (StoNED) to determine company specific efficiency targets. The StoNED model uses controllable operative expenditure, repurchase value of network, network length, cabling rate, distributed energy, the number of customers, the ratio of customers per connection point, customer outage costs and the general efficiency target to determine the DSO specific efficiency requirement. The company specific requirement is used to calculate allowed operational costs ATOTEX. Simplistically the company-specific efficiency incentive is determined by comparing ATOTEX with total realised operational costs TOTEX. Operational costs consist of controllable costs like maintenance and 50 % of customer outage costs. (EA, 2021a)

Innovation incentive is in place to encourage the DSO to develop and use new innovative technical and operational solutions in its electricity network operations. The innovation incentive consists of acceptable research and development costs and can be up to 1 % of the DSO’s total turnover from network operations in the year in question. Capitalized costs are not allowed in the innovation incentive. The innovation incentive is deducted when calculating the realised adjusted profit. (EA, 2021a)

3.2. Investments in electricity distribution infrastructure

There is growing need worldwide to invest more in electricity network as the green transition increases renewable production or processes that use fossil fuels are electrified, which demand more electricity transmission and distribution capacity. Annual worldwide grid investments are projected to rise in IEA’s scenarios between USD 550 billion and 630 billion by 2030, compared to USD 300 billion per year from 2012-2021 (IEA 2022).

In Finland the focus has been in security of supply investments in the past years. These investments are driven by the Electricity Market Act (588/2013) that set security of supply targets to be 6 h in city plan areas and 36 h in rural areas by latest 2036. Yearly replacement investment levels rose from c.a. 500 M€ to c.a. 1 000 M€ level from 2014 to 2020. (EA, 2021b) There is also growing need to invest into the electricity network due to the green transition in Finland. For example, Helen Electricity Network projected that they need to invest 370 M€ between 2022 and 2031 for network replacement and change investments from which 160 M€ is to enable green transition and the development of city of Helsinki. (Helen Sähköverkko, 2022)

The grown need for electricity network investments makes it important to analyse and optimize investments in the best possible way. Next chapter presents a short overview how network investments have traditionally been optimized in Finland considering the economic regulation.

3.2.1. Optimizing investments in electricity distribution network

Haakana, Lassila, Honkapuro and Partanen (2012) presented three different renovation strategies and cost optimization functions corresponding to them. The objectives for these strategies were to minimize costs, maximize the owner's profit and to minimize the total cost of customers. The general cost optimization functions were presented as follows:

Minimisation of costs:

$$\min Z_1 = \int_0^T Total\ costs\ (t)\ dt \tag{34}$$

where T is the lifetime of the network.

Maximisation of owner's profit:

$$\max Z_2 = \int_0^T \big(Allowed\ revenue(t) - Actual\ costs(t)\big)\ dt \tag{35}$$

Minimisation of total cost for the customer:

$$\min Z_3 = \int_0^T (Actual\ costs(t) + Customer\ outage\ costs(t))\ dt \tag{36}$$

Minimization of the total costs is a traditional way of planning network. When taking the Finnish regulatory model and the equation 29 into account, the minimization of totals costs function can be written as follows (Haakana et al., 2012):

$$\min Z_1 = \int_{t=0}^T \big(C_{CAP}(t) + C_{OPEX}(t) + C_{COC}(t)\big)\ dt \tag{37}$$

where

T = the planning period (lifetime),

$C_{CAP}(t)$ = the annual capital costs for year t

$C_{OPEX}(t)$ = the annual operational costs for year t

$C_{COC}(t)$ = the annual customer outage costs for year t.

The objectives of the DSO can be closely linked to the approach taken to network optimization. Combining the equation 30 to the Finnish regulatory methods the following equation can be used as a basis for optimization when maximising owner's profit (Haakana et al, 2012):

$$\max Z_2 = \int_{t=0}^{T} \left(D_{ap}(t) + D_{sld}(t) + D_{OPEX}(t) + \frac{D_{COC}(t)}{2} - C_{CAP}(t) + C_{OPEX}(t) + \frac{C_{COC}(t)}{2} \right) dt \qquad (38)$$

where

$D_{ap}(t)$ = the annual allowed return on capital for year t, (reasonable return)

$D_{sld}(t)$ = the annual straight-line depreciations for year t

$D_{OPEX}(t)$ = the annual reasonable operational costs for year t

$D_{COC}(t)$ = the annual reference value of the customer outage costs for year t

For the minimization of customers costs consists of reasonable regulatory costs and actual costs. The cost components for the minimization optimization are funding cost of investments, depreciations of investments, actual operational costs and the regulatory customer outage costs presented in equation (39) (Haakana et al, 2012)

$$\min Z_3 = \int_{t=0}^{T} \left(C_{CAP}(t) + C_{OPEX}(t) + C_{COC}(t) \right) dt \qquad (39)$$

The equation (39) is identical to equation (37), but if funding costs are eliminated there comes a difference between them. Eliminating funding costs can often be justified due to the

DSOs opportunity to fund their investments using only income funding. (Haakana et al, 2012)

The Finnish regulation limits the maximum profit that the DSO owner can gain from the operations. Minimizing total costs and minimizing customers total costs are strategies very close to each other. These strategies tend to lead to different investment programs, results for the customer and for the network structure. These investment strategies are applied within Helen Electricity Network, which is presented in the next chapter as part of the case study.

4. Case study

This case study focuses on implementing real options theory to Helen Electricity Network Ltd. investment planning and analysis practises using a real-life case for electricity distribution capacity investment need. First an introduction to the Case company and its operations linked to the thesis topic is presented. It includes an overview of Helen Electricity Network and its current investment process and investment analysis practices, to find out where and in which situations real options theory would be useful for the company. After getting to know the case company and its practices a real options valuation method to be implemented is chosen. The needed data and its sources for real options valuation are presented, following with detailed results and analysis.

4.1. Overview of Helen Electricity Network and its investment planning and analysis practises

There are 77 DSOs in Finland, and the case company Helen Electricity Network is the third largest when measured by the number of customers. Helen Electricity Network operates in the Helsinki municipality area and by end of year 2022 it had 414 000 customers connected to its network. Helen Electricity Networks turnover was 130 M€ in year 2022 and it has 93 employees. The total length of electricity network that Helen Electricity Network manages and operates is around 6500 km.

Helen Electricity Network has a growing need for investments to the electricity distribution network. The company plans to invest 420 M€ in its network between 2022 and 2031. From this 370 M€ is replacement and change investments and 50 M€ is investments for organic growth. Investments for organic growth are quite stable but the increased investment need is in replacement and change investments. A ten-year investment plan for replacement and change investments is presented in figure 4.1. (Helen Sähköverkko, 2022)

There is an incoming investment boom as the replacement and change investments are planned to more than double in years 2024-2028 compared to 2022 levels. The increase comes from replacement investments in energy metering and change investments to the high voltage network and substations. Change investments are investments that enable the green transition and development of the city of Helsinki. These investments are planned to be 180 M€ between 2022 and 2031, and they can be e.g., relocating high voltage power lines or substations, or investments in additional electricity distribution capacity. (Helen Sähköverkko, 2022)

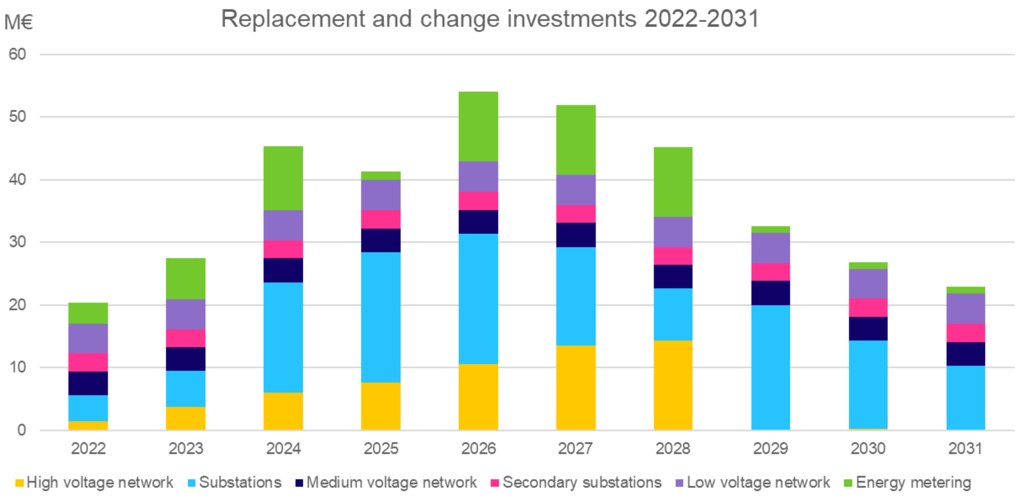


Figure 4.1 Helen Electricity Networks planned yearly investments for replacement and change investments divided by network component classes, years 2022-2031. (Helen Sähköverkko, 2022)

The increasing investment need careful planning and analysis for the network investments. It is in Helen Electricity Network's best interest avoid unprofitable or unnecessary investments that can be caused by uncertainties in customer needs, investment costs, operational costs related to the investments or regulation. The uncertainties in customer need are the amount and timing of electricity consumption of customers which can lead to premature investments and demolitions or insufficient distribution capacity. Investment and operational costs are often change from what is initially planned and the regulatory model contains uncertainties e.g., in the interest rate used to determine reasonable rate of return, the regulatory model is also under update which causes uncertainties in how to calculate value for the investment project. These uncertainties and the actions DSOs have to manage them tend to be neglected by traditional investment analysis methods which are currently used in Helen Electricity Network. There is a need to analyse the effect of uncertainties and the actions to manage them on investment profitability to help make informed investment decisions. For this real options theory and valuation method is implemented on Helen Electricity Networks investment analysis practises. Next the investment process of Helen Electricity network is described, opportunities where real options could be utilized and current practices for investment analysis are discussed.

4.1.1. Helen Electricity Network investment project process

Matthews et al. (2007) pointed out that much of the value of real options resides in “real options thinking” and not in the actual valuation calculations. The real options thinking is a critical part of decision making but not well articulated, although real options offer structure to decision making. For real options recognition and valuation, it is important to recognize where the real options thinking could be implemented in Helen Electricity Networks investment process for large investments.

The investment project process is based on gates that structure the investment project process. In the beginning of the process before gate 0 customer needs and investment project ideas are identified. Between gates 0 and 1 initial planning of the project is performed. Gate 1 is where a decision for continuing to detail planning is made. Gate 2 represents the investment decision. After the execution of the investment project the output of the project is approved in gate 3 and gate 4 is the closure of the project. Post evaluations are also made for the large investment projects. A general description of Helen Electricity Networks investment project process in described in figure 4.2.

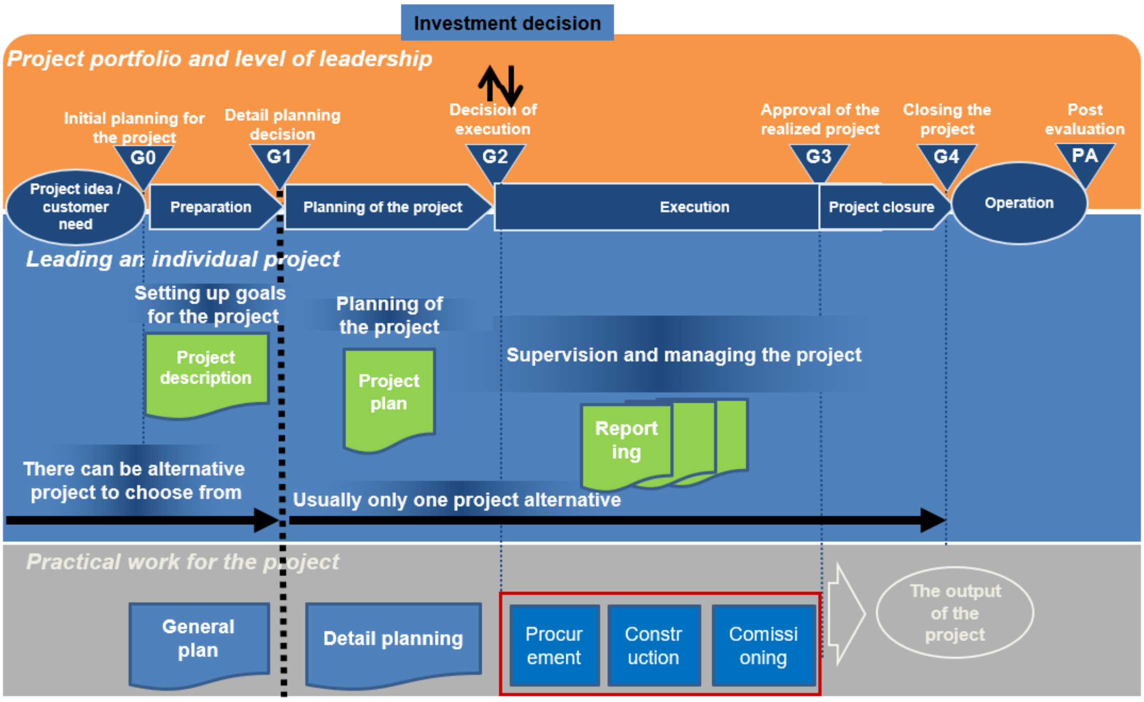


Figure 4.2 General overview of Helen Electricity Network investment project process, adapted from Helen Electricity Networks internal material.

The planning of investment projects is divided in two parts. Initial planning where a general plan is made, and initial analysis of the project and its profitability are calculated. Usually in this phase there are still a lot of uncertainties and there can be multiple investment options that solves the same challenges for the network. After the gate 1, usually only one investment option goes to detail planning phase as in the planning phase the project will start accumulating considerable costs. These costs come for example from the actual planning and permitting. However, in the detailed planning phase, there are still uncertainties that can affect the profitability of an investment project. The planning phases starting from the identification of customer needs and initial planning to the gate 2 when detailed planning for the project is ready can take several years. The procurement, construction and commissioning of the project can also take between one to five years.

This study focuses on the beginning of the investment process where project ideas and alternative investment projects are analysed. This would be a natural point in the process for implementing real options theory, as there can be several different investment options, there are usually lots of uncertainties and no considerable costs are yet incurred for the projects however, cases for real options can be found in the detailed planning phase before investment decision or even after the investment decision is made.

The most obvious real options recognized for the electricity network investments are option to expand and option to defer, option to switch and option to abandon can also be found in some cases. Option to defer can be found for example if there are uncertainties in customers electricity demand, deferring the investment and waiting for more knowledge can help to avoid overinvestments in electricity distribution capacity. Option to expand can be for example installing extra pipes for possible future needs in a cabling investment or a substation investment where a possibility to add an extra transformer or extra feeders is left possible without any additional work to the building. Most use cases for real options valuation in Helen Electricity Networks investment project process can be found before detailed planning decision is made. For the investment decision (G2) a description of uncertainties and their possible effects to the investment project would be in place to help management to make better informed decisions.

4.1.2. Investment analysis methods currently in use.

Helen Electricity Network uses a total cost of ownership (TCO) methodology in its investment analysis. TCO methodology focuses to capture all the costs associated with a particular project, operation or acquisition over its whole life span. (Sower, Sower 2015) Helen Electricity network uses the TCO methodology to make the overall cost-efficient investments to the electricity network. For electricity network investments costs that are accumulated are for example the investment cost, costs from land use, rents, inspections, maintenance and demolition. The objective is to minimise the total cost of ownership and at the same time get reasonable return for the operations.

Income side for electricity distribution network investments in the Finnish regulatory framework is somewhat tricky to calculate. For what the project generates as cash inflows Helen Electricity Network uses the variables of the economic regulation model described in chapter 3.1. How the investment project affects the reasonable return and investment incentive is calculated for the cash inflow. Quality and efficiency incentives can affect the results in either way. In replacement investments cost savings are also considered as cash inflows in the investment profitability calculations.

The overall investment and network renovation strategy is very similar to minimizations of total costs presented in chapter 3.2. However, the company also wats to make sure that the investments are also sensible when considering the Finnish regulatory framework and that there is a reasonable return on investments, which the regulatory framework allows.

For the analysis of investment profitability traditional measures are used and the calculations are based on projected cash flows, actual and regulatory. These include the NPV, IRR, payback period and profitability index. It is also calculated how much the investment costs differ compared to the regulatory unit prices by dividing the repurchase value of the invested regulatory components with the investment cost; this is called investment efficiency. The NPV and investment efficiency are presented always, the other investment profitability measures are used if they are needed to support in the investment decision making.

Although the investment analysis is comprehensive using the TCO methodology and taking the Finnish regulatory framework in to account, uncertainties and managerial actions are often neglected. Usually, uncertainties are taken into account by adding a premium on top of the investment costs, which weakens the indicated profitability of the investment and the measures for the investment and its profitability are presented in crisp numbers.

4.2. Data and methodology

Helen Electricity Network’s objective for this thesis is to get more insight on risks and uncertainties that investment projects face and on the actions that can be taken to mitigate the downside of these risks and uncertainties. As there can be different kind of network investment options to solve the same challenge and some actions can be taken to mitigate uncertainties, implementing real options theory seems appropriate. Next a real options valuation method is selected to be implemented. Use of the selected method is demonstrated via a real-life case.

4.2.1. Methodology

In Helen Electricity Network’s point of view, the real option valuation method should be easy to use and simple, as experts using the implemented tool are electrical engineers whose main focus is on electrical engineering. The analysis should also be easily shared in an open way with others. This means preferably an excel spreadsheet-based solution. A complicated valuation method or a calculation tool which is not easily used and shared would probably be of little use.

There are many uncertainties in the estimations of electricity distribution investments and their profitability. These uncertainties can be for example investment and maintenance costs, electricity demand of customers, timing of the customer electricity demand, permissions for the construction of electricity network, and regulatory methods. In practice, expressing probabilities for these events with accurate value based on experience and subjective estimations is unrealistic. Under these circumstances expressions with fuzzy or linguistic variables are more reasonable. (Zeng et al., 2007)

Considering the case company’s objectives and the nature of uncertainties that electricity distribution network investments can face, the Pay-off method, presented in chapter 2.2.5, is chosen to be implemented into the company’s investment analysis practises. In more detail the fully possibilistic pay-off method. The pay-off method uses cash inflows and outflows created by experts which supports choosing it as a methodology to be applied. For the experts it is quite straight forward to determine optimistic, best guess and pessimistic cashflow scenarios for the investments if the best guess scenario can be extracted from the normal investment planning process of the company.

For the pay-off method the extra premium that is usually assigned to cover unexpected costs needs to be withdrawn from the best guess scenario. These kinds of extra costs are included in the pessimistic scenario. The investment analysis before decision making is usually done before procurement therefore the investment cost is a rough estimation based on knowledge of the market and previous investments with similar network components. Planning is also often carried out with safety margins that might lead to lower realised investment costs than planned. Therefore, there should also be a possibilistic scenario with lower investment and maintenance costs.

Some of the regulatory parameters used to calculate reasonable rate of return, and inflation changes over time and can affect the investments profitability long after the investment project has been commissioned. However, these are the same for every investment and if different options or investment projects are compared via real option valuation the parameters should be the same for the different investment projects. In some rare cases, it might make a difference to have different regulatory parameter scenarios for real option valuation, if the TCO cost structure is very different between compared investments. For the investments going into G2 investment decision, different regulatory parameters are added to the pay-off methods CF scenario calculations to test how suitable the pay-off method is for sensitivity analysis.

4.2.2. Investment need and data

This chapter presents a description of the investments and investment options which are analysed. It includes the data needed for investment analysis and real option valuation and its sources, also the initial investment profitability calculations with the current company practices are provided.

The investment need chosen for analysis are meant for high voltage electricity distribution network capacity reinforcement in the Helsinki city area. The need for distribution capacity reinforcement comes from projected increase in Helen Electricity Network customers electricity demand. Some of this increasing demand can be considered certain and some of it is still uncertain. For example, the local district heating company announced investments on green transition where fossil fuels are replaced with heat pumps 230 MW and electric boilers 280 MW by year 2025. (Helen, 2023) There are also other individual large customers making inquiries for increasing electricity demand in Helen Electricity Networks area for substantial amounts, but these details are left outside of this thesis for nondisclosure reasons. The need for the reinforcement is inevitable, but there are major uncertainties in the electricity distribution capacity needed in the future. For the sake of this thesis detail information about the electricity demand is not needed. The information of which investments are enough for the lower demand, and which are needed for the higher demand is sufficient.

The reinforcement of the electricity distribution network capacity concerns the lines and cables feeding the inner-city area of Helsinki. The reinforcement need in more detail is for the high voltage distribution cross-section number 2 presented in a dashed red line in figure 4.3.

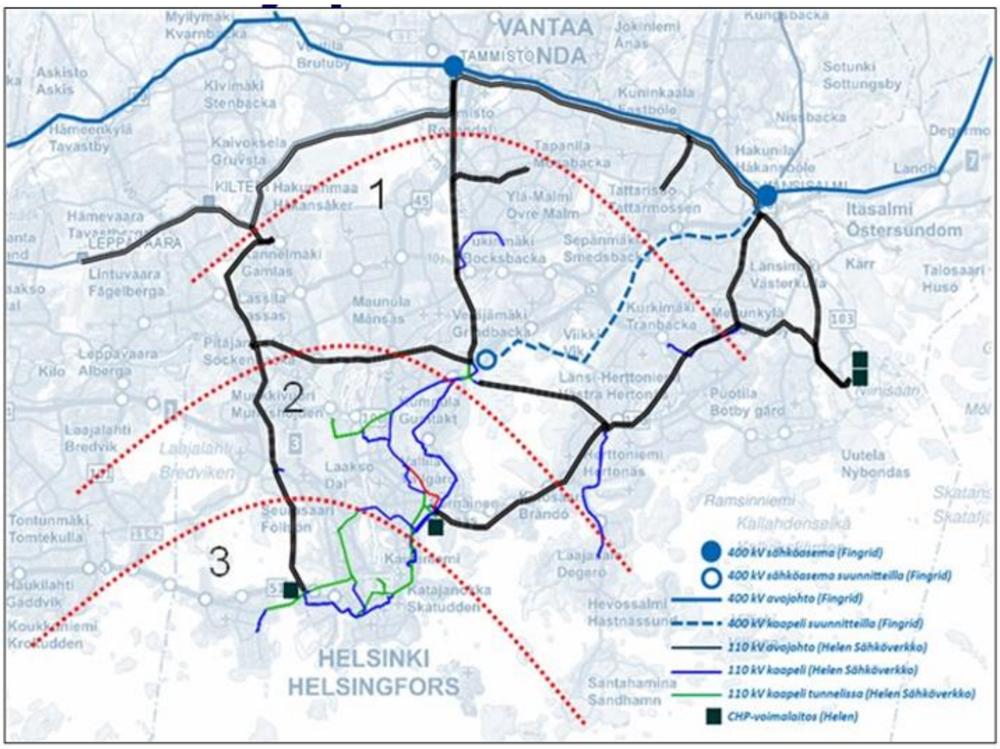
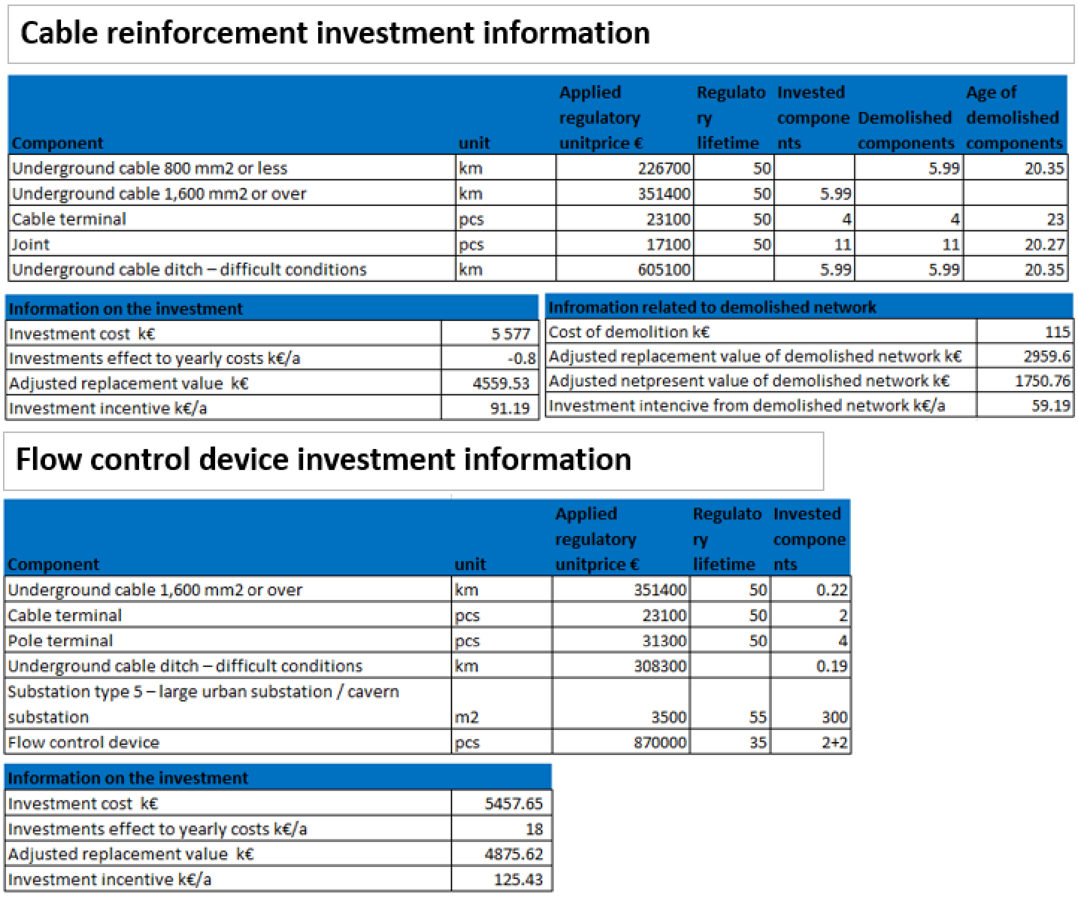


Figure 4.3 High voltage distribution network in Helsinki and cross-sections for high voltage distribution capacity.

Two sensible ways has been identified to increase the capacity in the second cross-section, depending on the electricity demand. First option is to invest in electrical equipment that are used to control electricity flows in different cables to optimise the use of existing capacity of the network. This investment is sufficient for the increase of electricity demand that is considered to be certain. The risk of even more increased electricity demand could be answered with an investment in cable reinforcement, which is to replace an old 110 kV transmission cable connection with new thicker cables that have higher electricity distribution capacity. The higher increase of electricity demand due to individual large customer inquiries can be expected in five to ten years. Detailed information of the investments provided by the experts in Helen Electricity Network is presented in figure 4.4. The investment cost and operational cost information is modified from actual costs in order not to disclose business sensitive information but so that the results can be interpreted in the same way as using the actual costs.



Cable reinforcement investment information

Component	unit	Applied regulatory unitprice €	Regulatory lifetime	Invested components	Demolished components	Age of demolished components
Underground cable 800 mm2 or less	km	226700	50		5.99	20.35
Underground cable 1,600 mm2 or over	km	351400	50	5.99		
Cable terminal	pcs	23100	50	4	4	23
Joint	pcs	17100	50	11	11	20.27
Underground cable ditch – difficult conditions	km	605100		5.99	5.99	20.35

Information on the investment	
Investment cost k€	5 577
Investments effect to yearly costs k€/a	-0.8
Adjusted replacement value k€	4559.53
Investment incentive k€/a	91.19

Infromation related to demolished network	
Cost of demolition k€	115
Adjusted replacement value of demolished network k€	2959.6
Adjusted netpresent value of demolished network k€	1750.76
Investment intencive from demolished network k€/a	59.19

Flow control device investment information

Component	unit	Applied regulatory unitprice €	Regulatory lifetime	Invested components
Underground cable 1,600 mm2 or over	km	351400	50	0.22
Cable terminal	pcs	23100	50	2
Pole terminal	pcs	31300	50	4
Underground cable ditch – difficult conditions	km	308300		0.19
Substation type 5 – large urban substation / cavern substation	m2	3500	55	300
Flow control device	pcs	870000	35	2+2

Information on the investment	
Investment cost k€	5457.65
Investments effect to yearly costs k€/a	18
Adjusted replacement value k€	4875.62
Investment incentive k€/a	125.43

Figure 4.4 Information on investment options for increasing transmission capacity in Helen Electricity Network high voltage network. Cost information is modified from actual costs in order not to disclose business sensitive information. Cost information in real terms.

The cable reinforcement investment option is more expensive compared to the flow control device and the old cables have more than half of their lifetime left, which means losing money for the DSO. In the Finnish regulatory environment, when calculating investment profitability, the change to reasonable return and incentives should be considered in the calculations. This means that in replacement investments demolished assets having NKA more than 0 have a negative effect to the regulatory cash inflows used in investment profitability calculations.

Compared to the average operational environment in Finland Helsinki is a very densely built environment. In the city area it is difficult to find room for electricity distribution network and as there is also other infrastructure using the same street areas. Therefore, the solutions how the electricity infrastructure is built can get very expensive, especially when compared to the regulatory unit prices. The new cable is estimated to cause less annual operational costs than the old cable, based on enhanced production techniques. Electrical losses are also included in the annual costs. The net present value for this project using the methodology described in chapter 4.1.2 is -246 000 € over the 50-year period used in the company practices. IRR is 4.70% and investment efficiency 0.82, the investment efficiency should be 1 to match the industry average investment costs. Based on this information the project should be rejected by the profitability point of view. The calculation was carried out with a 5% discount rate and with the values for WACC and inflation presented in table 4.1.

Increasing the distribution capacity with an electrical control device has the lowest investment cost, but more operational costs related to it than the other option. It is sufficient to the future customer demand for electricity that are considered to be certain at the moment. The lifetime for this electricity flow control device is estimated to be 35 years. This means that the flow control device needs to be renewed once during the 50-year period. Electrical losses are also included in the annual costs. For this project the corresponding values are NPV = 1652 000 €, IRR 8.57% and investment efficiency 0.89. Based on NPV and IRR values this project could be continued. However, there is a risk that in five to ten years the electricity demand of Helen electricity Networks customers increases to a level where more distribution capacity is needed for the cross-section 2. This would mean that the cable reinforcement is needed, and the flow control device is left unused and it will need to be demolished prematurely.

Calculation of the regulatory WACC is carried out using the measures presented in table 3.1. For the 10-year Finnish government bond rate and inflation the forecasts from the bank of Finland or the ministry of Finance is used depending on which is more recent, as forecasting interest rates are out of the scope for this thesis. For the first three years the 10-year Finnish government bond is obtained from the ministry of finance. (VM, 2023) For the following years a forecast of the 30-year Finnish government bond is used according to the company policy. The used inflation rates, the 10-year Finnish government bond and WACC are presented in table 4.1.

Table 4.1 Inflation, WACC and the 10-year Finnish government bond rates used in the study.

Measure/year in calculation	**0**	**1**	**2**	**3**	**4**	**5->**
Finnish 10 year interest rate for WACC calculation	1.76 %	3.30 %	3.20 %	3.40 %	3.20 %	3.10 %
Inflation	0 %	5 %	4 %	2 %	2 %	2 %
WACC	6.08 %	7.85 %	7.74 %	7.97 %	7.74 %	7.62 %

Usually, in the case company minimizing total costs of ownership would lead to a solution that solves the problem in hand and at the same time takes care of the future needs of customers. In this case it would mean the unprofitable cable reinforcement investment. However, the flow control device investment is profitable as long as it’s sufficient for the electricity distribution capacity needed. This creates potential for utilizing real options theory to the investment in electricity transmission capacity for the cross-section 2 as long as the negative side of the possible NPV distribution can be cut-off. In the following chapter 4.3 the results of real option valuation are presented and discussed. Also, the possibilities of using the fully possibilistic fuzzy pay-off method for sensitivity analysis to enlighten uncertainties the investment project faces are discussed.

4.3. Results

The future electricity demand causes reinforcement needs to Helen Electricity Networks high voltage grid. The increase in electricity demand for the near upcoming years can be solved with a profitable electricity flow control device investment. However, in five to ten years there is a risk of the electricity demand increasing more than the distribution capacity increase provided by the electricity flow control device. Therefore, a cable reinforcement investment would make more sense as it solves the possible future needs of the company customers. However, the initial calculations in chapter 4.2 show that executing the cable reinforcement is not profitable due to old network that has more than half of its life-time left needs to be demolished. This provides an opportunity to investigate real options.

The real option recognized in the cable reinforcement of cross-section 2 is the option to defer. The cable reinforcement investment, which is a replacement investment for an old cable connection, can be deferred to gain more information on customers future electricity demand by investing to the electricity flow control device. If in five to ten years the electricity demand increases more than the capacity provided by the electricity flow control device, which is a recognized risk, the cross section 2 capacity reinforcement can be switched to the cable reinforcement.

Using the same information about the investments provided in chapter 4.2.2 three cashflow scenarios can be created to cover the uncertainties in the customer demand: optimistic, best guess and pessimistic.

- **Optimistic**: The electricity flow control device investment is made in year 0. The electricity demand does not increase in the future any more than what is the increased electricity distribution capacity provided by the electricity flow control device. Thus. the cable reinforcement investment can be avoided. A reinvestment to the electricity flow control device is needed in 35 years.

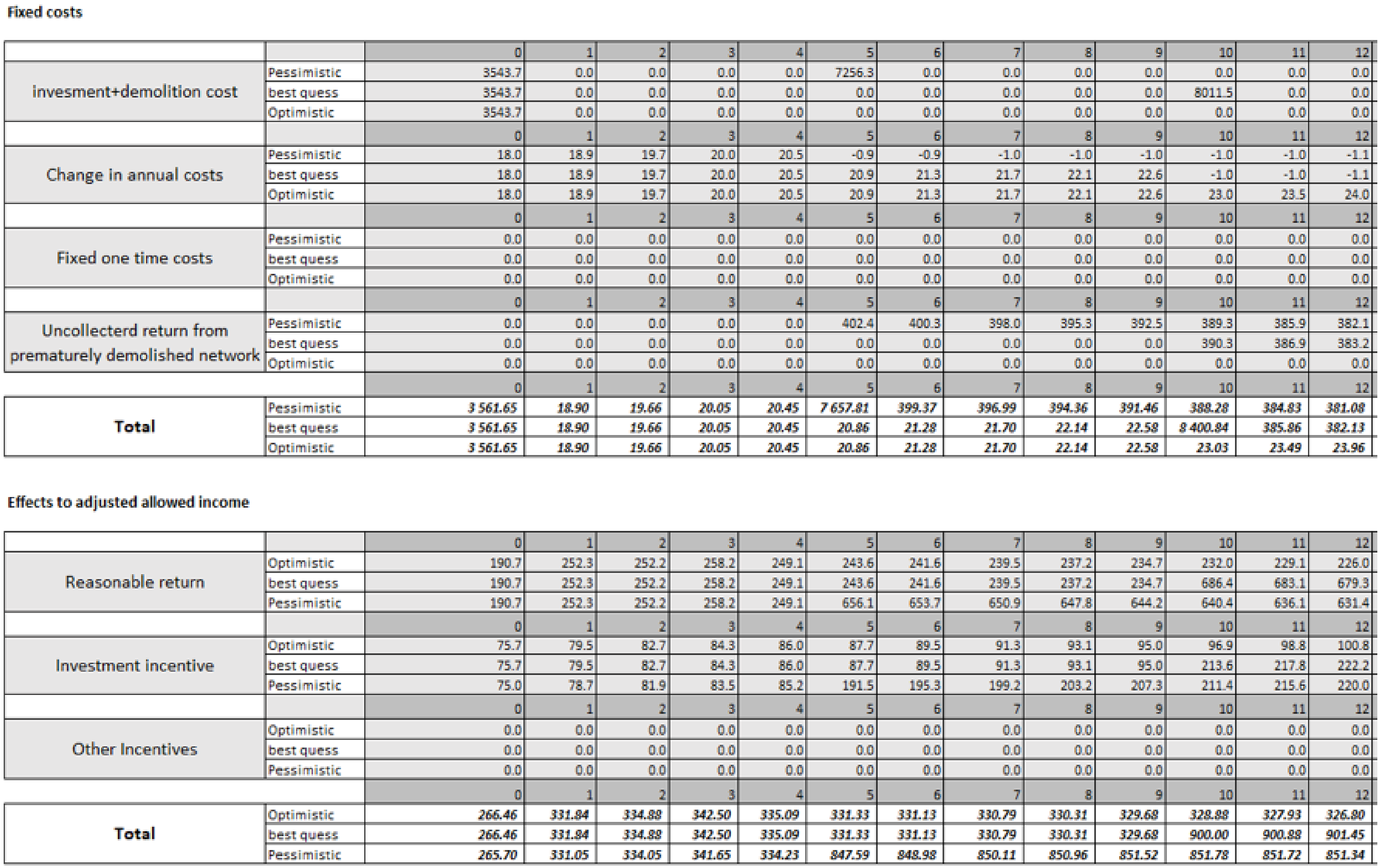
- **Best guess**: The electricity flow control device investment is made in year 0. However, electricity demand increases even more so that the cable reinforcement is needed in ten years. Executing the cable reinforcement in ten years, means that the old cable connection being replaces is demolished prematurely at the age of 30 years and the electricity flow control device is demolished prematurely at the age of 10 years. In the scope of this thesis there is no other use for the flow control device after demolition.

- **Pessimistic**: The electricity flow control device investment is made in year 0. However, electricity demand increases even more so that the cable reinforcement is needed in five years. Executing the cable reinforcement in five years, means that the

> old cable connection being replaced is demolished prematurely at the age of 25 years and the electricity flow control device is demolished prematurely at the age of 5 years. In the scope of this thesis there is no other use for the flow control device after demolition.

The cash flow scenarios are made in nominal terms. The nominal investment costs are expected to be stable. Postponing the cable reinforcement investment increases the investment cost by cumulative inflation, the yearly inflation rates used are provided in table 4.1. The cash flow scenarios for the first 12 years are shown in figure 4.5. The cash flows for the 50-year period are presented in Appendix 1. In the cash flow scenarios presented in Figure 4.5 fixed costs are the cash outflows and the effects to the reasonable return are considered as the positive cash inflows. The cash flow scenarios are the same for the optimistic scenario and the best guess scenario between years 0 and 9, as in both the optimistic and the best guess scenarios the same investment into the electricity flow control devices is made first. At year ten the effects of the cable reinforcement investment start to show difference. To clarify, the best guess scenario investment, operational and demolition costs are the same for the electricity flow control device and cable reinforcement as in the other scenarios, the numbers have been adjusted for inflation as mentioned earlier.

The uncollected return from prematurely demolished network is considered as cash outflow in the fixed costs. The cashflow scenarios point out that the prematurely demolitions in the best guess and pessimistic scenarios have a negative effect to the investment profitability. The cashflow scenarios do not take into consideration that the existing cable connection might need to be replaced when it comes to the end of its regulatory lifetime, which is inside the 50-year period. The analysis focuses on how the capacity reinforcement investment effects the company’s ability to make profit via the Finnish economical regulatory methods.



Fixed costs

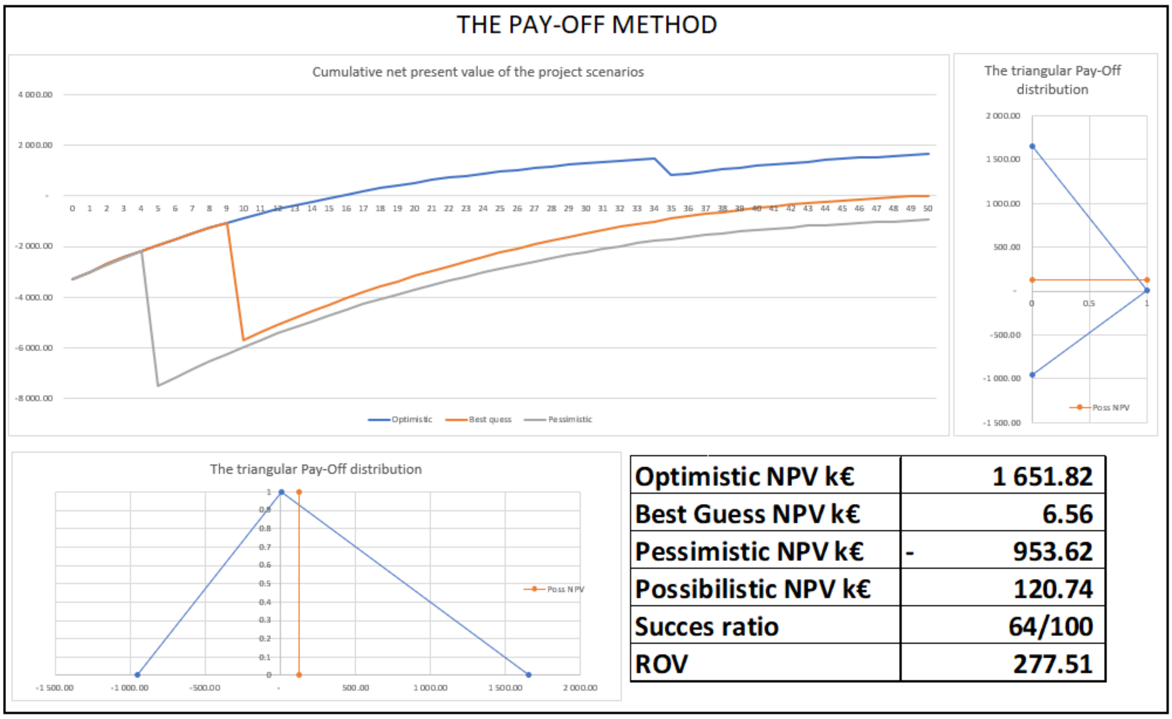
		0	1	2	3	4	5	6	7	8	9	10	11	12
invesment+demolition cost	Pessimistic	3543.7	0.0	0.0	0.0	0.0	7256.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8011.5	0.0	0.0
	Optimistic	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Change in annual costs	Pessimistic	18.0	18.9	19.7	20.0	20.5	-0.9	-0.9	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1
	best quess	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	-1.0	-1.0	-1.1
	Optimistic	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	23.0	23.5	24.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Fixed one time costs	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Uncollecterd return from prematurely demolished network	Pessimistic	0.0	0.0	0.0	0.0	0.0	402.4	400.3	398.0	395.3	392.5	389.3	385.9	382.1
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	390.3	386.9	383.2
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Total	Pessimistic	*3 561.65*	*18.90*	*19.66*	*20.05*	*20.45*	*7 657.81*	*399.37*	*396.99*	*394.36*	*391.46*	*388.28*	*384.83*	*381.08*
	best quess	*3 561.65*	*18.90*	*19.66*	*20.05*	*20.45*	*20.86*	*21.28*	*21.70*	*22.14*	*22.58*	*8 400.84*	*385.86*	*382.13*
	Optimistic	*3 561.65*	*18.90*	*19.66*	*20.05*	*20.45*	*20.86*	*21.28*	*21.70*	*22.14*	*22.58*	*23.03*	*23.49*	*23.96*

Effects to adjusted allowed income

		0	1	2	3	4	5	6	7	8	9	10	11	12
Reasonable return	Optimistic	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	232.0	229.1	226.0
	best quess	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	686.4	683.1	679.3
	Pessimistic	190.7	252.3	252.2	258.2	249.1	656.1	653.7	650.9	647.8	644.2	640.4	636.1	631.4
		0	1	2	3	4	5	6	7	8	9	10	11	12
Investment incentive	Optimistic	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	96.9	98.8	100.8
	best quess	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	213.6	217.8	222.2
	Pessimistic	75.0	78.7	81.9	83.5	85.2	191.5	195.3	199.2	203.2	207.3	211.4	215.6	220.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Other Incentives	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Total	Optimistic	*266.46*	*331.84*	*334.88*	*342.50*	*335.09*	*331.33*	*331.13*	*330.79*	*330.31*	*329.68*	*328.88*	*327.93*	*326.80*
	best quess	*266.46*	*331.84*	*334.88*	*342.50*	*335.09*	*331.33*	*331.13*	*330.79*	*330.31*	*329.68*	*900.00*	*900.88*	*901.45*
	Pessimistic	*265.70*	*331.05*	*334.05*	*341.65*	*334.23*	*847.59*	*848.98*	*850.11*	*850.96*	*851.52*	*851.78*	*851.72*	*851.34*

Figure 4.5 Cash flow scenarios for the first 12 years. Cash flows are presented as x1000€ and in nominal terms.

Using these three CF scenarios cumulative net present values are calculated for each project scenario as instructed in the pay-off method, using 5 % rate for discounting. The fully possibilistic real option value is calculated using equation (21) and the case for $a-\alpha \leq 0 \leq a$. The possibilistic NPV of the project is calculated using equation (22) and success ratio as demonstrated in the chapter 2.2.5. The results of the fully possibilistic pay-off method, including cumulative NPVs for the scenarios through the 50-year period, are presented in figure 4.6.



Optimistic NPV k€		**1 651.82**
Best Guess NPV k€		**6.56**
Pessimistic NPV k€	**-**	**953.62**
Possibilistic NPV k€		**120.74**
Succes ratio		**64/100**
ROV		**277.51**

Figure 4.6 Results of the fully possibilistic pay-off method.

As the cumulative NPVs of the project scenarios presented in figure 4.6 demonstrate the cashflows differ remarkably between the scenarios. With the optimistic and pessimistic scenarios NPV is the same as presented in chapter 4.2.2 ~ 1 650 000€ and ~-950 000€. The best guess scenario lands at a barely above zero with a 6 560 € NPV on the 50-year period. The triangular distribution is slightly skewed to the pessimistic side as the optimistic scenario is clearly more profitable than the other scenarios.

By deferring the decision for investing into the cable reinforcement for ten years, the negative side of the NPV distribution can be cut off. This creates real option for the cross-section 2 capacity reinforcement, and the real option value using the fully possibilistic pay-off method is valued to be 277 000 €. This real option creates value based on the avoidance of prematurely demolishing network components, if the electricity demand does not realize in a higher level of what the electricity flow control device can add to the distribution capacity. If the demand increases later, the company would have been able to utilize the existing cables for 10 years longer.

The success ratio calculated from the triangular NPV distribution of the scenarios is 64/100 and crisp value for the fuzzy triangular NPV distribution, the possibilistic NPV is 120 k€ indicate that the outcome of the project NPV is likely to be above zero. The possibilistic NPV and success ratio together with the ROV supports the decisions to invest into the electricity flow control device first and wait for more information on customers electricity demand.

The use of real options theory and the fully possibilistic pay-off method in investment analysis creates insight to analyse the cross-section 2 reinforcement investment when there is uncertainty in the electricity demand of customers. This helps to find a more profitable way to increase distribution capacity to the cross-section 2 when there are uncertainties in the customer demand and the needed distribution capacity. The previous analysis however neglects other uncertainties the investment faces, for example, uncertainties in investment or operational costs, inflation or the how the Finnish 10-year interest rate changes effecting the reasonable rate of return determined by the regulatory methods.

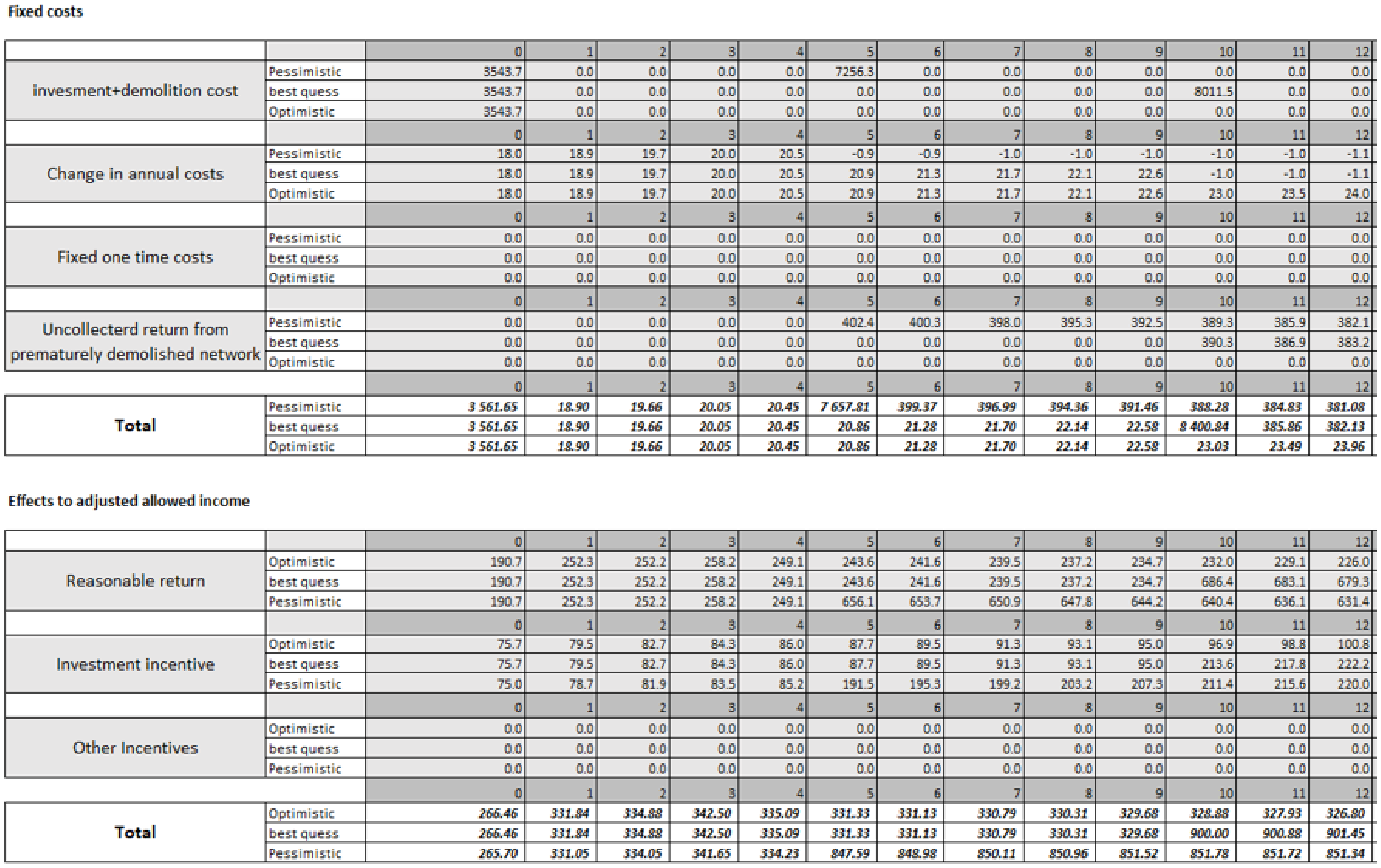
To illustrate how other uncertainties in the project can be analysed, a sensitivity analysis is carried out using the fully possibilistic pay-off method logic. Three scenarios are made where different simple cash flow scenarios are made using the best guess scenario as a basis, keeping it the same. This time the investment stays the same only the variables that are considered to be important, uncertain and effect the profitability of the project most are varied. These amount of variables from which the scenarios are made is limited to four, and they are the Finnish 10-year interest rate which effects the reasonable rate of return most, investment cost, operational costs and inflation. For the investment and operational costs the scenarios are based on expert evaluation. The Finnish 10-year interest rate and inflation scenarios are based on expert evaluation on how much sensitivity is seen reasonable in the analysis for the company. Table 4.2 illustrates how the simple scenarios are constructed.

Table 4.2 Scenario variables for sensitivity analysis. Cost information is modified from actual costs, due to business sensitive information, and presented in real terms.

Scenario	Total investment cost [k€]	OPEX before cable reinfor-cement [k€/a]	OPEX after cable reinfor-cement [k€/a]	Finnish 10-year interest rate [change in % units]	WACC [change in % units]	Inflation [change in % units]
Optimistic	9098	15.5	3,5	1 %	1.15 %	- 1 %
Best Guess	9678	18	4,2	best guess scenario values in table 4.1	best guess scenario values in table 4.1	best guess scenario values in table 4.1
Pessimistic	10065	19.5	6	-1 %	1.15 %	1 %

The scenarios in table 4.2 are rough estimates as this analysis is performed in the company's investment process in the initial planning phase between G0 and G1. At this point all details of the project are not yet fully planned and assumptions about the cost information must be made. These assumptions are based on previous projects and market knowledge of the expert. The thesis is not focusing on forecasting interest rates or inflation, and for illustration purposes the scenarios for these variables are simple ±1 %. For further use purposes the company should give more focus on interest rate and inflation forecasts and scenarios. These scenarios should be the same for all projects and not determined by experts who focus on electrical engineering. It is also possible to use the methodology also after G1 before the investment decision at G2 when the detailed planning is finished, and the scenarios are more accurate. Nominal cash flow scenarios for the first 12 years are presented in figure 4.7. The cash flow scenarios for the 50-year period are presented in Appendix 2.

The cash flow scenarios differ from each other in all of the components presented in figure 4.7. The cashflow scenarios try to cover the full span of possible outcomes, but keeping in mind that the scenarios need to be consistent. This means that when the WACC is high. This increases the reasonable return, but it also increases the negative effect of prematurely demolished network. The differences in investment and annual costs are obvious. The cash flows in the calculations that are related to the regulatory methods vary based on inflation and the Finnish 10 Y interest rate and WACC scenarios. The results of the sensitivity analysis with the fully possibilistic pay-off method are presented in figure 4.8.



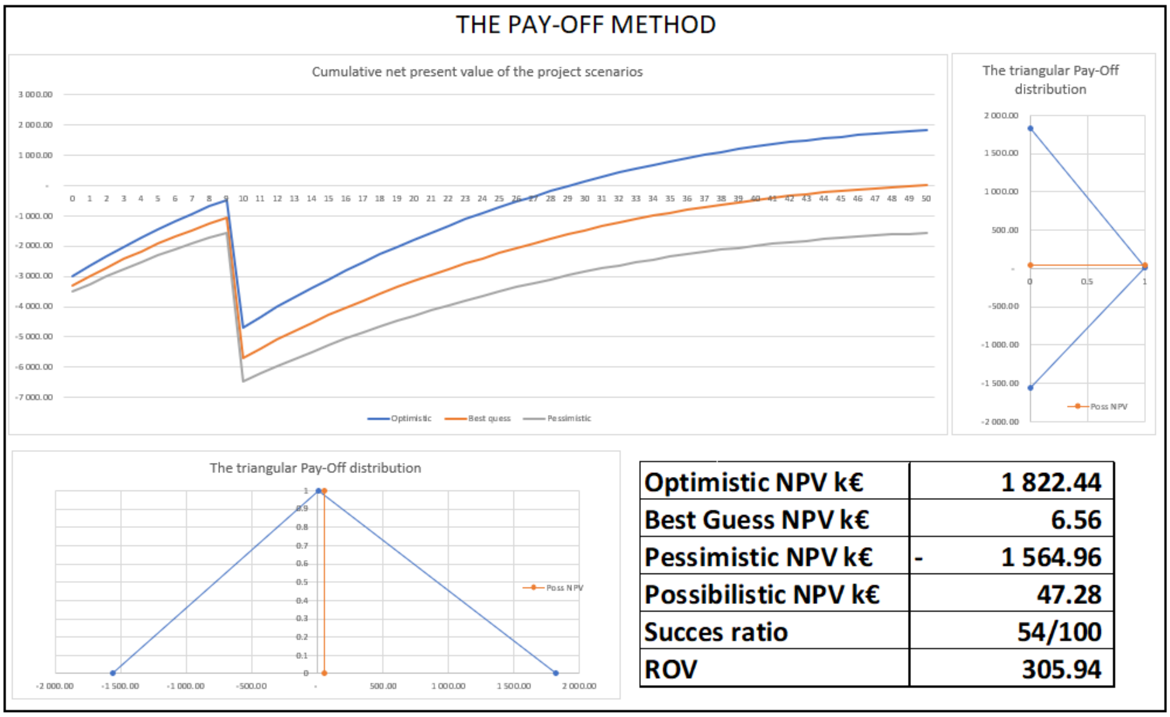
Fixed costs

		0	1	2	3	4	5	6	7	8	9	10	11	12
invesment+demolition cost	Pessimistic	3543.7	0.0	0.0	0.0	0.0	7256.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8011.5	0.0	0.0
	Optimistic	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Change in annual costs	Pessimistic	18.0	18.9	19.7	20.0	20.5	-0.9	-0.9	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1
	best quess	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	-1.0	-1.0	-1.1
	Optimistic	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	23.0	23.5	24.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Fixed one time costs	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Uncollecterd return from prematurely demolished network	Pessimistic	0.0	0.0	0.0	0.0	0.0	402.4	400.3	398.0	395.3	392.5	389.3	385.9	382.1
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	390.3	386.9	383.2
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Total	Pessimistic	*3 561.65*	*18.90*	*19.66*	*20.05*	*20.45*	*7 657.81*	*399.37*	*396.99*	*394.36*	*391.46*	*388.28*	*384.83*	*381.08*
	best quess	*3 561.65*	*18.90*	*19.66*	*20.05*	*20.45*	*20.86*	*21.28*	*21.70*	*22.14*	*22.58*	*8 400.84*	*385.86*	*382.13*
	Optimistic	*3 561.65*	*18.90*	*19.66*	*20.05*	*20.45*	*20.86*	*21.28*	*21.70*	*22.14*	*22.58*	*23.03*	*23.49*	*23.96*

Effects to adjusted allowed income

		0	1	2	3	4	5	6	7	8	9	10	11	12
Reasonable return	Optimistic	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	232.0	229.1	226.0
	best quess	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	686.4	683.1	679.3
	Pessimistic	190.7	252.3	252.2	258.2	249.1	656.1	653.7	650.9	647.8	644.2	640.4	636.1	631.4
		0	1	2	3	4	5	6	7	8	9	10	11	12
Investment incentive	Optimistic	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	96.9	98.8	100.8
	best quess	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	213.6	217.8	222.2
	Pessimistic	75.0	78.7	81.9	83.5	85.2	191.5	195.3	199.2	203.2	207.3	211.4	215.6	220.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Other Incentives	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12
Total	Optimistic	*266.46*	*331.84*	*334.88*	*342.50*	*335.09*	*331.33*	*331.13*	*330.79*	*330.31*	*329.68*	*328.88*	*327.93*	*326.80*
	best quess	*266.46*	*331.84*	*334.88*	*342.50*	*335.09*	*331.33*	*331.13*	*330.79*	*330.31*	*329.68*	*900.00*	*900.88*	*901.45*
	Pessimistic	*265.70*	*331.05*	*334.05*	*341.65*	*334.23*	*847.59*	*848.98*	*850.11*	*850.96*	*851.52*	*851.78*	*851.72*	*851.34*

Figure 4.7 Nominal cashflow scenarios for sensitivity analysis.



Optimistic NPV k€	**1 822.44**
Best Guess NPV k€	**6.56**
Pessimistic NPV k€	**- 1 564.96**
Possibilistic NPV k€	**47.28**
Succes ratio	**54/100**
ROV	**305.94**

Figure 4.8 Results of the sensitivity analysis using the fully possibilistic pay-off method.

The best guess scenario is the same from the earlier case. The possible outcomes based on expert scenarios of this investment project can be seen in Figure 4.8. The span of possible NPVs in the 50-year period goes from approximately -1 570 000 € to 1 820 000 €. The success factor in this project is 54/100, which reflects the possibility of this project being profitable. The possibilistic NPV is 47 000 €. The possibilistic NPV in line with the success ratio as it is greater than zero and the best guess NPV.

In this case there is no real option and therefore the use ROV value is not justified. In a case where the company would have an option to cut the negative side of the NPV distribution with its actions, the value of the project with this imaginary real option would be 306 k€.

Based on this analysis the investment for the base case scenario solution, where the case company first invests in electricity flow control device and in ten years in cable reinforcement contains risks on profitability. However, the investment project is only slightly more likely to end up with a positive NPV than negative NPV in the 50-year period. The results indicate that company should go forward to detailed planning to find out the true costs of the project and limit uncertainties. After detailed planning the uncertainties in costs are reduced but still there remain major uncertainties regarding the regulatory method. The investment decision should not be only based on a crisp number or on the other hand only on ROV. The company should use ROV, the sensitivity analysis and the possibilistic NPV together with the best guess NPV in to make informed investment decisions. The decision ultimately comes down to the company’s willingness to take risks.

The pay-off method illustrates the whole span of the possible NPV outcomes of the investment project. However, it lacs to describe what is the magnitude of impact from a single parameter in the investment analysis. The nominal cashflows show more detailed information on how different parameters change between the scenarios compared to the cumulative NPV figure. This still leaves room for unclarity as for example reasonable return is affected by both inflation and the Finnish 10 Y interest rate. This could be solved by creating multiple calculations with scenarios made only from one parameter, but it would be inconvenient for the experts to run several spreadsheets for analysing individual investment. The results of scenario-based sensitivity analysis with the pay-off method can be useful for managers who inspect the project in a higher level, to get quick insight of the risk level for the whole project.

Technical implementation of the fully possibilistic-payoff method to existing investment analysis is straight forward as they are already performed in excel spreadsheets. Calculating a limited number of cases is manageable. If there is a need for more detailed analysis how different parameters effect the profitability of the investment project, the amount of excel files to manage will rise with the corresponding amount.

The use of fully possibilistic pay-off method gives Helen Electricity network new insight to projects with uncertainties regarding timing of new electricity demand or cash inflows and outflows of a project. Finding cases with true real options can be difficult as the regulatory model incentives to invest into the distribution network and customer needs need to be fulfilled. Therefore, RO recognition and the use RO valuation methods should be included in the very early stages of the investment process.

5. Conclusions

The topic for this thesis arises from the increasing need for investments to the electricity distribution network that the clean energy transition causes. There are projections of high increases in electricity demand and in renewable electricity production. However, DSOs see uncertainties in these high projections, and they are often difficult to translate into numbers. This motivates the question if real options theory can help DSOs to analyse their investment with uncertainties.

To answer the research question "*How can real option methodology be used to analyse electricity distribution infrastructure investments?"* firstly a literature review was performed about real options theory and the use of real options in electricity network investment analysis. Secondly a case study was carried out, where real options theory was implemented on Helen Electricity Networks investment analysis practices. The selection of the real options valuation method came down to the fully possibilistic pay-off method, based on the use of excel and difficulties to formulae probabilities to the uncertainties, for which the fuzzy logic used by the method is suitable. This thesis shows that real option methodology can be used to analyses electricity distribution infrastructure investments. Real options thinking should be introduced already in the early stage of investment planning to help the company find profitable investment solutions for its electricity distribution network.

For the sub question 1. *"Can uncertainties in electricity distribution infrastructure investments be analysed using real option valuation methodology?"* the fully possibilistic pay-off method was used for analysing real options when there are uncertainties in customer electricity demand. The pay-off method can also be used for sensitivity analysis to illustrate risk involved with the NVP of an individual investment project. The pay-off methods CF and NPV scenarios shows the full span of possible future outcomes for the project but lacks to describe the magnitude of impact from individual parameters to the NPV. For sensitivity analysis the Helen Electricity Network should consider other solutions that might help the experts understand how much parameters on which they can have an impact effect the profitability of the investment.

To answer sub question 2. *"Is it feasible to implement real option valuation to Helen Electricity Networks investment analysis tool?"* the fully possibilistic pay-off method was easily implemented in Helen Electricity Network’s present investment budgeting tool as it was Excel spreadsheet-based tool. Also creating three different cash flow scenarios is manageable by the experts who are planning investments into the electricity distribution network.

The sub question 3. *“Is the selected real option valuation method valid for Helen Electricity Network?”* is a bit more difficult to fully disclose than the other sub questions. However, using real options theory and the fully possibilistic pay-off method, in investment analysis helps in Helen Electricity Network to analyse investments with major uncertainties in customers electricity demand. These uncertainties would be difficult to formulate with the conventional investment calculation methods that are currently in practice at Helen Electricity Network. Implementing real options into investment analysis and including ROV in investment decision making together with other profitability indicators gives more insight to the decision makers in the company compared to current practices.

Limitations of this research were recognised to be the use of excel, assumptions of the nominal costs being stable, and the economic regulatory model for the Finnish DSOs. Using other tools that allows faster simulation would give more opportunities for the real options valuation method. The regulatory methods in Finland are unique and in other countries the value creation of electricity distribution network investments can differ substantially. The regulatory methods in Finland are under update and will change after the completion of this thesis. The new methods may include changes that effect the profitability of the investment options analysed in this thesis. The geographical operating area of Helen Electricity network is relatively small and the number of cases to analyse without disclosing information of customers is small. The small sample size and the Finnish regulatory methods limit the opportunities to truly generalise the results of this thesis. Using other methods for real options valuation that are not limited to excel based solutions should be researched for analysing electricity distribution investments in the Finnish regulatory environment. Future research could focus on implementing real options theory to analyse investment programs where there are multiple different investments which increases possibilities for managerial decision making.

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Appendix 1. Cashflows in present values for real option valuation with the fully possibilistic pay-off method. Cash flows presented as k€.

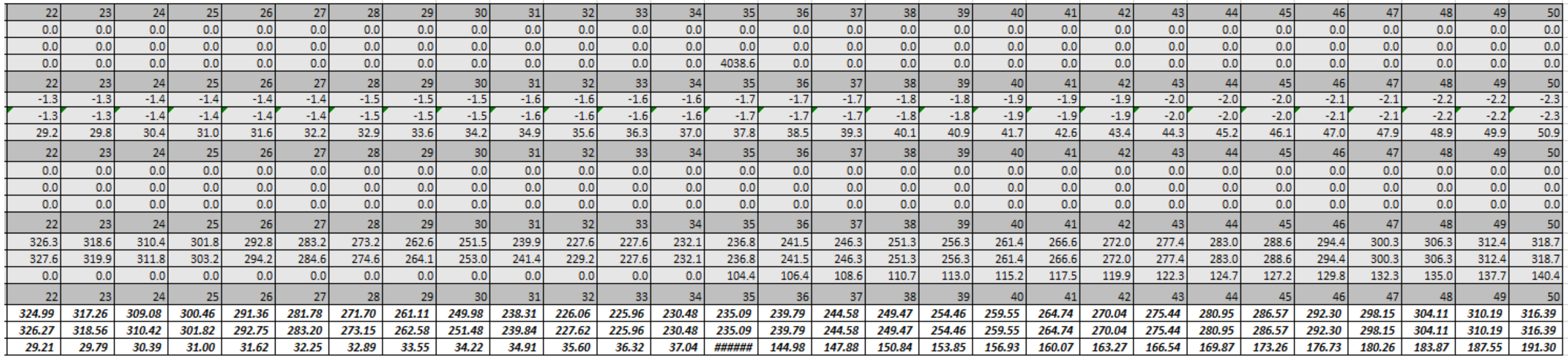
Fixed costs

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
invesment+demolition cost	Pessimistic	3543.7	0.0	0.0	0.0	0.0	7256.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8011.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Optimistic	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Change in annual costs	Pessimistic	18.0	18.9	19.7	20.0	20.5	-0.9	-0.9	-1.0	-1.0	-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.2	-1.2	-1.2	-1.2	-1.2	-1.3
	best quess	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.2	-1.2	-1.2	-1.2	-1.2	-1.3
	Optimistic	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	23.0	23.5	24.0	24.4	24.9	25.4	25.9	26.5	27.0	27.5	28.1	28.6
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Fixed one time costs	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Uncollecterd return from prematurely demolished network	Pessimistic	0.0	0.0	0.0	0.0	0.0	402.4	400.3	398.0	395.3	392.5	389.3	385.9	382.1	378.1	373.8	369.1	364.1	358.7	353.0	346.9	340.4	333.6
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	390.3	386.9	383.2	379.2	374.9	370.2	365.2	359.9	354.2	348.1	341.7	334.8
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Total	Pessimistic	***3 561.65***	***18.90***	***19.66***	***20.05***	***20.45***	***7 657.81***	***399.37***	***396.99***	***394.36***	***391.46***	***388.28***	***384.83***	***381.08***	***377.02***	***372.65***	***367.96***	***362.93***	***357.55***	***351.81***	***345.69***	***339.19***	***332.30***
	best quess	***3 561.65***	***18.90***	***19.66***	***20.05***	***20.45***	***20.86***	***21.28***	***21.70***	***22.14***	***22.58***	***8 400.84***	***385.86***	***382.13***	***378.09***	***373.74***	***369.07***	***364.06***	***358.71***	***352.99***	***346.90***	***340.42***	***333.55***
	Optimistic	***3 561.65***	***18.90***	***19.66***	***20.05***	***20.45***	***20.86***	***21.28***	***21.70***	***22.14***	***22.58***	***23.03***	***23.49***	***23.96***	***24.44***	***24.93***	***25.43***	***25.94***	***26.45***	***26.98***	***27.52***	***28.07***	***28.64***

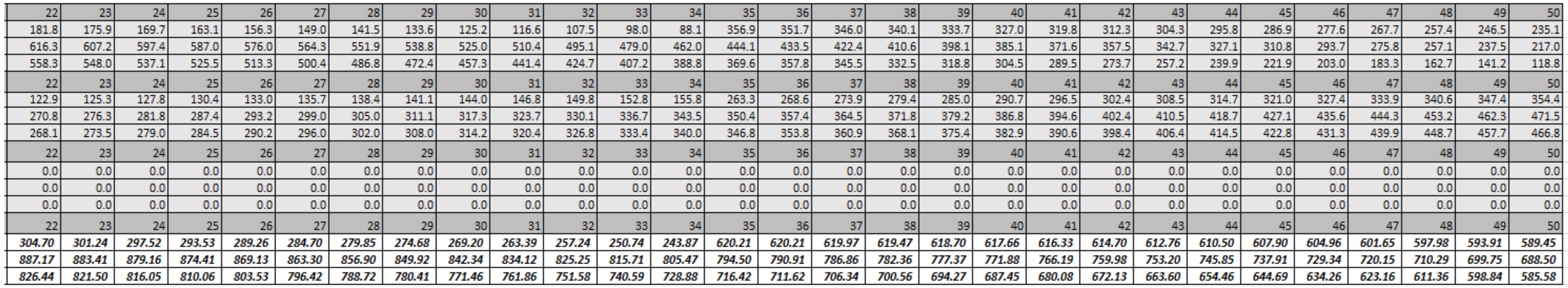
Effects to adjusted allowed income

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Reasonable return	Optimistic	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	232.0	229.1	226.0	222.7	219.2	215.4	211.4	207.1	202.6	197.8	192.8	187.5
	best quess	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	686.4	683.1	679.3	675.1	670.5	665.4	659.9	653.9	647.4	640.5	633.0	624.9
	Pessimistic	190.7	252.3	252.2	258.2	249.1	656.1	653.7	650.9	647.8	644.2	640.4	636.1	631.4	626.3	620.7	614.7	608.2	601.2	593.7	585.7	577.1	568.0
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Investment incentive	Optimistic	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	96.9	98.8	100.8	102.8	104.9	107.0	109.1	111.3	113.5	115.8	118.1	120.5
	best quess	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	213.6	217.8	222.2	226.6	231.2	235.8	240.5	245.3	250.2	255.2	260.3	265.5
	Pessimistic	75.0	78.7	81.9	83.5	85.2	191.5	195.3	199.2	203.2	207.3	211.4	215.6	220.0	224.4	228.8	233.4	238.1	242.8	247.7	252.7	257.7	262.9
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Other Incentives	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Total	Optimistic	***266.46***	***331.84***	***334.88***	***342.50***	***335.09***	***331.33***	***331.13***	***330.79***	***330.31***	***329.68***	***328.88***	***327.93***	***326.80***	***325.50***	***324.01***	***322.34***	***320.47***	***318.39***	***316.11***	***313.60***	***310.87***	***307.91***
	best quess	***266.46***	***331.84***	***334.88***	***342.50***	***335.09***	***331.33***	***331.13***	***330.79***	***330.31***	***329.68***	***900.00***	***900.88***	***901.45***	***901.69***	***901.61***	***901.17***	***900.38***	***899.21***	***897.64***	***895.67***	***893.28***	***890.45***
	Pessimistic	***265.70***	***331.05***	***334.05***	***341.65***	***334.23***	***847.59***	***848.98***	***850.11***	***850.96***	***851.52***	***851.78***	***851.72***	***851.34***	***850.62***	***849.54***	***848.10***	***846.27***	***844.05***	***841.42***	***838.35***	***834.85***	***830.88***

Appendix 1. Cashflows in present values for real option valuation with the fully possibilistic pay-off method. Cash flows presented as k€.



22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4038.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
-1.3	-1.3	-1.4	-1.4	-1.4	-1.4	-1.5	-1.5	-1.5	-1.6	-1.6	-1.6	-1.6	-1.7	-1.7	-1.7	-1.8	-1.8	-1.9	-1.9	-1.9	-2.0	-2.0	-2.0	-2.1	-2.1	-2.2	-2.2	-2.3
-1.3	-1.3	-1.4	-1.4	-1.4	-1.4	-1.5	-1.5	-1.5	-1.6	-1.6	-1.6	-1.6	-1.7	-1.7	-1.7	-1.8	-1.8	-1.9	-1.9	-1.9	-2.0	-2.0	-2.0	-2.1	-2.1	-2.2	-2.2	-2.3
29.2	29.8	30.4	31.0	31.6	32.2	32.9	33.6	34.2	34.9	35.6	36.3	37.0	37.8	38.5	39.3	40.1	40.9	41.7	42.6	43.4	44.3	45.2	46.1	47.0	47.9	48.9	49.9	50.9
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
326.3	318.6	310.4	301.8	292.8	283.2	273.2	262.6	251.5	239.9	227.6	227.6	232.1	236.8	241.5	246.3	251.3	256.3	261.4	266.6	272.0	277.4	283.0	288.6	294.4	300.3	306.3	312.4	318.7
327.6	319.9	311.8	303.2	294.2	284.6	274.6	264.1	253.0	241.4	229.2	227.6	232.1	236.8	241.5	246.3	251.3	256.3	261.4	266.6	272.0	277.4	283.0	288.6	294.4	300.3	306.3	312.4	318.7
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	104.4	106.4	108.6	110.7	113.0	115.2	117.5	119.9	122.3	124.7	127.2	129.8	132.3	135.0	137.7	140.4
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
324.99	317.26	309.08	300.46	291.36	281.78	271.70	261.11	249.98	238.31	226.06	225.96	230.48	235.09	239.79	244.58	249.47	254.46	259.55	264.74	270.04	275.44	280.95	286.57	292.30	298.15	304.11	310.19	316.39
326.27	318.56	310.42	301.82	292.75	283.20	273.15	262.58	251.48	239.84	227.62	225.96	230.48	235.09	239.79	244.58	249.47	254.46	259.55	264.74	270.04	275.44	280.95	286.57	292.30	298.15	304.11	310.19	316.39
29.21	29.79	30.39	31.00	31.62	32.25	32.89	33.55	34.22	34.91	35.60	36.32	37.04	######	144.98	147.88	150.84	153.85	156.93	160.07	163.27	166.54	169.87	173.26	176.73	180.26	183.87	187.55	191.30



22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
181.8	175.9	169.7	163.1	156.3	149.0	141.5	133.6	125.2	116.6	107.5	98.0	88.1	356.9	351.7	346.0	340.1	333.7	327.0	319.8	312.3	304.3	295.8	286.9	277.6	267.7	257.4	246.5	235.1
616.3	607.2	597.4	587.0	576.0	564.3	551.9	538.8	525.0	510.4	495.1	479.0	462.0	444.1	433.5	422.4	410.6	398.1	385.1	371.6	357.5	342.7	327.1	310.8	293.7	275.8	257.1	237.5	217.0
558.3	548.0	537.1	525.5	513.3	500.4	486.8	472.4	457.3	441.4	424.7	407.2	388.8	369.6	357.8	345.5	332.5	318.8	304.5	289.5	273.7	257.2	239.9	221.9	203.0	183.3	162.7	141.2	118.8
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
122.9	125.3	127.8	130.4	133.0	135.7	138.4	141.1	144.0	146.8	149.8	152.8	155.8	263.3	268.6	273.9	279.4	285.0	290.7	296.5	302.4	308.5	314.7	321.0	327.4	333.9	340.6	347.4	354.4
270.8	276.3	281.8	287.4	293.2	299.0	305.0	311.1	317.3	323.7	330.1	336.7	343.5	350.4	357.4	364.5	371.8	379.2	386.8	394.6	402.4	410.5	418.7	427.1	435.6	444.3	453.2	462.3	471.5
268.1	273.5	279.0	284.5	290.2	296.0	302.0	308.0	314.2	320.4	326.8	333.4	340.0	346.8	353.8	360.9	368.1	375.4	382.9	390.6	398.4	406.4	414.5	422.8	431.3	439.9	448.7	457.7	466.8
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
304.70	301.24	297.52	293.53	289.26	284.70	279.85	274.68	269.20	263.39	257.24	250.74	243.87	620.21	620.21	619.97	619.47	618.70	617.66	616.33	614.70	612.76	610.50	607.90	604.96	601.65	597.98	593.91	589.45
887.17	883.41	879.16	874.41	869.13	863.30	856.90	849.92	842.34	834.12	825.25	815.71	805.47	794.50	790.91	786.86	782.36	777.37	771.88	766.19	759.98	753.20	745.85	737.91	729.34	720.15	710.29	699.75	688.50
826.44	821.50	816.05	810.06	803.53	796.42	788.72	780.41	771.46	761.86	751.58	740.59	728.88	716.42	711.62	706.34	700.56	694.27	687.45	680.08	672.13	663.60	654.46	644.69	634.26	623.16	611.36	598.84	585.58

Appendix 2. Cashflows in present values for sensitivity analysis with the fully possibilistic pay-off method. Cash flows presented as k€.

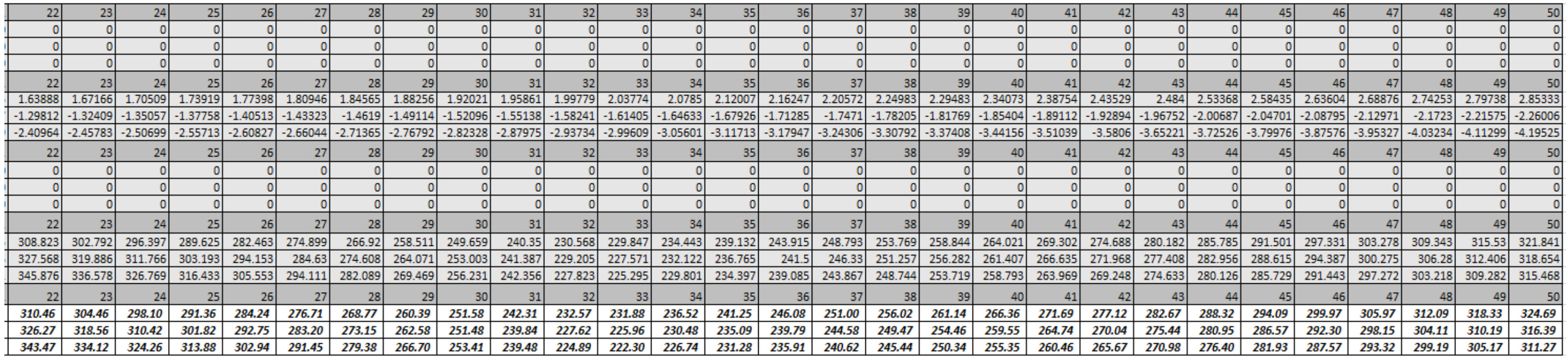
Fixed costs

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
invesment+demolition cost	Pessimistic	3722.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8408.8	0.0	0.0	0	0	0	0	0	0	0	0	0
	best quess	3543.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8011.5	0.0	0.0	0	0	0	0	0	0	0	0	0
	Optimistic	3297.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7465.2	0.0	0.0	0	0	0	0	0	0	0	0	0
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Change in annual costs	Pessimistic	19.7	20.7	21.5	21.9	22.4	22.8	23.3	23.7	24.2	24.7	1.3	1.3	1.3	1.371342	1.39877	1.42674	1.45528	1.48439	1.51407	1.54435	1.57524	1.60675
	best quess	18.0	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	-1.0	-1.0	-1.1	-1.086212	-1.10794	-1.13009	-1.1527	-1.17575	-1.19927	-1.22325	-1.24772	-1.27267
	Optimistic	15.3	16.1	16.8	17.1	17.4	17.8	18.1	18.5	18.9	19.2	-1.9	-1.9	-2.0	-2.016281	-2.05661	-2.09774	-2.13969	-2.18249	-2.22614	-2.27066	-2.31607	-2.36239
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Fixed one time costs	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Uncollecterd return from prematurely demolished network	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	356.7	354.3	351.5	348.535	345.291	341.779	337.987	333.908	329.53	324.843	319.837	314.5
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	390.3	386.9	383.2	379.1784	374.852	370.202	365.215	359.881	354.187	348.122	341.672	334.825
	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	423.1	418.8	414.2	409.1399	403.754	397.989	391.831	385.268	378.286	370.871	363.007	354.681
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Total	Pessimistic	3741.9	20.7	21.5	21.9	22.4	22.8	23.3	23.7	24.2	24.7	8766.8	355.6	352.9	349.91	346.69	343.21	339.44	335.39	331.04	326.39	321.41	316.11
	best quess	3561.7	18.9	19.7	20.0	20.5	20.9	21.3	21.7	22.1	22.6	8400.8	385.9	382.1	378.09	373.74	369.07	364.06	358.71	352.99	346.90	340.42	333.55
	Optimistic	3313.1	16.1	16.8	17.1	17.4	17.8	18.1	18.5	18.9	19.2	7886.4	416.9	412.2	407.12	401.70	395.89	389.69	383.09	376.06	368.60	360.69	352.32

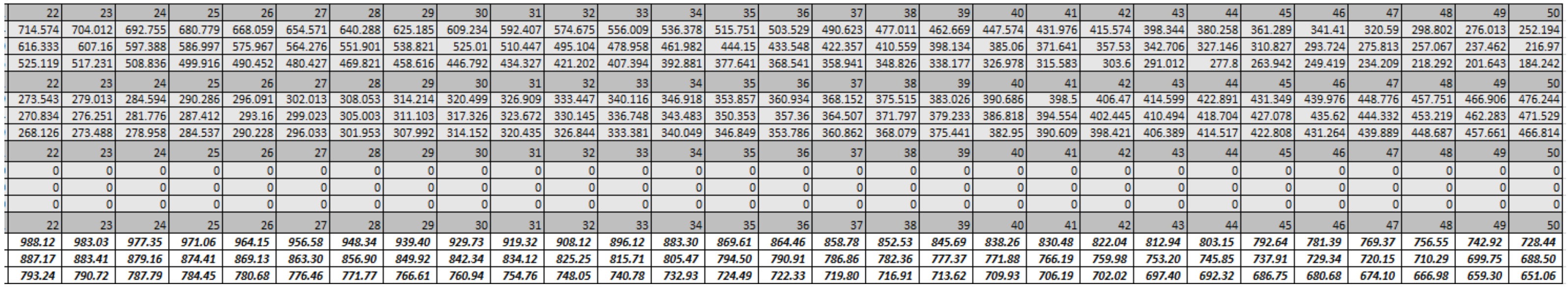
Effects to adjusted allowed income

		0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Reasonable return	Optimistic	229.1	292.2	292.6	298.4	288.9	283.1	280.9	278.4	275.7	272.8	794.9	791.0	786.7	781.9397	776.672	770.895	764.59	757.738	750.32	742.315	733.704	724.464
	best quess	190.7	252.3	252.2	258.2	249.1	243.6	241.6	239.5	237.2	234.7	686.4	683.1	679.3	675.0723	670.454	665.396	659.885	653.903	647.434	640.46	632.965	624.929
	Pessimistic	153.1	215.4	214.7	220.9	212.1	206.8	205.2	203.4	201.4	199.3	585.8	582.8	579.5	575.8737	571.854	567.462	562.685	557.508	551.917	545.898	539.436	532.515
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Investment incentive	Optimistic	76.5	80.3	83.5	85.2	86.9	88.6	90.4	92.2	94.0	95.9	215.7	220.0	224.4	228.8882	233.466	238.135	242.898	247.756	252.711	257.765	262.921	268.179
	best quess	75.7	79.5	82.7	84.3	86.0	87.7	89.5	91.3	93.1	95.0	213.6	217.8	222.2	226.622	231.154	235.778	240.493	245.303	250.209	255.213	260.317	265.524
	Pessimistic	75.0	78.7	81.9	83.5	85.2	86.9	88.6	90.4	92.2	94.0	211.4	215.6	220.0	224.3558	228.843	233.42	238.088	242.85	247.707	252.661	257.714	262.869
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Other Incentives	Optimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
	best quess	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
	Pessimistic	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0	0	0	0	0	0	0	0	0
		0.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13	14	15	16	17	18	19	20	21
Total	Optimistic	305.5	372.5	376.1	383.6	375.8	371.8	371.3	370.6	369.7	368.7	1010.5	1011.0	1011.1	1 010.83	######	######	######	######	######	######	996.62	992.64
	best quess	266.5	331.8	334.9	342.5	335.1	331.3	331.1	330.8	330.3	329.7	900.0	900.9	901.4	901.69	901.61	901.17	900.38	899.21	897.64	895.67	893.28	890.45
	Pessimistic	228.1	294.1	296.6	304.4	297.2	293.7	293.8	293.8	293.6	293.3	797.2	798.5	799.5	800.23	800.70	800.88	800.77	800.36	799.62	798.56	797.15	795.38

Appendix 2. Cashflows in present values for sensitivity analysis with the fully possibilistic pay-off method. Cash flows presented as k€.



22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
1.63888	1.67166	1.70509	1.73919	1.77398	1.80946	1.84565	1.88256	1.92021	1.95861	1.99779	2.03774	2.0785	2.12007	2.16247	2.20572	2.24983	2.29483	2.34073	2.38754	2.43529	2.484	2.53368	2.58435	2.63604	2.68876	2.74253	2.79738	2.85333
-1.29812	-1.32409	-1.35057	-1.37758	-1.40513	-1.43323	-1.4619	-1.49114	-1.52096	-1.55138	-1.58241	-1.61405	-1.64633	-1.67926	-1.71285	-1.7471	-1.78205	-1.81769	-1.85404	-1.89112	-1.92894	-1.96752	-2.00687	-2.04701	-2.08795	-2.12971	-2.1723	-2.21575	-2.26006
-2.40964	-2.45783	-2.50699	-2.55713	-2.60827	-2.66044	-2.71365	-2.76792	-2.82328	-2.87975	-2.93734	-2.99609	-3.05601	-3.11713	-3.17947	-3.24306	-3.30792	-3.37408	-3.44156	-3.51039	-3.5806	-3.65221	-3.72526	-3.79976	-3.87576	-3.95327	-4.03234	-4.11299	-4.19525
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
308.823	302.792	296.397	289.625	282.463	274.899	266.92	258.511	249.659	240.35	230.568	229.847	234.443	239.132	243.915	248.793	253.769	258.844	264.021	269.302	274.688	280.182	285.785	291.501	297.331	303.278	309.343	315.53	321.841
327.568	319.886	311.766	303.193	294.153	284.63	274.608	264.071	253.003	241.387	229.205	227.571	232.122	236.765	241.5	246.33	251.257	256.282	261.407	266.635	271.968	277.408	282.956	288.615	294.387	300.275	306.28	312.406	318.654
345.876	336.578	326.769	316.433	305.553	294.111	282.089	269.469	256.231	242.356	227.823	225.295	229.801	234.397	239.085	243.867	248.744	253.719	258.793	263.969	269.248	274.633	280.126	285.729	291.443	297.272	303.218	309.282	315.468
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
310.46	***304.46***	***298.10***	***291.36***	***284.24***	***276.71***	***268.77***	***260.39***	***251.58***	***242.31***	***232.57***	***231.88***	***236.52***	***241.25***	***246.08***	***251.00***	***256.02***	***261.14***	***266.36***	***271.69***	***277.12***	***282.67***	***288.32***	***294.09***	***299.97***	***305.97***	***312.09***	***318.33***	***324.69***
326.27	***318.56***	***310.42***	***301.82***	***292.75***	***283.20***	***273.15***	***262.58***	***251.48***	***239.84***	***227.62***	***225.96***	***230.48***	***235.09***	***239.79***	***244.58***	***249.47***	***254.46***	***259.55***	***264.74***	***270.04***	***275.44***	***280.95***	***286.57***	***292.30***	***298.15***	***304.11***	***310.19***	***316.39***
343.47	***334.12***	***324.26***	***313.88***	***302.94***	***291.45***	***279.38***	***266.70***	***253.41***	***239.48***	***224.89***	***222.30***	***226.74***	***231.28***	***235.91***	***240.62***	***245.44***	***250.34***	***255.35***	***260.46***	***265.67***	***270.98***	***276.40***	***281.93***	***287.57***	***293.32***	***299.19***	***305.17***	***311.27***



22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
714.574	704.012	692.755	680.779	668.059	654.571	640.288	625.185	609.234	592.407	574.675	556.009	536.378	515.751	503.529	490.623	477.011	462.669	447.574	431.976	415.574	398.344	380.258	361.289	341.41	320.59	298.802	276.013	252.194
616.333	607.16	597.388	586.997	575.967	564.276	551.901	538.821	525.01	510.447	495.104	478.958	461.982	444.15	433.548	422.357	410.559	398.134	385.06	371.641	357.53	342.706	327.146	310.827	293.724	275.813	257.067	237.462	216.97
525.119	517.231	508.836	499.916	490.452	480.427	469.821	458.616	446.792	434.327	421.202	407.394	392.881	377.641	368.541	358.941	348.826	338.177	326.978	315.583	303.6	291.012	277.8	263.942	249.419	234.209	218.292	201.643	184.242
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
273.543	279.013	284.594	290.286	296.091	302.013	308.053	314.214	320.499	326.909	333.447	340.116	346.918	353.857	360.934	368.152	375.515	383.026	390.686	398.5	406.47	414.599	422.891	431.349	439.976	448.776	457.751	466.906	476.244
270.834	276.251	281.776	287.412	293.16	299.023	305.003	311.103	317.326	323.672	330.145	336.748	343.483	350.353	357.36	364.507	371.797	379.233	386.818	394.554	402.445	410.494	418.704	427.078	435.62	444.332	453.219	462.283	471.529
268.126	273.488	278.958	284.537	290.228	296.033	301.953	307.992	314.152	320.435	326.844	333.381	340.049	346.849	353.786	360.862	368.079	375.441	382.95	390.609	398.421	406.389	414.517	422.808	431.264	439.889	448.687	457.661	466.814
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50
988.12	***983.03***	***977.35***	***971.06***	***964.15***	***956.58***	***948.34***	***939.40***	***929.73***	***919.32***	***908.12***	***896.12***	***883.30***	***869.61***	***864.46***	***858.78***	***852.53***	***845.69***	***838.26***	***830.48***	***822.04***	***812.94***	***803.15***	***792.64***	***781.39***	***769.37***	***756.55***	***742.92***	***728.44***
887.17	***883.41***	***879.16***	***874.41***	***869.13***	***863.30***	***856.90***	***849.92***	***842.34***	***834.12***	***825.25***	***815.71***	***805.47***	***794.50***	***790.91***	***786.86***	***782.36***	***777.37***	***771.88***	***766.19***	***759.98***	***753.20***	***745.85***	***737.91***	***729.34***	***720.15***	***710.29***	***699.75***	***688.50***
793.24	***790.72***	***787.79***	***784.45***	***780.68***	***776.46***	***771.77***	***766.61***	***760.94***	***754.76***	***748.05***	***740.78***	***732.93***	***724.49***	***722.33***	***719.80***	***716.91***	***713.62***	***709.93***	***706.19***	***702.02***	***697.40***	***692.32***	***686.75***	***680.68***	***674.10***	***666.98***	***659.30***	***651.06***