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Risks and Prospects of Smart Electric Grids Systems measured with Real Options

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Älykkäiden sähköverkkojärjestelmien riskit ja näkymät reaalioptioilla mitattuna

Tiivistelmä

Tämä väitöskirja analysoi sähkön hinnan riskitasoja ja arvioi reaalioptioiden arvostusmenetelmään perustuen älykkäiden sähköverkkojen tutkimus- ja tuotekehitysprojekteja ja teknologiamahdollisuuksia. Value at Risk –menetelmällä on arvioitu sähkön dynaamiseen hinnoitteluun sisältyvä riski. Prosessi koostuu Historic- ja Monte Carlo -simulaatioista käyttäen hyväksi Nordpool-Spotin markkinahintatietoja ja laskemalla voittojen ja tappioiden jakauman kvantiili tavoitellulle ajanjaksolle. Tutkimuksilla, kyselyillä ja Case-toimintatutkimuksilla kerättyjä tietoja käytettiin tulevaisuuden skenaarioiden hahmotteluun sekä yritysten johtoon ja strategiaan vaikuttavien tekijöiden tutkimiseen. Näitä tekijöitä on sijoitettu paremmuusjärjestykseen käyttämällä kriittisen tekijän indeksointia sekä analyyttista hierarkiaprosessia älykkäiden sähköverkkojen teknologian ja palveluiden arvioimiseksi.

Sähköhinnan riskianalyysin mukaan volatiliteetti on laskenut Nordpool-markkinan perustamisesta lähtien ja korrelaatio keskenään yhdistettyjen alueiden välillä on vahva.. Taustatestauksen tulosten perusteella voidaan päätellä, että VaR-menetelmät, joita käytetään yleisesti pankkien salkunhallinnan johtamisessa, ovat yleisesti käytettyjä pankkien salkunhallinnan johtamisessa, ovat sopivia älykkäiden sähköverkkoprojektien markkinariskien mittaamiseen. Strateginen analyysi osoitti joustavuuden kasvavaa kysyntää resurssien allokoinnissa. Tämä työ korostaa empiiristen analyysimenetelmien ja rahoituksen hintariskimallien käyttämisen käytännöllisyyttä investointien arvottamisessa teollisuusyritysten, markkinasijoittajien sekä yksittäisten kuluttajien näkökulmasta. Tällainen yhdistetty viitekehys auttaa vähentämään uuden teknologian kehitysprojektien riskiä. Se auttaa muotoilemaan vastauksia todennäköisiin ja epätodennäköisiin skenaarioihin, jotka sisältävät moniulotteisia päätöksenteon parametreja. Se tarjoaa myös työkaluja koherenssin saavuttamiseen älykkäiden sähköverkkojen eri sidosryhmien erilaisten strategioiden välillä.

Asiasanat

Energiatalous, Reaalioptiot, Älykäs sähköverkko, Päätöksenteko, Riskienhallinta, Investointien suunnittelu

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Risks and Prospects of Smart Electric Grids Systems measured with Real Options

Abstract: The purpose of this dissertation is to analyse electricity price risk levels and using Real Option pricing method, evaluate smart grid R&D projects and technology opportunities. Risk implied in dynamic pricing of electricity is appraised by Value at Risk measures. The process consists of performing Historic and Monte Carlo simulations using Nordpool-Spot market price data and calculating the quantile of the distribution of profit and loss over a target horizon. Data collected from surveys, questionnaires and action research case studies was used to outline future scenarios and examine factors affecting companies' management and strategy. These factors are ranked using critical factor indexation and analytical hierarchy process to assess the potential to develop smart grid technologies and services.

Electricity price risk analysis showed decreasing volatility since the establishment of Nordpool Market and strong correlation among interconnected regions. Based on the backtesting results it can be derived that VaR measures that are commonly used in banks' portfolios management are suitable for measuring market risk in smart grid projects. Strategic analysis showed increased demand for flexibility in resource allocation. This work highlights the practicality of using empirical analysis methods and financial price risk models to value investments from the perspective of manufacturing companies, market investors and individual consumers. Such combined framework helps mitigate the risk of new technology development projects. It assists to formulate responses to likely and unlikely scenarios with multi-factor decision parameters. It also provides tools to achieve coherency among diverse strategies between smart grid stakeholders.

Keywords

Energy economics, Real Options, Smart grid, Decision making, Risk management, Investment planning

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With warmest regards,

Vaasa, March 2016

Rayko Toshev

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Abbreviations:

AHP	Analytic hierarchy process
AMI	Advanced metering infrastructure
CAMP	Capital asset pricing model
CFaR	Cash flow at risk
CFI	Critical factor index
CMI	Competitive manufacturing index
DCF	Discounted cash flow
DER	Distributed energy resources
DSM	Demand side management devices
DSS	Decision support system
EE	Energy efficiency
HS	Historical simulation
ICT	Information and communication technology
IT	Information technology
KMI	Knowledge management index
KPI	Key performance indicator
MCS	Monte Carlo simulation
MU	Market uncertainty
NPV	Net present value
OPM	Options pricing model
R&D	Research and development
RAL	Responsiveness, agility, and leanness model
RES	Renewable energy sources
RF	Risk factors
RO	Real options
S&R	Sense and Respond
SCA	Sustainable competitive advantage
SET	Strategic energy technology
SG	Smart grid
SME	Small and medium enterprises
SP	Strategic planning
ST	Strategic types
TM	Technology management
TSO	Transmit system operators
TU	Technological uncertainty
VaR	Value at risk
VPP	Virtual power plant

1 INTRODUCTION

The energy sector is currently experiencing fundamental changes. Fossil energy resources are diminishing while the global population and energy demands are increasing at a steady pace. We are approaching a human population figure of eight billion and, at the same time, countries seek independence from foreign energy imports. There is also a vital need to reduce pollution. Such an environment is characterized by the risks of volatile market prices, uncertainty of energy sources, disruptive technologies and natural disasters. This clustering of major risk factors, combined with financial market turbulence and social unrest, requires a focus on policies that are needed for intelligent energy usage.

A robust and comprehensive method combining probable risk assessment and sufficient scenario analysis is a very effective instrument for understanding the quantitative implications of strategic decisions, and thus supporting companies' decision-making in uncertain contexts.

1.1 Stimulus

The question of how to find a solution to such contradictory trends is stimulating research work in a number of fields, such as renewable energy generators and storage capacities combined with smarter electric-grid systems. This dissertation focuses on a number of technological innovations in electricity generation and distribution, commonly known as a "smart grid".

The smart grid exerts a huge transformative influence. It is receiving consideration from utilities and institutions across Europe and North America, such as the Electric Power Research Institute, the Global Smart Grid Federation (GSGF) Smart Grids European Technology Platform, etc. The smart grid has the potential to transform the way we generate and consume electricity; as it contains numerous new elements, however, its core value scheme remains a trial on a large scale (Faruqui, Hledik & Sergici 2009).

A set of current developments are about to change the situation and put the electricity networks under pressure to change. Reasons for modification are both external to the network, like preparing for a low-carbon future, as well as internal, like the need for the replacement of an ageing infrastructure. The following issues are the focus of energy transformation: (EEGI 2010)

– Climate change and climate policy;
– Risk analysis and security of supply;
– Sustainability;

– Energy and electricity markets — liberalization, (de- or re-) regulation;
– Demand response;
– Energy and economic growth;
– Economics of energy infrastructure;
– Environmental policy;
– Energy policy;
– Energy derivatives;
– Forecasting energy demand;
– Elasticity of supply and demand in energy markets;
– Energy elasticity.

Smart-grid deployment, as a large-scale project, contains a great number of uncertainties. On top of project management uncertainties concerning schedules, resource planning and execution, uncertainties associated with new products and technology performance can also have a significant impact. Policymakers and business companies are combining their efforts to lead the installation of large numbers of dispersed, clean generation systems. Conducting risk and sensitivity analysis for costs and benefits is imperative in the decision-making process (Mukherjee 2008). To meet the goal of resource adequacy, companies could adopt fast strategies that may change the outcome of their business case significantly (Doz & Kosonen 2008).

As Ketter et al. (2009) point out, the strategy of companies in the electricity sector must be consequently modified. While the hierarchical command-and-control approach works well for large-scale generation facilities, flexible and self-organizing control is better for small consumers. The future grid will have to combine the distribution and control of both high-voltage grids and independent, lower voltage sub-grids. The concept of the smart grid is currently evolving, as it had to lay the foundations for future development (Block et al. 2009).

The enterprises have had to implement a dynamic yet sensitive approach and the corresponding resource-allocation activities, allowing them to proactively monitor technologies and use effective decision-support tools to help them act in a timely manner. Future products and services will require more coordinated management, better decision-making and improved predictability of the state of the energy system. The question of how to implement a competitive strategy for future energy grids prompted the author to investigate market-risk factors.

In order to develop smart-grid solutions, energy companies require strategic agendas, action plans and technology road maps for decision-making. They need a modelling framework that enables risk assessment and the evaluation of investment returns. Companies in the sector also need prompt responses to emerging technologies, so that all key decision constraints can be considered and managed effectively. Such processes enhance their strategic foresight at a time when innovation and change are combined with increased market uncertainty.

The Nord Pool Spot market is the world's biggest market for buying and selling power in the Nordic and Baltic regions. The developments in electricity-trading markets are giving individual consumers the possibility to participate in the market as "active generation nodes" and sell surplus energy or demand a limiting reaction. Development of services is essential for progress towards the "smart grid" (NP Spot 2010).

As financial markets' transaction times approach picoseconds, the electricity prices change aims at minutes, seconds and real-time traffic measurement. The monitoring and process automation of smart grids and data for a large number of consumers allows for a great degree of technological innovation. As logical this appears, it is difficult for small-component manufacturing companies to innovate in such large-scale projects. Many of the risks faced by the sector require national- and government-level actions, which frustrates companies' strategic decision-making. Managers and R&D are focused on quarterly and annual indicators, and they are far outside the scope of politics. Together with risks, great opportunities are provided for technological innovators in the creation of companies' strategies.

Open electricity markets, where decisions are decentralized and the outcomes of demand-supply equilibrium depend on the actions of groups of "prosumers" (producing consumers), create a new environment for companies to enhance strategic analysis with risk management, scenario planning and simulation as suitable tools. This study supports the management necessity of conducting a scenario analysis based on the solid foundation of forward price, volatility and options analysis.

1.2 Research objectives and questions

This thesis has three main objectives. Firstly, to evaluate the electricity-market price risk of Nord Pool Spot price levels in Finland, Sweden and Norway as interconnected regions.

Secondly, to use those risk levels in real-options valuation concepts and traditional financial-valuation techniques for the smart grid's technological evolution. This work thereby attempts to provide analysis of smart-grid opportunities and generate scenarios for technology transition, in order to reveal which combination of capabilities has the maximum potential, to discuss risk factors together with costs and how innovative technology will influence the grid system's evolution.

Consequently, the third objective is to utilize those analyses together with managers for a strategic planning purpose, applying them in case studies of electrical-component manufacturing companies for classifying strategic decision priorities and critical factors. The main research objectives are presented in Table 1.

Table 1. List of research objectives

Research objective
1. Evaluate the electricity market price-risk levels in Finland, Sweden and Norway.
2. Demonstrate the existing real-options valuation techniques and concepts in a case study of component manufacturing companies.
3. Provide analysis of smart-grid technological opportunities and generate scenarios for a transition to the smart-grid technology.

From this scope of objectives, the following questions were formed and discussed in this dissertation:

RQ1: What are the volatility levels of electricity market prices in the interconnected Nordic countries?

RQ2: How does Nordic electricity market affect the volatility of electricity prices?

RQ3: How does prise risk and technological uncertainty affect company strategies?

RQ4: What is the value of investment in "smart-grid home" systems?

RQ5: How will the progress of additive manufacturing affect "smart grid" technologies?

1.3 Research design

This dissertation reflects on the principle of positivism in its research philosophy. It uses a deductive approach to solve a specific, empirical problem, identifying risk levels and critical factors for appropriate resource allocation in strategic management. This work predominantly presents research in the field of professional and applied science. It uses the theoretical foundations of information and computation to study various business models and associated decision-making processes in uncertain environments.

The thesis uses a mixed research paradigm. It combines both quantitative and qualitative analyses (see Figure 1) and evaluates the different aspects of investments in innovative technologies. Probabilistic market risk assessment and investment project valuation use analytical methods such as historical simulation, Monte Carlo simulation and binomial approximation. In addition to that, a qualitative analysis of the smart-grid industry and related government policies is performed in order to enhance the investment decision-making process. The qualitative section aims to offer a better understanding of the present and future development of smart-grid technologies.

Observations, conversations and unstructured discussions were piloted as qualitative methods to study how optimal resource allocation can be achieved while using an improved strategic decision-making process such as a critical factor index (CFI) in the management of innovation departments.

The research approach taken is to gather a critical mass of information for the development of an intelligent electrical distribution system. Following induction logic, the researcher tries to interpret the existing environment of electricity markets and formulate objective rules for the evolution towards smart grids and renewable energy generation

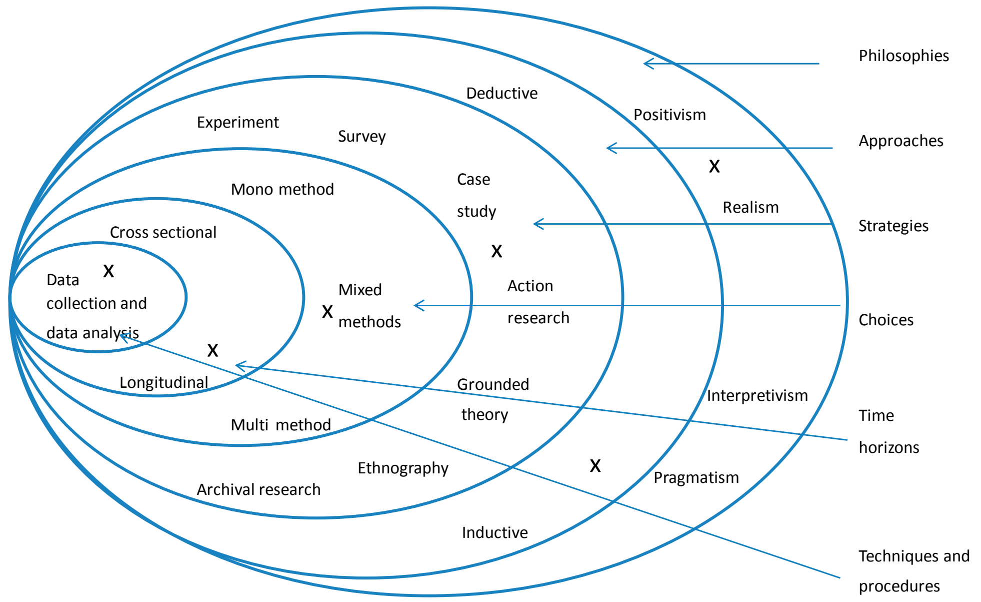

Figure 1. Mapping research methods on the research onion

Factors discussed are common market-risk measures and capital budgeting concepts, such as value at risk, cost of capital, time value of money, and discount cash flow. This work uses the concepts of financial options theory, and more specifically the real options concept. The results part presents the value at risk (VaR) Black-Scholes options pricing model (OPM) and binomial approximation figures. These methods are commonly used to value real options in projects or physical assets.

Multiple case studies were chosen as the research approach for this part of the dissertation. The case study is a favoured strategy when "how" or "why" questions are being asked, when the researcher has little control over events or when the focus is on a contemporary phenomenon in a real-life context (Eisenhardt 1991).

A secondary data set was extracted from the day-ahead trading at Elspot, the system price for the quantitative methods and techniques used in the thesis. A risk explanatory longitudinal study of the price of energy was conducted, together with a risk evaluation, for the collection of historical information. Macro level electricity-price risk measures are compared between countries and regions. This research presents several case studies. Surveys were carried out in the electrical component manufacturing companies, which identified the main decision-making factors in a time-based strategy within an organization's hierarchy in order to support the knowledge-based resource allocations. The electricity-price market risk was observed over the period of case-study data collection in order to triangulate and feed scenario planning and simulation processes.

Due to the diversity of issues and methods applied, this work discusses a number of academic sub-disciplines of economics, as follows.

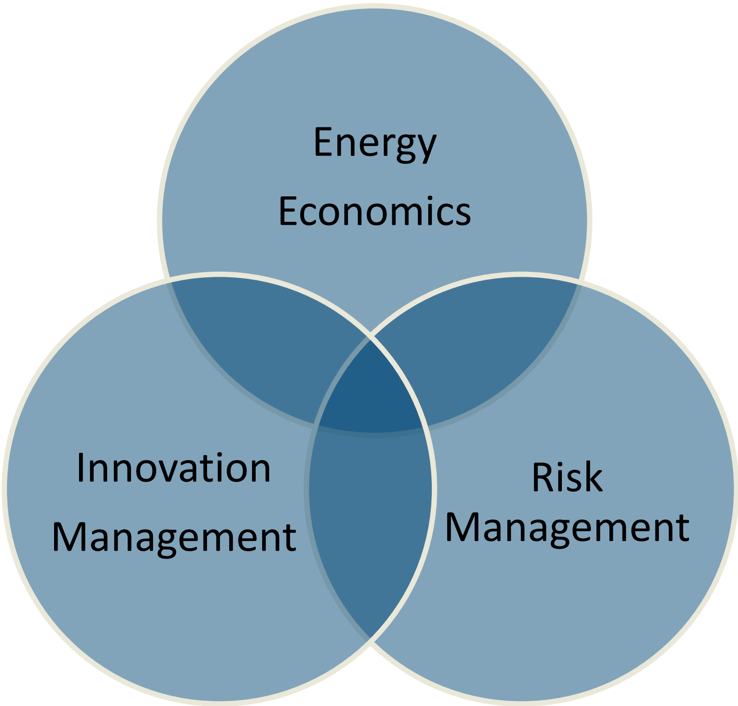

Figure 2. Research disciplines

1.3.1 Energy economics

Energy economics is a broad scientific subject area that includes topics related to the supply and use of energy in societies. From the list of main topics of economics, some relate strongly to energy economics:

- Finance;
- Industrial organization;
- Resource economics;
- Econometrics.

Energy economics also draws heavily on energy engineering, geology, political sciences, ecology, etc.

1.3.2 Innovation management

This discipline describes management practices in innovation; it refers to developing both product and process innovation (Tidd, Pavitt & Bessant. 2001). Without the proper processes, it is not possible for R&D to be efficient; innovation management includes a set of tools that allow managers and engineers to cooperate with a common understanding of goals and processes. Innovation management allows the company to respond to an external or internal opportunity, and to use its creative efforts to introduce new ideas, processes or products. (Kelly 1978)

1.3.3 Risk management

Risk management involves identification, assessment and prioritization of risks. Subsequently, the task of risk experts is to synchronize a company's activities in order to minimize, monitor and control the probability of disastrous events occurring. It also considers how to maximize the realization of opportunities and the economic potentials of resources (Campbell et al. 2007, Rabaey 2012). Decision-making and risk communication is also a complex cross-disciplinary academic field.

In linking these research areas, a company investment can be referred to as a portfolio, which in the future could enable, but not obligate, the firm to expand in different directions (Kim & Kogut 1996). McGrath and Nerkar (2004) have given evidence that firms' R&D investments create a pool of options, the underlying asset of which is the present value of the cash flows that can be acquired through subsequent discretional investments. As there is no obligation to exercise these options, their value goes up with the increase in variance of the returns on the underlying assets. (Grandi & Oriani 2009)

One significant factor in explaining a company's market strategy is the volatility of the expected returns from R&D investments. Such volatility can arise from various sources of uncertainty (Huchzermeier & Loch 2001). This dissertation discusses previous studies that have separated the environmental uncertainty that is relevant to technological innovation into its market and technological domains (Abernathy & Clark 1985, Anderson & Tushman 2001, Oriani & Sobrero 2008).

Market uncertainty is connected to the volatility of the electricity prices. It is subject to a set of exogenous factors, such as the economic cycle and demographic changes (Huchzermeier & Loch 2001). Technological uncertainty increases when there is no clear or single "state of the art technology" to dominate in the industry (Tushman & Rosenkopf 1992, Anderson & Tushman 2001). The actual situation obtaining in many industries is that one or more alternative technologies compete for the companies' budgets. Under such conditions, firms must choose and implement a particular technology with which to compete on the future market (Krishnan & Bhattacharya 2002). Adopting a certain technology can be crucial for a firm's survival and defines the returns from R&D investments (Suarez & Utterback 1995, Tegarden, Hatfield & Echols 1999). Technological uncertainty increases with the number of competing technologies that are potentially available (Oriani & Sobrero 2008). These two categories of uncertainty are not mutually exclusive and can influence the strategic decision-making balance (Clark 1985). Some authors, such as Anderson and Tushman (2001), noted that market and technological uncertainties can have separate effects on the performance and survival of companies. As Helo (2003) startes, technological trajectories and uncertainty creates an additional layer of risk beyond market uncertainty for the firms (Anderson & Tushman 2001). There may be growing demand for a company's innovative products and it can still fail on the market if it is unable to implement the dominant technology rapidly (Tegarden, Hatfield & Echols 1999).

Managers have at least two alternatives to deal with market uncertainty (Kulatilaka & Perotti 1998, Folta & O'Brien 2004). One is to delay the investment of extra resources in R&D, thus holding an option to wait (McDonald & Siegel 1982). The other is to acquire a growth option by investing in small portions' R&D. (Oriani & Sobrero 2008)

In the case of higher technological uncertainty, a company may decide not to invest in any more R&D, waiting instead for the development of the technology. Then again, a company may allocate incremental R&D investments to the creation of an option allowing it to switch to alternative technologies (McGrath 1997). Financial investors on the market appraise the company based on its R&D decisions. (Oriani & Sobrero 2008)

In this line of thought, market and technological uncertainties and real options can be linked within a framework as represented in Figure 3.

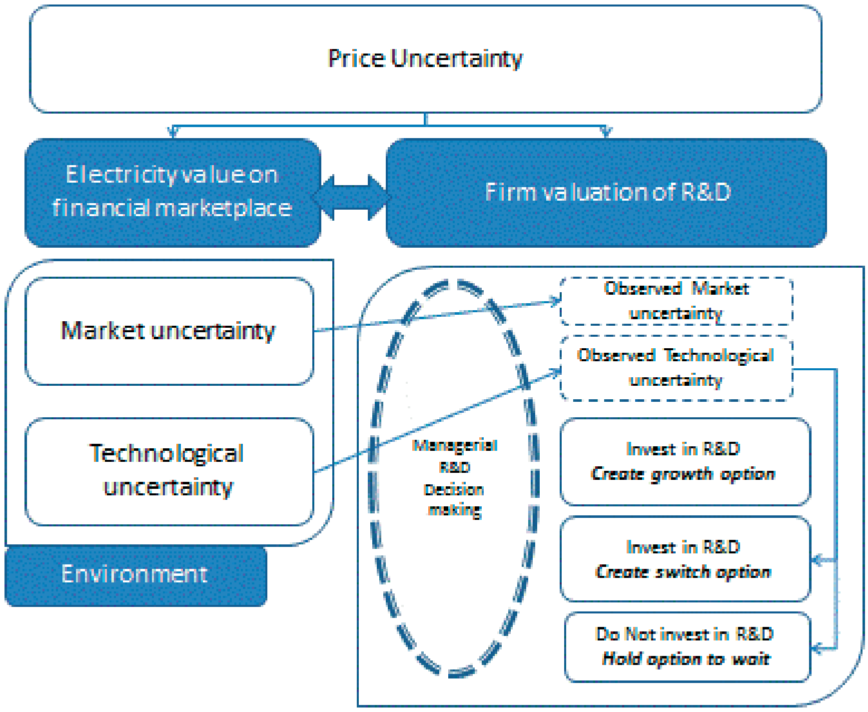

Figure 3. Research framework

The next section describes how the theoretical model was built from this framework.

1.4 Research gap and hypothesis

Most of the existing budgeting techniques use partial equilibrium with the assumption of perfect market conditions. Common methods used to quantify general market risk levels for a company's project management include the net present value (NPV), the breakeven point, value at risk measures and real options analysis.

Discounted cash flow (DCF) and the other traditional capital budgeting methods estimate the value of future cash flows. Often, their modelling conditions determine a constant level of uncertainty for the duration of the R&D project. Such modelling overlooks managerial flexibility and usually decreases the net present value with the price of flexibility. However, many different scenarios can present themselves throughout a project's lifespan, and how the company responds to them affects the cost and success of the project. Predicting future cash flows is a complicated task.

In order to evaluate managerial flexibility, this thesis uses real options analysis methods. The methods calculate the NPV value with flexibility and model the evolution of the project value over time and during periods of uncertainty. That creates a decision tree and allows for project modifications. Such a capability increases the project value because unfavourable scenarios can be evaded (Tsui 2005).

The development of innovative technologies can be very costly and it may take several years before economic profit appears. An R&D process can last a very long time and frequently include research and development, testing and commercialization phases. During that time, various risks can arise and many decisions have to be taken according to the stream of new information.

A realistic and accurate investment valuation model to prioritize projects within a company's limited resources allows decision-makers to constantly manage the uncertainty that arises. In financial terms, the flexibility to change equals the exercise of an option when it is profitable. In existing R&D projects, the object of change is called a "real option" because this object is a real asset (Tsui 2005).

When investing in R&D, a company acquires the present value of future cash flows and creates some real options. Nevertheless, the net effect of uncertainty on the cost of the investment is difficult to predict, especially for small and medium-sized companies, where strategic decisions are often made without use of sophisticated techniques. When the investment decision is exercised, it cancels the option to defer. With the rise of the uncertainty level, the value of all options increases and managers have to choose the ones that best fit their strategies (Oriani & Sobrero 2008).

The valuation of an investment must count both its strategic value and the value of not investing (Kulatilaka & Perotti 1998: 1029).

V(R&D), the valuation of a company's investment in R&D, can be stated as a function of the NPV:

- the growth option -G
- the option to switch -S
- option to wait -W

To integrate the impact of different sources of uncertainty into the models of Kulatilaka and Perotti (1998), as well as those of Folta and O'Brien (2004), the analysis is extended to incorporate the effect of technological uncertainty (TU) and market uncertainty (MU) on the value of the growth option, the option to wait and the option to switch (Henriques & Sadorsky 2011).

Higher discount rates are used for the NPV as the project's uncertainty and risk rises. It is assumed that the NPV is negatively affected by MU. That is not the case for TU, which is not correlated to the economic cycle but is industry specific and depends on technological designs and innovation breakthrough. It generates industry sector risks that may be avoided by diversifying the portfolio (Oriani & Sobrero 2008).

The option to wait becomes more valuable with an increase in market and technological uncertainty as the investment is irreversible, while the choice to defer from the investment is reversible (McDonald & Siegel 1982).

The growth option is exercised when there is an increase in demand. It limits the potential loss of the initial investment, so its value rises with market uncertainty. The potential profit from future growth has no upper limit (Kulatilaka & Perotti 1998).

In the case of electric grid technology and a transition to smart-grid systems, innovation speed depends on having quick access to existing expertise and knowledge. Therefore, the value of a company's project is influenced by the change of the price of the option to switch to a new technology. For the company, it is even more significant to obtain a novel technology as soon as possible. Market uncertainty does not affect that relationship, as it is not directly linked to the technological life-cycle curve; moreover, it has no impact on flexibility (Oriani & Sobrero 2008).

In such a way, the present value of an R&D project with real-options flexibility included is equal to:

$$V(R\&D) = NPV(MU) + \delta G(MU) + \kappa S(TU) - W(MU, TU) \quad (1)$$

This equation helps us to express the hypotheses about the different effects that market and technological uncertainty have on the evaluation of such a project.

H1*: An increase in the volatility of electricity market's price will increase the value of technology investment.*

Technological uncertainty influences the value of an R&D investment in a different way than market uncertainty does. TU normally increases the value of the option to switch and to wait, and managers can create value by waiting for new information, or by investing in R&D to generate an option to switch to a different technology.

H2: *Strategic choices of companies are affected by electricity market price volatility.*

H3: *Companies' operational competitiveness is affected by technological uncertainty.*

1.5 Structure of the thesis

This thesis performs risk analysis and economic valuation of R&D investments in smart-grid technology. It evaluates the potential of shifting a manufacturing strategy towards smart-grid innovation projects. Correspondingly, it discusses whether the investment is beneficial. The costs and the potential benefits of these projects are inherently uncertain and difficult to quantify, as is the case with any new technology.

This dissertation is divided into six chapters, the first of which introduces the motivation behind the research and presents the research philosophy and approach. The organization of the Nord Pool Spot market and electricity trading is described in Chapter Two, together with a discussion on energy policies and regulations of different countries, offering an outline of a literature review on the subject. Presented here are theoretical backgrounds of conventional and renewable energy-risk evaluation and strategic planning in the sector. Chapter Three describes the methodological design of the study, allowing for sensitivity analysis of the important aspects of modelling to be conducted. Chapter Four presents the results of data analysis and case studies. The final part draws the conclusions and outlines further research possibilities.

1.6 Expected contributions

This work contributes to the research area in several ways. Firstly, it incorporates theoretical models based on market-price risk and real-options logic to unravel different components of the connections between R&D investments, uncertainty and a firm's decision-making process. Secondly, it tests four hypotheses that are consistent with the theoretical model on a data set, including three countries and two case companies that manufacture electrical components. These results reveal new knowledge on how financial markets' risk and technological uncertainty can enhance a manager's decisions on resource allocation.

This dissertation produces a body of valuable research data and statistics to increase confidence that a market mechanism can be firmly implemented into electric-grid systems. The described process can be used as an organizational tool for companies in the electricity sector, combining market-price risk with innovation management to create a proactive approach in technology adaptation. It also provides tools to achieve coherency among diverse strategies between smart-grid stakeholders.

Proposed here are several assumptions about how the logic of such a framework can be expanded by calculations for additional systemic risk factors, like wind-turbine component failures or strategic governmental policy. Future modification of the presented models can be tested to validate whether extending risk factors works similarly for other industries.

The conducted research assists firms in developing consistent scenarios for strategic analysis. Some of the methods use scenarios' designs for electrical components' producers and consumers. The models are bootstrapping in a simulation environment with real historical price data. Such scenario planning provides a low-risk framework that combines real-world data and simulated markets to clarify uncertainty factors and help build an intelligent energy grid for the future.

This work describes how risk measures can be used in resource allocation and innovation management to help companies to assess technological advances in a rapidly changing environment.

The thesis brings together various tools to enhance projects' operational efficiencies. Technological advances in smart grids are compared in order to reveal what combination of capabilities has the most potential. Building a robust framework with sufficient research and validations helps companies to shift their strategies from intuitive to more analytical ones.

1.7 Justification for the research

Examining the performance of electricity prices' risk helps strategic management to move from an intuitive to more analytical decisions, and increase confidence in economic projections for electric-grid innovations.

This research can be used to evaluate emerging innovative technologies with respect to the market risk. Future operations' and strategy planning requires better understanding and improved predictability of the state of the power system. Economic modelling with price risk assessment is vital for justifying investments in the energy sector. Such investments are needed to accelerate the innovation pace and increase the number technology adaptors.

1.7.1 Power grid infrastructure

The unique physical attributes of electricity, and the government regulation of its supply and sale, have prevented the development of smart grids in the past. This situation is now beginning to change across the world. Due to the difficulty of storing electricity, the prices can vary substantially. There have been instances where prices have fallen to below €5.00 per megawatt hour (MWh) for short periods while, on other occasions, prices have risen to over €250.00 per MWh.

Electricity demand varies according to many factors. Daylight loads are higher than night-time loads, while weekend usage is less than that of weekdays. There are also seasonal variations and occasional demand spikes caused by other factors, such as television schedules (see Figure 4). In the longer term, upturns in economic activity are reflected in increased electricity usage. Peak national demand normally occurs during winter weekdays between 17:00 and 17:30 and can reach 48GW, while demand can drop to 16GW on a warm day in the summer.

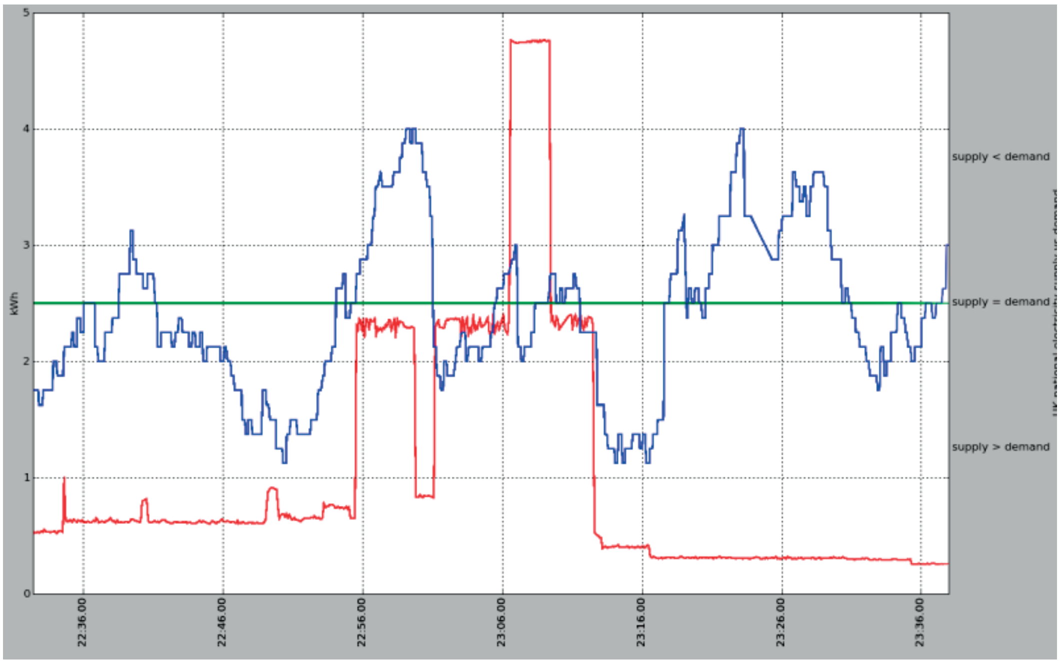

Figure 4. Electricity Demand vs.Supply Real grid data example (Source: Nordpool Spot)

To service the differing levels of demand, generators use traditional plants that may be classified into three main groups: a continuously operating (or base load) plant that is characterized by high capital costs but relatively low running costs; a plant with lower utilization that has lower capital costs, but progressively higher running costs and a plant that operates for only a few hours each year to service peaks in demand (known in the industry as a "peak lopping plant"), which has the lowest capital costs but the highest running costs. Interconnectors provide for an exchange of power across these borders that NGC also owns, and runs pumped storage sites. These systems pump water into hillside reservoirs during periods of low-priced electricity; the water is then allowed to run back down the hillside, driving turbines, during periods of peak demand. The system is approximately 80% efficient and has an important balancing effect on pool prices. NGC Pump Storage bids and offers the pool as a generator, but also acts as an immediate reserve for the system because of its ability to respond quickly in the event of a system failure.

A power-grid infrastructure consists of a few centralized control centres that manage a limited number of large power plants, such that their output meets the energy demands in real time. This framework had already been used by Edison, Tesla and Westinghouse in the establishment of electric-grid systems. As the proportion of distributed and intermittent power production capacity increases, the task of management becomes much harder, especially for the case of the local and regional distribution grids where renewable energy producers are usually installed (Bichler et al. 2010; Block et al. 2009, 2010).

There is a lack of real-time metering and, in many cases, systems are not built to cope with power-flow inversions (Ketter et al. 2009).

The performance of markets depends on economically motivated behaviour of the participants. Smart-grid pilot projects are complex (Collins et al. 2010) and limited in their ability to test systems for extreme situations. They also lack the competitiveness of open markets, because a single project consortium typically controls and optimizes the interaction of all parts of the pilot regions. Therefore, an open and competitive market platform should be developed that will address the need for policy guidance based on robust research on the structure and operation of retail power markets (Ketter et al. 2009).

Electricity production and distribution systems are complex adaptive systems (Miller et al. 2007). It is crucial that they are managed in real time in order to balance production and demand. Electricity markets are undergoing a shift from centrally regulated systems to decentralized markets (North et al. 2002). Such evolution contains many risks concerning the market size and demands for safety. There are various security issues that attend decentralized energy systems. History provides a list of electrical failures (Table 2) that caused major damage (Borenstein et al. 2002). In addition, the collapse of Enron can be included as a market-generated risk event that undermined the logic of deregulating the electricity industry. The successful realization of a competitive electricity market is determined by the market design, demand response, capacity reserves, financial risk management and reliability control throughout the entire electricity supply chain (Block et al. 2009).

Table 2. List of largest power outages (Sources: Küfeoğlu and Lehtonen 2015, Dobson et al. 2007, Dayu 2004).

Name	Millions affected	Location	Duration
July 2012 India blackout	620	India	30 July 2012-31 July 2012
January 2001 India blackout	230	India	02-Jan-01
November 2014 Bangladesh blackout	150	Bangladesh	01-Nov-14
2015 Pakistan blackout	140	Pakistan	26-Jan-15
2005 Java–Bali blackout	100	Indonesia	18-Aug-05
1999 Southern Brazil blackout	97	Brazil	11-Mar-99
2009 Brazil and Paraguay blackout	87	Brazil, Paraguay	10–11 Nov 2009
2015 Turkey blackout	70	Turkey	31-Mar-15
Northeast blackout of 2003	55	United States, Canada	14–15 Aug 2003
2003 Italy blackout	55	Italy, Switzerland, Austria, Slovenia, Croatia	28-Sep-03
Thailand Nationwide blackout of 1978	40	Thailand	18-Mar-78
Northeast blackout of 1965	30	United States, Canada	09-Nov-65

1.7.2 Electricity market Nord Pool Spot

A power-grid structure is organized in a strict hierarchy: a few centralized control centres manage a relatively small number of large power plants and schedule their production according to energy-demand forecasts. These typically come from day-ahead wholesale markets and long-term contracts, which are influenced by weather forecasts and synthetic load profiles, i.e., average historical consumption time series for different consumer groups. Anticipated shortages and surpluses are traded on wholesale markets among regions, subject to the capacity limitations of cross-regional grid interconnections (Block et al. 2010).

The electricity pool was introduced when the industry was privatized in order to facilitate the bulk trading of physical electricity between generators and suppliers. In order to appreciate the mechanism, it is important to identify the key characteristics of electricity that set it apart from most other commodities:

1. Because electricity is difficult to store, it is necessary to constantly match generation with demand.
2. In an integrated system, it is not practical to trace the supply of electricity from particular generators to particular suppliers.
3. The variation in demand, together with the variation in generating capacity, gives rise to enormous volatility in price.

“Nord Pool Spot is leading market for electrical energy measured in volume (TWh) trading. It operates in Nordic, Baltic, Germany and UK. Nord Pool delivers transparent, efficient and secure power markets. It is world's first multinational exchange for trading electric power. Nord Pool Spot offers both day-ahead and intraday markets, making it suitable for displaying risk” (NP Spot 2013).

System Price

The Elspot market’s system price is also referred to as the 'unconstrained market clearing price. The primary role of a market price is to establish equilibrium between supply and demand. This task is especially important in the power markets because of the inability to store electricity and the high costs associated with any supply failure. The day-ahead market at Nord Pool is an auction based exchange for the trading of prompt physically delivered electricity.. Nord Pool Spot’s system price is the reference price for futures, forwards, and options contracts traded on the exchange with Nord Pool ASA. The system price is also the reference price for the Nordic over-the-counter (OTC)/bilateral wholesale market. (NP Spot 2013)

All of the electricity supplied must presently be traded through the pool, except when industrial users elect to generate their own electricity on-site. The procedure for setting pool prices is complex, and begins with NGC forecasting the national demand for the day ahead (taking into account current weather patterns and historical data). Each generator then submits an offer to the grid operator for each of the generating sets that it owns. The generator's offers detail the price at which it is prepared to produce power, the operating characteristics of its plant and the availability of that plant for the next 24 hours. A coal or nuclear set will have high start-up and shut-down costs, but will be relatively cheap to run. Conversely, an open-cycle gas turbine can be called online immediately for a low start-up cost, but will be expensive to operate. The computerized system must identify the most economical method overall for meeting national demand. The uplift element of the pool price is a cost designed to cover transmission losses, ancillary services, the cost of providing reserve-generating capacity and the differences entailed in both scheduled and actual operation (for instance, overcoming constraints in the grid and responding to unanticipated demand) (N Pool 2004)..

The power price is determined by the balance between supply and demand. Factors such as the weather or power plants not producing to their full capacity can impact how much power can be transported through the grid and will therefore influence the price of power. This is called plants' 'transmission capacity'. Now that the transmission capacity and coupling is in place between the Nordic countries, the European continent and the Baltics, the power market covers large parts of Europe. This means that power from many different sources, hydro, thermal, nuclear, wind and solar enters the grid. This ensures a more 'liquid' market, in which large volumes are traded daily and the power supply is more secure. (NP Spot 2014)

Hourly prices are typically announced to the market at 12:42 CET or later. Once the market prices have been calculated, trades are settled. From 00:00 CET the next day, power contracts are physically delivered hour for hour according to the contracts agreed. (NP Spot 2014)

In this research, we will consider both system price and area prices in: Finland, Norway, Sweden, Denmark and Estonia.

1.7.3 Smart grid development

Smart grid deployments, like any other large-scale project (e.g., power plants), are faced with inherent risks. In addition to the usual project management uncertainties regarding the project schedule, resource planning and execution, uncertainties related to the new product and technology performance can also have a significant impact on the business case's outcome. Depending on the complexity of the deployment, conducting risk analysis and identifying sensitivities in costs and benefits to variation in key inputs may become important in the decision-making process. For example, energy demand elasticity is usually variable. To meet the goal of resource adequacy if certain aspects of demand response were assumed in lieu of constructing new facilities (and, in the process, some avoided capital benefits were taken), variation of demand may occur, forcing construction of new facilities that may otherwise result in a change to the outcome of the business case (Mukherjee 2008).

The industries now know how to build smart-grid components that can record energy usage in real time and help consumers better manage their energy usage. However, this is only the technical foundation. Variable energy prices that truly reflect energy scarcity can motivate consumers to shift their loads to minimize costs and motivate producers to better dispatch their capacities. This, combined with a decreasing availability of fossil energy resources, is leading to an increasing reliance on variable-output sources such as renewable energy like wind and solar, and zero-carbon technologies (Collins, Ketter & Gini 2010).

Many households and businesses are installing small, distributed and variable-output renewable energy sources. These are connected to the medium- and low-voltage distribution grid, and are outside the control of centralized management (Collins, Ketter & Sadeh 2010).

Effective use of renewable resources will require that energy usage adapts to the availability of sustainable power. Smart metering equipment and demand-side management (DSM) devices are being installed on customers' premises to help them monitor and actively manage their energy usage. Consequently, customer demand elasticity will increase, and demand predictions may become more difficult, especially as time-of-use and real-time energy price tariffs are introduced (Block et al. 2010).

It is certain that renewable energies and smart grids constitute key elements of a sustainable future. A number of additional articles argued that a set of activities are of great influence to functioning renewable implementation systems and intelligent distribution (Jacobsson & Johnson 2000, Sagar & Holdren 2002, Foxon et al. 2005).

To facilitate the risk analysis and usage of probabilistic risk assessments, such as Monte Carlo simulation and other sophisticated valuation techniques, real-options methods need to be either incorporated into the model or performed post-modelling. While it may be argued that quantified cost-benefit analysis should not be the only consideration in deciding the merit of an investment case, it certainly has become the principal focus for evaluating smart-grid investments and in deciding whether the investment is in the public interest. The costs and the potential benefits of these projects are inherently uncertain and difficult to quantify, as is the case with any new technology and uncertainty in terms of service level and customer acceptance. A robust and exhaustive model, with sufficient scenario analyses and probabilistic risk assessments, has become a very important part of helping decision makers to make the best choices given all of these uncertain considerations (Mukherjee 2008).

1.7.4 Energy policies

There is a general agreement among politicians and other stakeholders in the Nordic and Baltic power markets that this power model serves society well. While the price of power is determined according to supply and demand, it also becomes clear where there are issues in the grid when the price of power goes up. This makes it easier to identify where production or capacity is lacking, as demand is too high compared to production supply.

The Nordic countries deregulated their power markets in the early 1990s and brought their individual markets together to form a common Nordic market. Estonia and Lithuania deregulated their power markets in the late 2000s.

The term 'deregulation' means that the state no longer runs the power market and, instead, that free competition is introduced. Deregulation was undertaken to create a more efficient market, with an exchange of power between countries and an increased security of supply. Available power capacity can be used more efficiently in a large region when compared to a small one, and integrated markets enhance productivity and improve efficiency (EU Commission 2007).

Policymakers in the USA and European governments need to determine whether the benefits of a smart grid will cover its costs. The European Union expects to spend €56 billion by 2020 with €184 million on estimated smart-grid investments (FP6 FP7 and H2020 European funding for projects in the JRC catalogue (EU Commission 2011) and about €200 million from the European Recovery Fund: ERDF, EERA.

The percentage by which Western countries' electricity prices will soar in the next 30 years if electricity grids do not become smart grids is 400%, according to the Global Smart Grid Federation.

Table 3. Categories for the classification of Smart Grid projects in Europe and the USA (Source: Jiménez et al. 2011)

	European Union	USA
Smart Grid project categories	Smart Network Management	Advanced Metering Infra-structure
	Integration of DER	Electric Transmission Systems
	Integration of large scale RES	Electric Distribution Sys-tems
	Aggregation (Demand Respon-se, VPP)	Integrated and crosscut-ting Systems
	Smart Customer and Smart Home	Customer Systems
	Electric Vehicles and Vehi-cle2Grid	Storage Demonstration
	applications	Equipment Manufacturing
	Other	Regional Demonstration

From the variety of categories in Table 3 it is clear that power grids in the US and European countries, including Finland, need additional investment and development to meet the requirements of forthcoming challenges and new operational scenarios. These include uncertainties in schedules and transfers across regions, and the increasing penetration of renewable energy systems. It faces increased occurrence of unpredictable cataclysmic events due to limited knowledge and the management of complex systems and threats. Consumers are also demanding increased quality and reliability of supply. More efficient use and maintenance of assets to reduce environmental impacts are in focus, today (Momoh 2009).

Network technologies, R&D and demonstration activities are needed to validate state-of-the-art power technologies for transmitting and controlling the flow of large amounts of power over long distances and from offshore sources. They are also needed to develop new monitoring and control systems to ensure the integration of large numbers of variable renewable energy sources while providing the expected power quality and voltage, and to operate pan-European networks in normal and critical conditions. Demonstration activities on solutions for automating distribution-network control and operation, including self-healing capabilities, are required. These will increase power quality and reduce operational expenditure (EU Commission 2006, EU Commission 2007).

"Long-term evolution of electricity networks — R&D activities to develop modelling and planning tools for the long-term evolution of the grid, and validating innovative pan-European grid architectures, needed to increase the capacity to

transport large quantities of renewable energy from all sources and to develop methods and tools for asset management, for preventive maintenance and for optimizing the assets' life cycle."

"Active customers — Demonstration activities on different solutions to activate demand response for energy saving, for the reduction of peak consumption and for balancing variable renewable electricity generation using visualization of consumption for consumers, dynamic time of use tariffs and home automation technologies (up to 500,000 customer points) and on solutions for smart metering infrastructure to unlock the potential of smart meters as the key to provide detailed information to customers, and to provide benefits to retailers and network operators, identifying regulatory, technical and economic opportunities" (EU Commission 2007).

"*Innovative market designs* — R&D activities on cross-cutting issues to proposing market designs that provide incentives for all actors to contribute to the overall efficiency, cost effectiveness and carbon footprint of the electricity supply system to provide inputs to updates of regulatory frameworks to ensure their following the policy and technology developments. Indicative costs (2010–2020)" (EU Commission 2007).

This reflects the total sum of the required public and private investments. Indicative key performance indicators (KPI) are:

- The number of customers involved.
- A greatly increased capacity to host RES electricity from central and distributed sources (to at least 35% of electricity consumption), including a readiness for massive offshore wind integration.
- Increased overall quality of the electricity supply (by a 2–10% reduction of energy not supplied).
- Reduced peak to average load ratio (by 5–10%), and thus a reduced need for investments.

The EU Commission had set government regulations and policy to support all utilities to "provide customers with time-based rates and the ability to receive and respond to electricity price signals." Boards of Directors of unregulated utilities have to "consider and determine" what these utilities must do to comply with the objectives of the EU Acts. This regulatory driver, in tandem with recent developments in communication and information technology (IT) and an increased cost of "clean" conventional energy sources, have created an opportune environment to seriously consider technologies such as smart meters, advanced metering infrastructures (AMI) and “smart grids” as practical solutions to address the power delivery needs of the future (EU Commission 2007).

Full integration of customers in market mechanisms promoting energy efficiency and active demand practices (EU commission 2010). Nord Pool Spot is determined to take a lead role in ensuring the successful integration of European power markets for the benefit of suppliers and consumers alike. More can be learned about this from the North-Western European Price Coupling (NWE) and Price Coupling of Regions — key initiatives in the strengthening of European power-market integration.

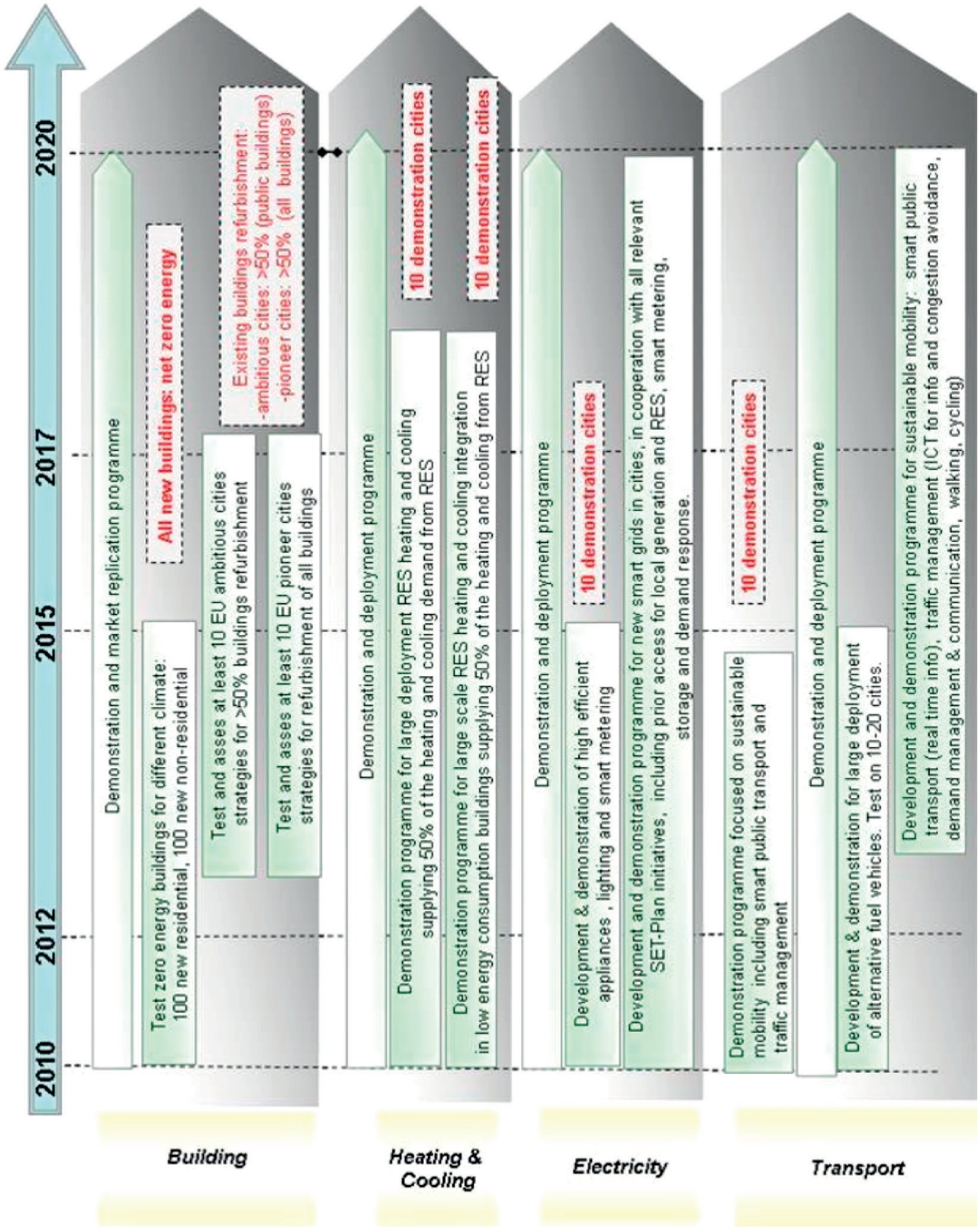

Figure 5. European Initiative on Smart Cities: Indicative Roadmap (Source: SETIS 2009)

In 2009, the EU Commission announced the European Initiative on Smart Cities Technology Plan along with a technology roadmap, see Figure 5. One of the priority actions mentioned in this roadmap is the development of "smart cities" that efficiently and intelligently manage local energy production and consumption.

Strategic objective

As an overall objective for the European Union, the commission set to transmit and distribute up to 35% of electricity from dispersed and concentrated renewable sources by 2020. Completely decarbonized electricity production have to be achieved by 2050; also to integrate national networks into a market-based and genuinely pan-European network; to guarantee a high-quality electricity supply to all customers; to engage them as active participants in energy efficiency and to anticipate new developments, such as the electrification of transport (EU Commission 2007).

EU also aims to demonstrate the feasibility of rapidly progressing towards our energy and climate objectives at a local level while proving to citizens that their quality of life and local economies can be improved through investments in energy efficiency and reduction of carbon emissions. This Initiative foster the dissemination throughout Europe of the most efficient models and strategies to progress towards a low carbon future. (SETIS 2009)

Buildings and electricity

New buildings with net zero energy requirements or net zero carbon emissions with improved energy performance of buildings, innovative hybrid heating and cooling systems from biomass, solar thermal, ambient thermal and geothermal with advanced distributed heat storage technologies.

Smart grids, allowing renewable generation, electric vehicles charging, storage, demand response and grid balancing, smart metering and energy management systems, smart appliances (ICT, domestic appliances), lighting (in particular solid state lighting for street and indoor), equipment (e.g. motor systems, water systems). To foster local RES electricity production (especially PV and wind applications). (SETIS 2009

Industrial sector objective

As a target for the industry sector it is set to substantially reduce capital and operational expenditure for the operation of the networks while fulfilling the objectives of a high-quality, low-carbon, pan-European and market-based electricity system (EU Commission 2007).

The current electricity networks in Europe are mostly based on technology that was developed more than 30 years ago, and the need for innovation has until now been limited. The electricity system has been designed for one-way energy flows from large, centralized and fully controllable power plants to the customers at the other end of the network.

Technology objectives

1. Developing and validating advanced network technologies to improve the flexibility and security of the network, and to mitigate future capital and operational expenditure. These include new high-powered equipment, the integration of electricity storage and monitoring and controlling systems.

2. Preparing the long-term evolution of electricity grids to ensure that proper investments are made in the coming years to address the requirements of the future portfolio of electricity generation and consumption.

3. Engaging the active participation of customers in energy markets and energy efficiency through providing better information about their consumption, incentives such as dynamic pricing mechanisms and appropriate ICT tools.

4. Elaborating and testing innovative market designs to ensure a proper functioning of the internal market for electricity at both European and local scales. Structured interactions will be set up with the other industrial initiatives — particularly for wind and solar energy, and with the public-private partnerships on green cars and efficient buildings — in order to ensure a coordinated development of the appropriate technologies and, where appropriate, to organize joint demonstration activities. (SETIS 2009)

2 THEORETICAL FRAMEWORK

2.1 Basic definitions

This section introduces basic terms used in this thesis.

2.1.1 Uncertainty and risk

The Oxford English Dictionary defines ‘uncertainty’ as “the quality of being uncertain in respect of duration, continuance, occurrence, etc.” and ‘risk’ as “hazard, danger; exposure to mischance or peril”.

Cash flows of a project are subjected to uncertainties in cost, supply and demand. The monetary loss that may occur due to the uncertainties is called risk.

2.1.2 Volatility

A mathematical measure for uncertainties is volatility, or σ. There are three popular ways to measure volatility: make an educated guess, gather historical data or simulate project returns by using Monte Carlo methods (Luehrman 1998). Volatility has a major impact on cash flows. As volatility grows, a higher discount rate is necessary to reward investors (Tsui 2005).

2.1.3 Flexibility

The capability to revise the decisions in a project is defined as managerial flexibility. It allows managers to abandon, contract, invest or delay their plans if necessary. With no flexibility, project estimation could only depend on management intuition (Tsui 2005).

2.1.4 Risk analysis and strategic decisions under uncertainty

The definitions for risk found in the theory state that it is the dispersion of unexpected outcomes due to the movement of variables. It is measured by the standard deviation of unexpected outcomes, which is sigma (σ), also called ‘volatility’. In electricity markets, volatility risk is the probability of fluctuations in the price of electricity over time (Lintner 1965). It is actually a probability measure of the threat that variations in electricity prices pose to an investor's portfolio in a smart-grid project. The standard deviation of a data set of prices' movements measures the volatility of the price (Basel Committee on Banking Supervision, BSBC 1996, Basel Committee on Banking Supervision, BSBC 2006).

Risks can come from uncertainty in financial markets, project failures, legal liabilities, credit risk, accidents, natural causes and disasters, as well as deliberate attacks from an adversary. Several risk-management standards have been developed, including the Project Management Institute, the National Institute of Science and Technology, actuarial societies and ISO standards: ISO/IEC 31000 (Risk Management 2009). ISO (2009) defines risk as "the effect of uncertainty on objectives" whether positive or negative.

To distinguish between different causes of uncertainty, Jorion (2000: 14) describes five types of financial risk: market risk, credit risk, operational risk, liquidity risk and legal risk.

There are various other metrics of market risk — volatility, delta, gamma, duration, convexity, beta, etc. Measure that supports a risk metric is referred to as a risk measure. Risk measures are categorized depending on the risk metrics they support (Holton 2003). VaR-based risk management techniques can be easily adapted from the financial market to manufacturing companies for the purposes of related products and services' development. Basak and Shapiro (2001) acknowledged the VaR summary measure's appealing rationale, as it allows professionals to focus attention on "normal market conditions".

Choudhury (2003) defines risk as a probability that outcomes could be damaging or result in a loss. In the presence of risk, the outcomes can have some level of uncertainty. As Cabedo and Moya (2003) recommended, VaR can be used within markets to quantify the maximum price changes and associate them with a likelihood level. Such quantification is essential when crafting risk-management strategies. Horcher (2005: 2) defines risk as a probability of loss, which is a result of exposure.

For the purpose of this dissertation the author focus on market risk in the form of price change.

2.1.5 Price risk

The risk of a decline in the market value is called the price risk, which is the single biggest risk for all investors and cannot be fully diversified away. Price risk depends on the volatility of the monetary assets. Investors can use different tools and techniques to hedge against price risk, such as buying put options or short selling. In business, it is vital to be able to convert the findings of risk assessments into financial numbers (Crockford 1986). Additional research suggested that the advantages of risk management are further dependent on the regularity and means of risk assessment (Carr et al. 1993).

2.2 Risk management process

According to ISO/IEC 31000 (2009) risk is “the effect of uncertainty on objectives” and risk management is “the range of activities that an organization intentionally undertakes to understand and reduce these effects”: Additionally to the risk terminology and definitions this standard contains a set of principles to guide and notify effective risk management inside an enterprise. ISO 3100 outlines a practice for creating risk management framework and risk management process. Such process starts with establishing the context and assessing the risk. Assessment includes risk identification, risk analysis and risk evaluation. Possible risk treatments and feedback loop conclude the process. (ISO 2009)

Establishing the context

That is, the identification of risks, outlining a framework and agenda, followed by the analysis of risks involved in the process. It also involves developing solutions for risk management using the available technological, human and organizational resources (ISO 2009).

Identification

Identification classifies potential risks. Risks are generally events that cause problems and identification can begin with the source of the problem or with the problem itself. Risk sources may be internal or external to the system. Risks are associated with recognized threats. When either a problem or its source is known, the events that may occur can be inspected (ISO 2009).

Risk-identification methods include, but are not limited to:

- Objectives-based risk identification defines the risk of achieving the goals of the company.
- Scenario-based risk identification consists of creating hypothetical alternatives to occurring events within a certain timeframe. This is followed by

evaluation of the different forces affecting the outcome of the scenarios. Any unwanted options can be identified as risks (Godet & Roubelat 1996).

- Taxonomy-based risk identification approaches possible separate causes of risk and constructs a questionnaire using a taxonomy and knowledge of best practices. The answers expose various risk factors (Carr et al. 1993).

- Common-risk checking lists familiar risk categories existing in numerous industries. These lists can be checked for a particular situation (Martin 2001).

- Risk charting combines the previous method with monitoring resources at risk of threats and those resources that may increase or decrease the risk. Creating a kind of risk matrix allows for a variety of approaches: starting with resources that are more exposed to risk and possible consequences or, instead, starting with the threats and examining which resources they would affect, or determining which combination of threats and resources would be most harmful to the organization (Crockford 1986).

Assessment

After a company has identified all possible risks, they have to be assessed to determine their probable losses and probability of occurrence. These values can either be simple to measure, such as the value of a lost automobile, or nearly impossible to predict for certain, as in the case of the probability of an unlikely event occurring. Therefore, in the assessment process, it is critical to make the best educated guess in order to correctly evaluate and prioritize the risks (Miccoli & Destefano 2010).

Determining the rate of occurrence is the fundamental challenge of risk assessment, since statistical information is not available for every kind of past event. Furthermore, evaluating immaterial assets presents a quite difficult problem and, in order to solve it, all available primary sources of information need to be reviewed. However, the information analysis must be easy for the management to understand so that risks may be prioritized (Barth, Beaver & Landsman. 2001).

2.2.1 Risk treatments

After risks have been identified and assessed, most of the techniques to manage the risk fall into one or more of the four major categories as defined by Agrawal and Srivastava (2013).:

– Avoidance;
– Reduction;
– Sharing;
– Retention

Adjustments involve the use of any combination of these approaches.

Risk avoidance

Risk avoidance can be defined as not performing an activity that will possibly carry risk. Avoidance may appear to be the answer to all risks but, correspondingly, avoiding risks means missing the potential gains that accepting risks may allow. Not entering a business to avoid the risk of loss also avoids the possibility of earning profits. Risk avoidance actions are typically focused on one or more of the main risk options: (Loomba 2013: 28)

– Designing a new business process with adequate built-in risk control and containment measures from the start.
– Periodically reassessing risks that are accepted in ongoing processes as a normal feature of business operations and modifying mitigation measures.
– Transferring risks to an external agency (e.g., an insurance company).
– Avoiding risks altogether (e.g., by closing down a particular high-risk business area).

Risk reduction

Risk reduction includes steps to reduce the effects of the loss or the likelihood of the loss occurring (Crockford 1986). In recognizing that risks can be positive or negative, adjusting for risks means finding a balance between negative risk and the benefits of the operation or activity, and between risk reduction and the effort applied (Dorfman 2007).

Outsourcing could be an illustration of risk reduction if the outsourcer can prove their higher capability at managing or reducing risks (Roehrig 2006).

Risk sharing

Risk sharing involves sharing with a partner the burden of a loss or the benefit of a gain, and taking measures to decrease risk (Bischoff 2008: 176).

Sometimes ‘risk transfer’ is used instead of risk sharing in order to address risk insurance or outsourcing. In practice, if the insurance company goes bankrupt, the risk is likely to revert to the original owner (Loomba 2013). Commonly, the purchase of insurance is a synonym for the ‘transfer of risk’. The buyer of the contract still retains a legal responsibility for the losses and can be compensated after the event (Kumar 2012).

Risk retention pools are, in principle, retaining the risk within industry groups, as losses are calculated for all members of the group (Boland 1996).

Risk retention

Risk retention entails accepting the cost or benefit from a risk when it arises (Loomba 2013). Risk retention is a practical strategy for minor risks, where the cost of insurance would be greater than that of the total losses (Meulbroek 2002).

All risks that are unavoidable are retained by default (Kumar 2012). The amount of potential loss over the amount insured is also classed as retained risk (Williams 2007). This may be tolerable if the chance of a large loss is minimal or if the insurance cost is so significant that it would undermine the goals of the company (Agrawal & Srivastava 2013).

2.3 Basic Valuation Concepts

Net present value is one of the most popular valuation methods to assess project investments. It discounts all net cash flows during the project’s lifespan with a predetermined rate to calculate the sum at the start of the project. NPV is a decision-making tool in capital budgeting for resource allocation; one that offers a choice between investment projects based on their full life-cycle value (Trigeorgis 1996). Positive NPV signals to management that there is profit in the project, that they have a reason to consider it and choose the one that will produce the highest amount of net discounted cash flow. They can also prioritize a company’s project portfolio. There is a positive correlation between net cash flows and the company’s shareholder wealth (Tsui 2005).

Different evaluation criteria exist in capital budgeting, namely: the cost-benefit ratio, the internal rate of return, discounted cash flow and real options valuation. This dissertation’s emphasis is on the real options concept and does not reveal the cost-benefit ratio or internal rate of return.

NPV serves as a basis for the project evaluation, so the following factors are presented in further detail: the building blocks of the method, the time value of money, the cost of capital, the discounted cash flow and the NPV formula.

2.3.1 Weighted-average cost of capital (WACC)

In real-world markets, companies have a limited amount of resources; hence, they have to make choices and prioritize projects. For all investment decisions, the cost of capital should be estimated prior to irreversible actions being made (Tsui 2005).

The cost of capital can be calculated from the weighted average market-traded equity and the return to debt, as expressed by Modigliani, and Miller (1958) in Equation 2,

$$WACC = r_{equity}\left(\frac{E}{V}\right) + r_{debt}\left(\frac{D}{V}\right) \qquad (2)$$

where:
- WACC = cost of capital,
- r equity = expected rate of return on equity,
- r debt = expected rate of return on debt,
- E = equity,
- D = debt,
- V = market value of the firm V = E + D.

As Equation 2 shows, WACC is an aggregate measure for a portfolio of a company's assets (Brealey, Myers & Myers 2003: 525).

2.3.2 Capital asset pricing model (CAPM)

The capital asset pricing model (CAPM) is the process used in assessing risk. It compares a "risk-free" market rate associated with industry or the economic sector with the project-specific risk and adds a premium for shareholders bearing risk that is higher than the systematic risk level Markowitz, H. (1952). Treynor, J. L. (1962) and Sharpe, W. F. (1964). The project's operating cash flows are then discounted using this rate (Copeland, Weston & Shastri. 2005: 42).

CAPM is defined as the following,

$$E(r_i) = r_f + \beta_{im}(E(r_m) - r_f) \tag{3}$$

where:
- $E(r_i)$ = expected return on the capital asset,
- r_f = risk-free rate of interest,
- βim = the sensitivity of the asset returns to market returns, as presented in Equation 4,

$$\beta_{im} = \frac{Cov(r_i, r_m)}{Var(r_m)} \tag{4}$$

where:
- (r_i) = expected return of the asset,
- (r_m) = expected return of the market.

Historical data can be used to obtain the values of the parameters and then Excel is used to calculate the covariance and variance. Then, the derived value E(r) is used for the NPV calculation.

2.3.3 *Time value of money*

One of the oldest fundamental concept in finance dating back to 15 century is the "time value of money". The saying "money today is worth more than money tomorrow" indicates that money can earn interest and deliver a higher value later on, as discussed by (Menger 1892; Pigou 1917; Fisher 1930). Consequently, all future payoffs have to be adjusted with the time value of money in mind. Equation 5 shows the connection between present value PV and future value FV

$$PV = \frac{FV}{(1+r)} \tag{5}$$

where:
- r = rate of expected return on the investment, adjusted for risk,

2.3.4 Net present value

NPV is a widely used method for discounting cash flows to the present period Fama and Miller (1972). The most important tasks in implementing NMV are to determine all the expected cash incomes and outflows generated by the project, as well as to define the proper discount rate (Dixit & Pindyck 1994).

NPV is expressed in Equation 6,

$$NPV = -I_0 + \sum_{t=1}^{n} \frac{E(FCF_t)}{(1+r_t)^t} \qquad (6)$$

where:

- I = investment at time zero,
- E(FCF) = expected value of free cash inflows at time t,
- r = the rate of expected return on the investment, adjusted for risk,
- n = the number of periods into the future when payoffs occur, provided that r remains constant in each period.

2.3.5 Discounted cash flow (DCF)

Another frequently used capital budgeting technique is DCF. Current project value is calculated using a formula identical to that for the NPV, summing up all cash flows to the present time. DCF assumes a fixed project scope and a management plan that does not vary over the project's lifespan. Therefore, the project's value is defined at a primary stage. In reality, however, the project's scope and plan change with new information updates and the project's value is not static (Tsui 2005).

2.4 Value at risk methodology

The formal definition of the Value at Risk measure (VaR) states that it describes the quantile of the projected distribution of gains and losses over a target horizon. In its general form, VaR can be derived from the probability distribution of a future portfolio f(w), according to Jorion (2000). At a given confidence level, VaR represents the worst possible realization of W*, such that the probability of exceeding this value is c:

(7) $$c = \int_{W^*}^{\infty} f(w)dw$$

or such that the probability of a value lower than W*, p=P(w≤W*), is 1-c:

(8) $$1 - c = \int_{-\infty}^{W^*} f(w)dw = P(w \leq W^*) = p$$

The number W* is called the quantile of the distribution, which is the cut-off value with a fixed probability of being exceeded.

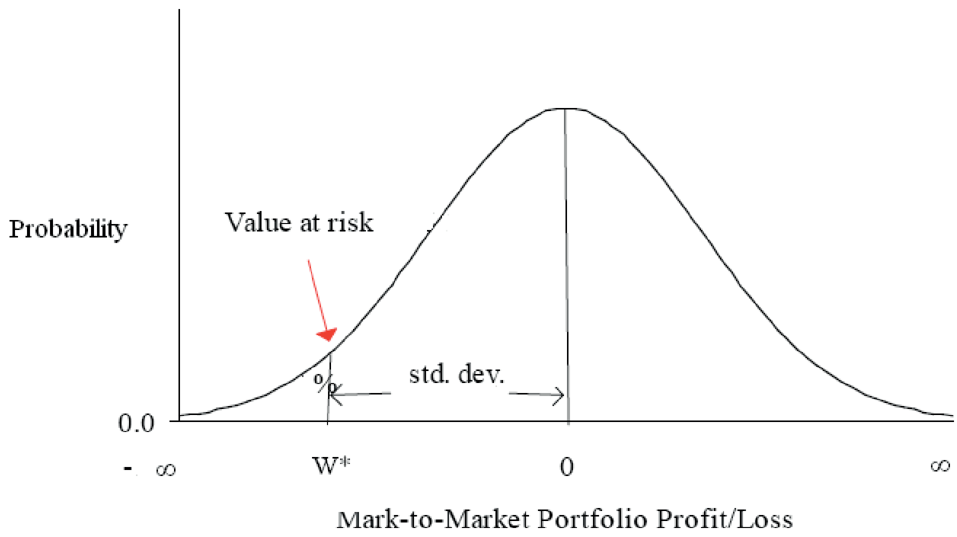

Figure 6. VaR diagram for normal distribution.

Advantages of VaR include the simplicity and elegance of its result-a single money figure and its possible implication to any kind of assets. The disadvantages are its ignorance of all risk above certain level and its vulnerability to fraud by traders. Calculation can be difficult when a portfolio consist of many different instruments.

The first company that introduced VaR measure was Bankers Trust. Their risk-adjusted return on capital system (RAROC) adjusts profits for capital at risk, defined as the amount of capital needed to cover 99 percent of the maximum expected loss over a year. 1-year horizon is used for all RAROC computations, no matter what the actual holding period is, in order to allow better comparisons across different types of assets (Jorion 2000:77).

At the early 90's Dennis Weatherstone, the chairman of JP Morgan established the classical framework of VaR in a "4:15 report" that he required from his employees. It contained measurement of the boundaries of all company risks on one page, available within 15 minutes of the market closure. In 1993 on an annual conference the bank made its risk model public and vastly disseminated VaR. They made it separate from the mother company, establishing a consulting firm RiskMetrics to improve the methodology. (Nocera 2009.)

The expansion of VaR popularity did not stop and in 1993 in a report the international body of economic and financial issues (G30) recommended its use as a consistent daily market risk measure (Global Derivatives Study Group 1993).

VaR calculated with Nord Pool data uses measurements of the dispersion of electricity's return during a predefined period. The distinction of VaR is that it expresses the downside of that dispersion and the loss in a single figure, while traditional methods apply statistical analysis to determine the standard deviation of those returns (Venter 2000: 186).

There are several methods for calculating VaR. For example, Sadeghi and Shavvalpour (2006) use methods based on historical information for the oil price risk in managing the price risk of energy markets. VaR methods can be classified into three groups:

– Historical simulation approach,
– Monte Carlo simulation method,
– Variance-covariance method (Hull & White 1998).

Simulation approaches are essentially analytical methods that imitate the behaviour of a system. The spreadsheet software Excel, with embedded plug-in software, is used to represent a real-life system and capture the interactions between participants within it. Monte Carlo simulation is used to generate the distribution and characteristics of the possible values of an output, by repeatedly sampling from probability distributions of the input factor (electricity prices). Historical and Monte Carlo simulations were completed for the data set to access the projected distributions of gains and losses of a portfolio of energy technology project assets over a target horizon.

2.4.1 Historical simulation: model description

Historical simulation (HS) is an approach that does not require many assumptions about the statistical distribution of the underlying market factors (Linsmaier & Pearson 1996: 7). As RiskMetrics describes it, it is a non-parametric method of using past data to make interpretations about the future. Applying the HS technique means taking today's portfolio or assets and revaluing them using previous prices. In short, HS's basis consists of taking actual historical price changes in market rates that occurred over previous trading days (that would be the data window) and revaluing the asset or portfolio as if those changes were to occur again in the next holding period.

$$R_{p,\tau} = \sum_{i=1}^{N} w_{i,t} R_{i,\tau}, \tau = 1,...,t \qquad (9)$$

HS is a direct implementation of full valuation methodology, where R is the historical asset return, N is the number of portfolio position, τ represents observations times and w is the weight of the position (Jorion 1997: 193). A historical VaR value is calculated by using historical changes in market prices to construct a distribution of potential future portfolio profit and losses, and then reading off that the VaR number as the loss that is exceeded in only a certain percentage of the time (Linsmeier & Pearson 1996: 7).

HS approximates the quantiles of an underlying distribution from the realization of the distribution. The VaR in this case is estimated by:

$$VaR_t(\alpha) = F^{-1}(\alpha)r \qquad (10)$$

where $F^{-1}(\alpha)r$ is the qth quantile $(q = 1 - \alpha)$ of the sample distribution. Statistical calculations are simplified, as this methodology uses the actual observed changes to estimate the expected future market changes. Many financial models consider markets and the prices of instruments to be continuous in nature and assume that there are no sharp jumps or discontinuities in prices. Since HS exploits actual returns, the method captures true market behaviour and does not rely on the assumption of normal distribution of market returns (Venter 2000: 6). Changes in market prices are used as inputs to calculate prospective gains and losses, so that any "fat tails" or other distortions are fully captured in the model (Stambaugh 1996: 617).

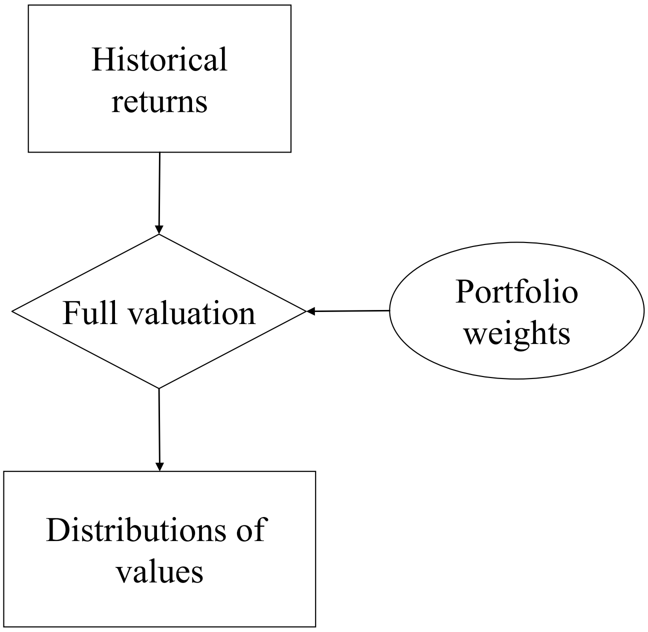

Figure 7. HS Process flow chart (Source: Jorion 2000:194)

There are five key steps in conducting an HS for a single financial instrument. First, the basic market factors that affect the instrument have to be identified. Second, a formula containing these factors and expressing the mark-to-market value of the instrument in the portfolio has to be obtained. The next step is to extract the historical values of the market factors for the last period of interest (100 and 250 days). Subjecting the chosen instrument to the daily changes in market rates and prices of the factors create hypothetical profits and losses. Then, a histogram of all profits and losses is created, and from it, the desired percentiles (1% and 5%) are subtracted (Linsmeier & Pearson 1996: 15).

Advantages

The HS method is relatively simple to implement if historical data are available for all the financial instruments over the time horizon for daily mark-to-market values. Its intuitiveness makes it easy to explain to managers, supervisors and regulators. This assists in the process of acquiring conclusions from VaR analysis and supports the disciplines putting risk management practices to work (Stambaugh 1996: 617). As HS VaR is derived from actual prices, the method allows non-linearities and non-normal distributions. It captures gamma, vega risk and correlations. HS does not depend on specific assumptions about valuation models or the structure of the market and is not subject to model risk. Its biggest advantage is that it can account for fat tails (Jorion 1997: 195). HS is also able to incorporate changes in option prices with changes in option volatilities, if they are collected and included as additional factors for the period used in the simulation (Linsmeier & Pearson 1996: 17). HS is the most widely used method to compute VaR values.

Problems

HS has its shortcomings. It cannot be done without sufficient recorded history of price changes for all assets. Based on the data, only one sample path is generated, and the quality of the results depends critically on the length of the chosen period. HS suggests that the past closely represents the immediate future. If the chosen time window does not include important events, the tails will not be well represented or the period may contain events that will not reappear in the future. Linsmeier and Pearson (1996: 19) refer to this problem as “atypical” historical data. One hidden danger of this fact is that if HS VaR is used as a trading-desk limit, this shortfall opens the door for informed traders to exploit the model and take additional risks. It is also hard to perform “what if” scenario analyses when the price path is directly linked to historical changes. The HS method puts equal weights on all observations in the window, without considering the influence that the most recent ones will have on the immediate future. Thus, HS will be very slow to incorporate structural breaks. (Jorion 1997: 196.)

2.4.2 Monte Carlo simulation: model description

The Monte Carlo simulation (MCS) method uses simulation techniques to produce a huge number of random price paths in order to estimate the behaviour of future asset prices. In such a fashion, it generates diverse scenarios for the value of a portfolio. MCS includes a wide range of hypothetical values of financial variables and can also implement possible correlations between them (Jorion 1997: 231).

Conducting MCS for a single instrument begins like HS, with the identification of basic market factors and its value being formulated accordingly. Afterwards, a specific distribution for the changes in these factors has to be estimated by the modeller. One has the freedom to choose the distribution parameters that best fits the objectives of the simulation. Consequently, by using the random number generator, one can create a sufficient number (N) of hypothetical values of changes in the market factors. They are used to calculate N hypothetical mark-to-market values of the instrument. Subtracting the actual instrument value gives us N hypothetical profits and losses, and then a histogram is again created and a VaR value is taken from it (Linsmeier & Pearson 1996: 15).

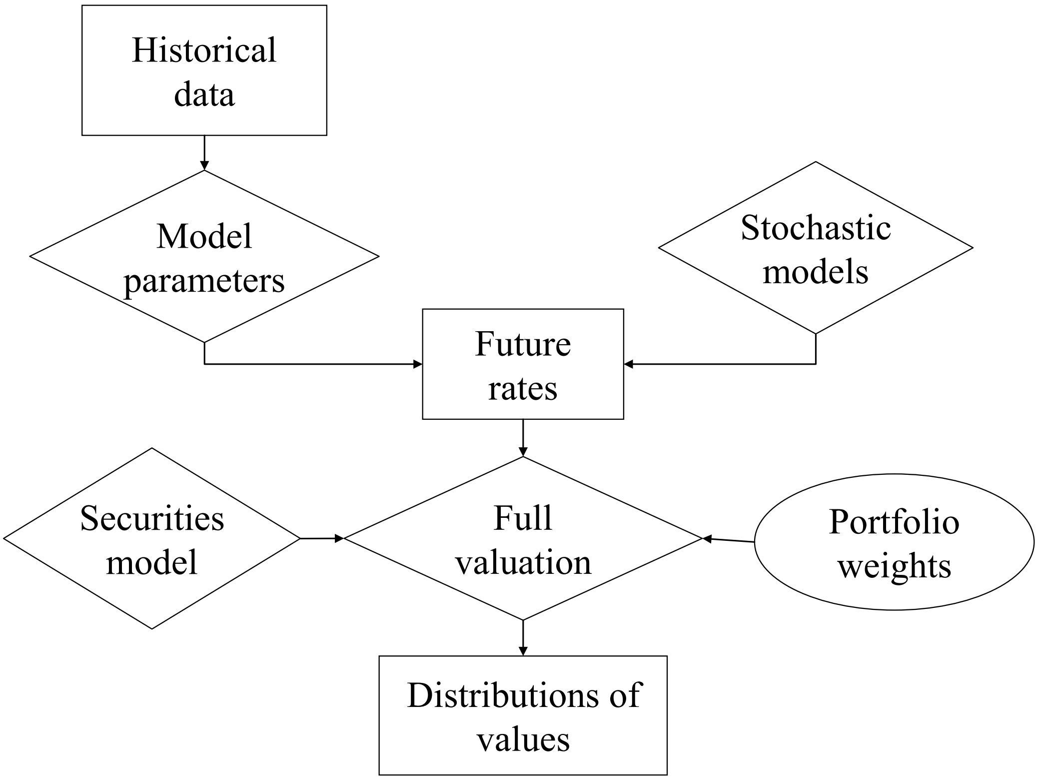

Figure 8. MCS Process flow chart. (Source: Jorion 2000)

HS and MCS methods are quite similar, except that in MCS, the hypothetical changes in price are created by random draws from a pre-specified stochastic process instead of being sampled from a real data set.

Advantages

MCS is one of the most powerful VaR methods. If its modelling of parameters is accurate, MCS is really extensive and limited only by computational power. It is flexible enough to include time variations in volatility, fat tails and extreme scenarios. It can also implement additional types of risk, such as price risk, volatility risk and, to some extent, model risk. The MCS method can also include user-defined scenarios, non-linear positions, non-normal distributions and implied parameters (Jorion 1997: 200). Generally, MCS is able to integrate price volatility randomness by extending the simulation in such a manner that it includes a distribution of volatilities. All kinds of “what if” scenarios are compatible with the MCS method. (Linsmeier & Pearson 1996: 17).

Problems

MCS is heavily influenced by model risk. It relies on stochastic processes for defining risk factors and pricing models that can be arguable or completely incorrect. Incorrect assumptions about the parameters of statistical distributions of market factors lead to mistakes in VaR values. A great deal of expertise and professionalism is needed to make the right choice. A portfolio with exotic options may be difficult to value if one lacks adequate pricing models. As finite numbers of price-path replications are performed, MCS VaR estimates can vary significantly from sample to sample. Another drawback is the fact that it is difficult to explain to senior managers (Linsmeier & Pearson 1996: 17).

Comparison of the two VaR methodologies according to several criteria can be seen on Table 4

Table 4. Comparison of VaR methodologies. (Source: Linsmeier & Pearson)

Comparison criteria	***Historical Simulation***	***Monte Carlo Simulation***
Able to capture the risks of portfolios which include options?	Yes. regardless of the options content of the portfolio	Yes
Easy to implement?	Yes, for portfolios for which data on the past values of the market factors are available	Yes. for portfolios restricted to instruments and currencies covered by available "off-the-shelf software. Otherwise moderately to extremely difficult to implement
Computations performed quickly?	Yes	No, except for relatively small portfolios
Easy to explain to senior management?	Yes	No
Produces misleading value at risk estimates when resent past is atypical?	Yes	Yes, except that alternatives estimates of parameters may be used
Easy to perform “what if” analysis to examine effect of alternative assumptions?	Yes	Yes

2.5 Options theory

Options theory in finance provides the framework to define and calculate the value of real options. The financial definition of an option is a “contract giving the buyer the right, but not the obligation, to buy or sell an underlying asset as stock or index, at a specific price on or before a certain date”. Just like stocks or bonds, options are a security, a binding contract with strictly defined terms (Tsui 2005).

There are many regulations for trading options; the most important are commissions, taxations, government regulations, margins and dividends. The most important information that a financial option delivers is its pricing. To calculate it, Black and Scholes proposed a differential equation that gives a solution. This equation must be satisfied by the price of any derivative dependent on a non-dividend-paying stock (Black & Scholes 1973).

The following part explains how to value simple options, based on the value of the underlying asset. The basic pricing approaches employed in order to value real options include Black and Scholes’ model and binomial approximation. By using binomial approximation, practitioners simulate the stochastic behaviour of the underlying asset and in such way as to avoid solving the differential equation through the Ito process (Tsui 2005).

2.5.1 Basic concepts, relationship and net profit

Options are divided into two basic types. Call options give the holder the right to buy the underlying asset on a specific date for an exact price. Put options give the holder the right to sell the underlying asset on a specific date for an exact price. Table 5 presents the most important definitions and terminologies (Hull 2006).

Table 5. Option Terminologies and Definition (Source: Chicago Board Options Exchange 2005)

Option terminologies	***Definitions***
Underlying asset	Market-traded stocks, stock indices, foreign currencies, debt instruments, or commodities.
American option	An option contract that may be exercised at any time between the date of purchase and the expiration date.
European option	An option contract that may be exercised only diving a specified period of time just prior to its expiration
Exercise or strike price	The stated price per share for which the underlying security may be purchased (in the case of a call) or sold (in the case of a put) by the option holder upon exercise of the option contract
Option price	The price of an option contract, determined in the competitive marketplace, which the buyer of the option pays to the option seller for the rights conveyed by the option contract. If you decide not to use the option to buy the stock, and you are not obligated to, your only cost is the option premium.
Exotic options	Variants of the traditional vanilla options (put. call) that possess different payoff schemes.

The definition of options is obtained from the Chicago Board Options Exchange and characterizes the option type: call or put, American or European. Factors like the expiration date, stock price, exercise price, the volatility of the stock price and the interest rate affect the value of the option. Table 6 reviews the factors and their effects on the call-option price (Hull 2006).

Table 6. Effect on the Price of a Call Option

If there is an increase in:	***The direct changee in the call option price is:***
Stock price. S	Positve
Exercise price {strike price. K)	Negatve
Interest rate (risk-free rate), r	Positve'
Time to expiration. T	Positve
Volatility of the stock price (<r)	Positve'

Payoff schemes

Some authorities refer to “payoff” instead of the term “net profit”. Payoff differs from net profit as can be seen from the definition: “an option’s payoff takes into account only what the holder gets at expiration, rather than considering the total out-of-pocket expense from the holder” (Hull 2006).

Figure 9 shows European call payoff scheme, its payoff = Max (ST – K, 0), where ST is the stock price at the expiration date, and K represents the strike price.

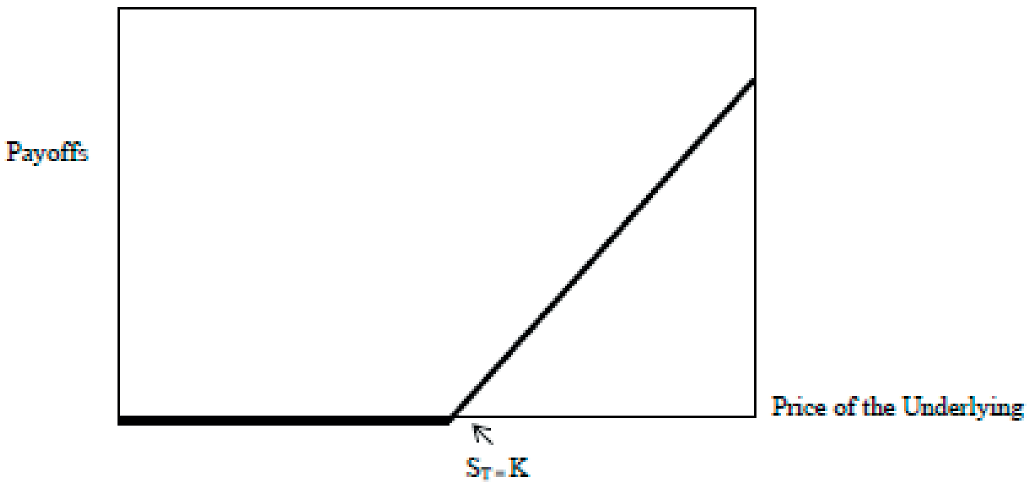

Figure 9. General Payoff Diagram of a European Call

Figure 10 shows a European put payoff diagram, where = Max (K - ST, 0), where ST is the stock price at the expiration date; and X represents the strike price.

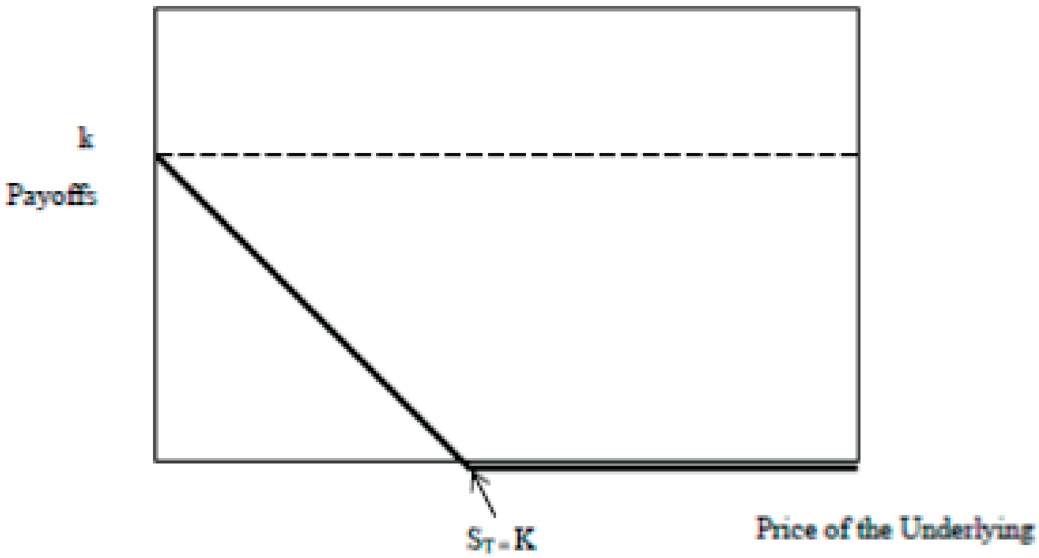

Figure 10. Payoff of European put options

The payoff diagrams show that an option will be exercised only when it is profitable to do so. There are asymmetric payoffs for the options: the earning potential for call options is unlimited, while put options have the strike price as a ceiling (Hull 2006).

Furthermore, this work describes two commonly used methods for pricing call and put options: the Black-Scholes options pricing model and binomial approximation.

2.5.2 Black-Scholes options pricing model (OPM)

The Black-Scholes OPM approach uses a closed-form solution of the Black-Scholes-Merton differential equation. Black-Scholes OPM is able to price European call and put options on a non-dividend paying stock. European call options are calculated using the following formula:

$$c = S_0 N(d_1) - Ke^{-rT} N(d_2) \quad (11)$$

where

$$d_1 = \frac{\ln(S_0 / K) + (r_f + \sigma^2 / 2)T}{\sigma\sqrt{T}} \quad (12)$$

$$d_2 = d_1 - \sigma\sqrt{T} \quad (13)$$

N(x) is the cumulative probability distribution function for a standardized normal distribution (Black & Scholes 1973).

Other notions are denoted as follows:
- S = the price of the underlying stock at time 0,
- K = the predetermined strike price,
- r_f = the continuously compounded, risk-free interest rate,
- T = the time until the expiration of the option (this unit depends on how σ is defined),
- σ = the implied volatility of the underlying stock for the time period.

Black and Scholes (1973) describe the solution at time zero for the price of a European put option on a non-dividend-paying stock:

$$p = Ke^{-rT}N(-d_2) - S_0N(-d_1) \quad (14)$$

When discussing the OPM assumptions, different authors take different approaches: some only comment on the major assumptions: arbitrage-enforced pricing and the condition that stock price evolution follows geometric Brownian motion with fixed volatility (Tsui 2005).

2.5.3 Binomial approximation by binomial lattice

Cox, Ross and Rubinstein (1979) were the first to introduce the binomial approximation method, which uses a binomial lattice to estimate the price progress and the payoffs of an underlying asset. It is assumed that the price of an asset will move either up or down within a single time period with the assigned probabilities u and d. These two movements are sufficient to describe behaviour in a short period of time. Multiple paths and values can be observed after numerous time steps (Cox, Ross & Rubinstein 1979).

P is the probability for the up movement and 1- p is a down movement, since the total probabilities have to add up to one. Figure 10 presents a stock-price fluctuation model that is recombining, meaning that the up and down movements in time have identical steps and connect in the following nodes (Cox, Ross & Rubinstein 1979).

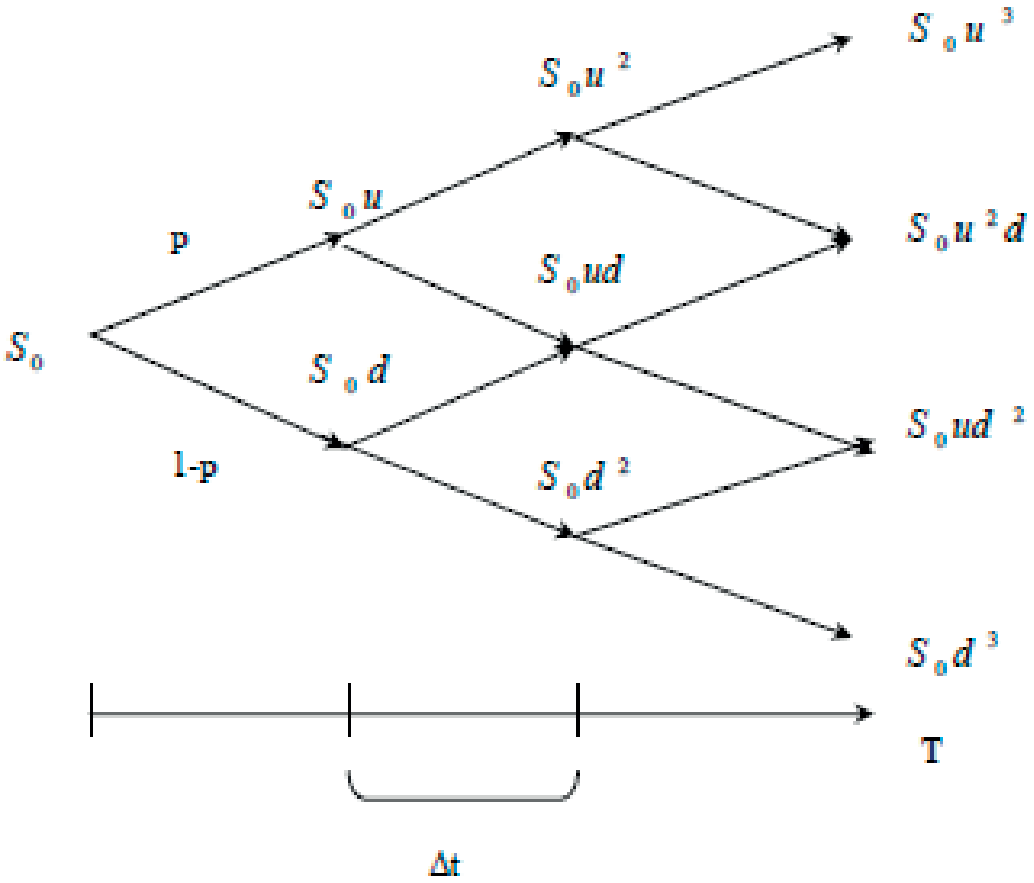

Figure 11. Three-Period Binomial Lattice

The evolution of a stock price for three periods is presented in Figure 11. The period length Δt = t/n so the time to expiration T is divided into n identical periods. Starting from the last period and moving backward through the nodes, the option valuation procedure is repeated. Equation 16 shows the binomial option-pricing formula for n periods:

$$C = \frac{\sum_{j=0}^{n} \frac{n!}{j!(n-j)!} p^j (1-p)^{n-j} \max[u^j d^{n-j} s - k, 0]}{(1+r)^n} \qquad (15)$$

The risk neutral probability, p, derived by Cox, Ross and Rubinstein (1979), is

(16) $$p = \frac{r - d}{u - d}$$

(17) $$1 - p = \frac{u - r}{u - d}$$

where r = 1+ f r , in addition,

(18) $$u = e^{\sigma \sqrt{\Delta t}}$$

(19) $$d = e^{-\sigma \sqrt{\Delta t}} = \frac{1}{u}$$

where σ = the volatility of the natural logarithm of the underlying free cash-flow returns as a percentage.

2.6 Real options

Options theory is a widely used concept in finance. The real options approach derives from its logic. It differs from traditional capital budgeting methods (NPV analysis), as its underlying assumption is that managers can defer the decision for irreversible investment, opposite to the "now or never" NPV scheme. The RO approach to investment was explained by Dixit and Pindyck (1994). It provides a novel attitude for capacity-expansion planning in the electricity sector (Kumbaroglu et al. 2008).

"Buying financial options is the right, but not the obligation, to take an action (to buy or sell options) at a predetermined cost, now or in the future" (Leslie & Michaels 1997). The real options approach allows for similar flexibility. It allows managers to include options to expand, switch or defer projects, or to take a decision to abandon, switch or contract the project. Such flexibility allows companies to capture upside potential and limit downside loss. Compared to financial options, which are mainly contracts, these options are "real" as they represent real projects (De Neufville et al. 2004).

Various real-options opportunities can be found in capital investment projects. They appear naturally in the course of the projects, or may be formed in advance as investment opportunities for an additional expense (Copeland & Antikarov 2001). It is better to invest that extra amount when the present value of the modifications that will be required later is greater than the cost of creating project flexibility. With the price of variability in financial markets, companies that use real options for managing projects are more likely to gain a competitive advantage in the future (Tsui 2005).

Real options logic allows the designing of a company's strategy with more flexibility in project management. It gives us the opportunity to create value in an uncertain environment. Unlike the attitude of "avoiding all risks if possible," a real-options framework teaches engineers and managers how to react to uncertainties proactively (Tsui 2005).

2.6.1 Types of real options

Table 6 presents common types of real options. It is important to recognize them and be able to modify them according to one's project, and then to choose appropriate valuation methods (Trigeorgis & Mason 1987).

Table 7. Types of Real Options (Source: Trigeorgis. 1993)

Option	Description	Example
Deferral options	The firm postpones the investment to gather information or wait for the best entry time to the market.	All natural resource extraction industries; real estate development; farming; paper products
Abandonment options	If market conditions decline severely, the firm can abandon current operations permanently and realize the resale value of capital equipment and other assets in second hand markets.	Capital intensive industries, such as airlines and rail-roads; financial services; new product introductions in un-certain markets.
Staged investments: sequential options	The firm partitions investment as a series of outlays, creates the option to abandon the enterprise in mid-stream if new information is unfavourable. Each stage can be viewed as an option on the value of subsequent stages, and valued as a com-pound option.	All R&D intensive industries, especially pharmaceuticals; long- development capital-intensive projects, e.g. large-scale construction or energy-generating plants; start-up ventures
Scaling options	The firm can expand, contract or temporarily shut down	Natural resource industries such as mine operations; facilities planning and construction in cyclical industries; fashion apparel; consumer goods; commercial real estate.
Growth options; barrier options	As early investment is a prerequisite or a Link h a chain or inter-related projects. The early entry and associated knowledge gained allow the firm to capture future opportunities.	All infrastructure-based or strategic industries. especially high-tech, R&D. or industries with multiple product generations or applications
Multiple inter-action options; compound options	The firm holds multiple real options in a project. The collection of options, both upward-potential enhancing calls and downward-protection put options present in combination. Their combined option value may differ from the sum of separate option values. i.e., they interact They may also interact wish financial flexibility options.	Real-life projects in most industries discussed.

2.6.2 A real-options approach to investment planning in competitive energy markets

The introduction of "smart grids" has required the combination of operational efficiencies with the costs of multiple technology options and functionality in order to reveal which combination of capabilities has the greatest potential value.

The restructuring of energy markets, which aims at the introduction of competition and an increase in economic efficiency, is a process that generates various risks and uncertainties that affect the energy sector. As the level of risk and uncertainty increases, traditional deterministic discounted cash flow (DCF) modelling approaches used for capacity investment planning need to be complemented by other, more sophisticated methods in order to deal with the potential fluctuations in both demand and price trajectories (Dyner & Larsen 2001, Venetsanos et al. 2002, Kagiannas et al. 2004, Olsina et al. 2006, among others). The real options (RO) approach to investment decision planning provides an attractive opportunity to evaluate investment alternatives in power generation in a deregulated market environment (Kumbaroglu, Madlener & Demirel 2008).

A main feature of the RO approach is the inclusion of the possibility of delaying an investment and evaluating the value of waiting as part of the decision-making problem, which allows for a much richer analysis than if this aspect was neglected. In addition, it may help to avoid erroneous conclusions from overly simplistic investment modelling, which has frequently been criticized (e.g., Venetsanos et al. 2002, Smith & McCardle 1999, Awerbuch & Berger 2003).

Case studies and examples of applying the RO approach to energy industry investment problems can be found in Ronn (2003), among others. Applications of the RO approach to investment planning in the electricity sector, however, have only started to penetrate the literature in recent years and are, therefore, still very limited in number. Frayer and Uludere (2001), for instance, conducted an RO analysis on two-generation assets in a regional market with a volatile electricity price. Keppo and Lu (2003) made use of the RO approach in order to introduce uncertainty for the electricity price, which is assumed to be affected by the investment behaviour of a large producer. Botterud (2003) studied three different decision-support models for long-term generation capacity investment planning in restructured electricity markets, one of which is based on RO theory. Botterud and Korpås (2004) used a real-options approach to investigate the adequacy of power-generation capacity in liberalized electricity markets and how/what regulatory mechanisms could ensure a sufficient electricity supply.

Takizawa and Suzuki (2004) studied the effect of electricity price regulation on the decision to invest in power plants, focusing on investment in nuclear power plants in Japan. Näsäkkälä and Fleten (2005) studied the value of the flexibility of peak-load and base-load gas-fired power plants by modelling the spark spread (i.e., the difference between the price of electricity and the cost of gas used for electricity generation) and analysing the threshold for upgrading a base-load plant to a peak-load plant. Laurikka and Koljonen (2006) explored the consequences of the EU emission-allowance trading scheme on investment decisions concerning a hypothetical 250 MWe condensing power plant to be built in Finland, taking into account the option value of waiting and the option value to alter the operating scale

2.7 Technology management and strategic decision making

There are generations of models of strategic planning; strength, weakness, opportunities and threats (SWOT) analysis was popular in the 1950s, while qualitative and quantitative models dominated in the 1960s. The understanding of strategy as applied by management has been transformed, but one element remains key: the aim of achieving competitive advantage. The concept of strategic planning, revived after almost 20 years and modified this time as contextual strategic planning, is a "process with particular benefits in particular contexts" (Mintzberg 1998).

Porter's models became the norm in decision-making from the 1980s, together with the shareholder value model. Porter (1996) introduced his model in his book *The Competitive Advantage of Nations*, after research into the 10 leading trading countries. He presented a theory of competitiveness based on the grounds of productivity on which companies compete. Porter discusses the structural analysis of industries with the five forces model. He defines three standard competitive strategies — overall cost leadership, focus and differentiation — offering an excellent framework for understanding competitor analysis, competitive moves, strategy towards buyers and suppliers, structural analysis within industries (strategic groups, strategic mapping, mobility barriers) and industry evolution (life cycle, evolutionary processes). Porter discusses competitive strategy within various generic industry environments, such as fragmented industries (with no real market leader), emerging industries, mature industries, declining industries and global industries. Also discussed are strategic decisions that businesses/firms can take, such as vertical integration (forward, backward, partnerships), capacity expansion and entry into new industries/businesses (Porter 1996, 1998, 2008).

Though Porter had important justifications for his concept, highly volatile and turbulent market conditions do not tolerate inflexible business strategies. Big businesses try to implement agility and responsiveness in such market and environmental conditions (Helo 2004). Market turbulence has drastic implications for firms' operations. If a company's business strategy cannot cope with the technological and market contingencies, its long-term survival becomes unrealistic. Diversifying strategic options for companies' project portfolios enables them to use the opportunities and prepare for the threats created by market conditions.

Critical analysis performed separately for cost-leadership strategy and differentiation strategy identifies elementary value in both strategies in creating and sustaining a competitive advantage. A consistently superior performance to that of the competition could be achieved with stronger foundations in the event that a "hybrid strategy" is adopted. Depending on the market and competitive conditions, a hybrid strategy should be adjusted regarding the extent to which each generic strategy (cost leadership or differentiation) should be given priority in practice.

Subsequent newer models of strategic planning were focused on adaptability to change, flexibility and the importance of strategic thinking and organizational learning. "Strategic alertness" is becoming more important than the strategy itself, because the organization's ability to succeed "has more to do with its ability to transform itself, continuously, than whether it has the right strategy. Being strategically agile enables organizations to transform their strategy depending on the changes in their environment" (Gouillart 1995).

In their 1978 book *Organization Strategy, Structure, and Process*, Miles and Snow (1978) argue that different company strategies arise from the ways in which companies decide to address three fundamental problems — the entrepreneurial problem (how a company should manage its market share), the engineering problem (how a company should implement its solution to the entrepreneurial problem) and the administrative problem (how a company should structure itself to manage the implementation of the solutions to the first two problems). Based on that, they classify companies into four strategic types: prospectors, analysers, defenders and reactors. No single strategic orientation is the best. Miles and Snow (1978) argue that what ultimately determines the success of a company is not a particular strategic orientation, but simply establishing and maintaining a systematic strategy that takes into account a company's environment, technology and structure.

One of the "smart grid" challenges is to integrate more renewable energy sources while managing energy balance with the higher variation. Various alternative energy sources have emerged with technological progress. Such innovation occurs by knowledge push, need pull and further development towards mass customization. Increased open innovation and users' innovation also contribute to technological progress. Sometimes, chance also plays a role in breakthrough discoveries, or they can appear apparently by accident. The research on emerging technologies done by Gartner created famous hype cycle for perception dynamics, which vary from very low at the technology triggering phase to high peak of inflated expectations, then down low again at trough of disillusionments to rice again on the slope of enlightment and reach the plateau of productivity. (Fenn & LeHong 2011)

Four main elements influence the spread of a new idea: the innovation itself, communication channels, time and a social system. Technology life cycles usually appear as an S-curve (Orlikowski 1992: 398). The speed of adoption is characterized by the features of the technology. Individuals are classified into five groups, innovators, early adopters, early majority, late majority and laggers (Moore 1991). This is because customers respond to new products in different ways, depending on their levels of readiness for adopting innovations. Only after mass adoption and the passage of time can it truly be judged as a success or failure.

Management of the change is seeking of a permanent transformation in the organization. This may mean constant change from multiple small steps rather than radical changes achieved in a single step. The success of the management of change requires designing a realization process, open communication, active participation and commitment to changing the projects (Laamanen et al. 2005: 57).

Uncertain environment conditions require that changes are made more quickly than the energy companies are able to respond; they must re-engineer themselves to become sense-and-respond (S&R) organizations. The same conclusion would be drawn if the company's production life cycle lagged behind that of its competitors (Kapoor 2005). In order to make timely, well-informed decisions, energy company executives must have a clear window into the operational health of the business and possess a suitable decision-support system. As Jacobsson and Johnson (2000) state: "This process needs to be studied using an innovation system perspective where the focus is on networks, institutions and firms' perceptions, competencies and strategies." That provides a more comprehensive view of processes' motions, which in turn helps organizations to act in their best long-term interests.

Innovation in organizations occurs by knowledge push, need pull and further development towards mass customization (see Figure 12), as described by Pine (1993).

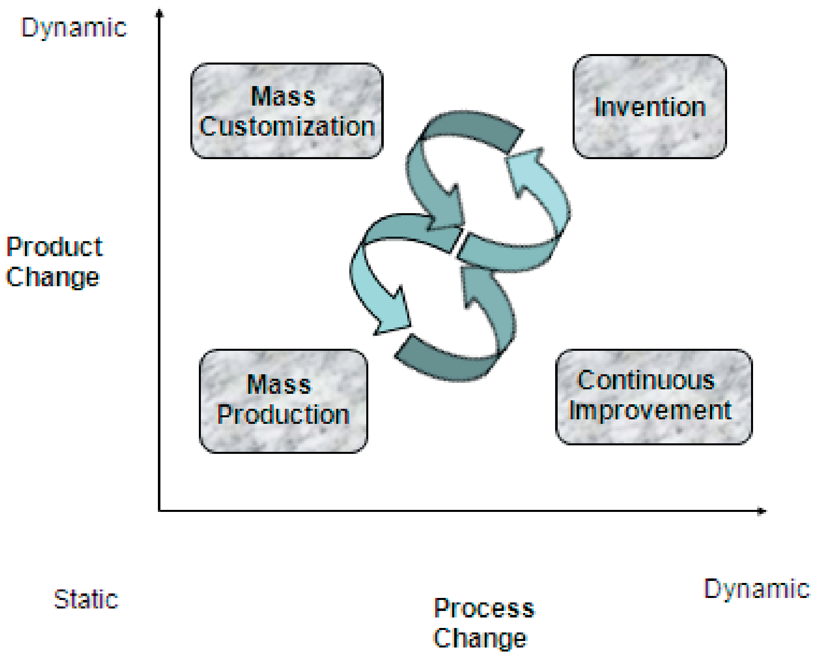

Figure 12. Path from mass production to mass customization adopted from (Pine 1993)

Deliberate research, market pull and technology push also spark innovation, sometimes even by accident. Effective enterprises have to adjust repeatedly to new policies, new technologies, new concepts and new products. Sorter product life cycles and planned by design obsolescence of represent additional problems.

According to Haeckel (1999), important factors in having a company strategy that allows for flexible changes are the processes answering the individual demands, the modular solutions reducing costs, teams and networking establishing important roles and the share of customers spending on a class of needs. S&R models help companies to anticipate, adapt and respond to continually varying environmental conditions. As Haeckel (1999) shows, large, complex organizations can adapt in a systematic way to the unpredictable demands of rapid, relentless change if the organization is designed and managed as an adaptive system. It is highly convenient for such an adaptation to build a Decision Support System DSS.

An adaptive management model is crucial in the effort to transform businesses into adaptive organizations. S&R systems consist of information-collection sensors, communication links, processors and responders. The design consist of proposing an operational structure capable of implementing focused decisions in a reasonable time and developing algorithms for optimally sensing and responding to the environment. Adaptive people, technologies and infrastructures are necessary but insufficient in themselves, because the redundancy of systematic change discourages the exploitation of adaptive capabilities. S&R systems fill the adaptive management gap. S&R framework systematically enhances adaptive organizational behaviour. (Kapoor 2005).

Examining the functional relationships within an organization reveals complex relationships between processes. A change in any layer requires verification with respect to higher layers as well as the spreading of the change to lower layers. In order to evaluate any decision or action in an organization, it is necessary to identify all the important interactions and to determine the impact on the entire organization.

To ensure that the implementation is driven by technology and business requirements, multilayer model-driven approach is used. DSS model of a business can be presented as hierarchy consisting of four layers, see Figure 13. This information-driven management practice provides specialized problem-solving expertise that is stored as facts, rules and procedures and requires a structured approach. Presented here is model of a business as a hierarchy consisting of four layers.

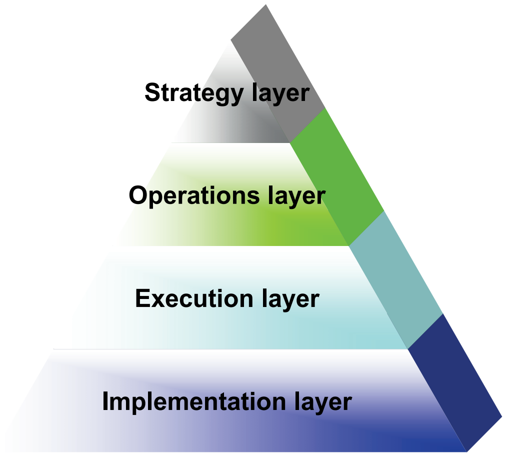

Figure 13. Firms Layer's Model Hierarchy adopted from (Kapoor 2005).

2.7.1 Strategy layer

An analytical hierarchy process (AHP) model specifies what the business plan aims to achieve a "strategy execution model" to distinguish it from the strategy formulation.

An AHP model's goal is to integrate different measures into a single overall score for ranking decision alternatives with a pairwise comparison of chosen attributes. An AHP model also allows considering quantitative and qualitative measures, and making trade-offs. The process is initiated by structuring the decision problems in a hierarchy of criteria, and then connecting the comparisons to get the weights of each criterion with respect to the goal.
Value for a competitive index is calculated for different types of business groups, such as prospectors, analysers and defenders, according to Miles and Snow's (1978) organization types. The index was calculated using normalized values of the main priorities: quality Q, time T, cost C and flexibility F. AHP process generates priority weighting for the decision attributes' quantitative evaluation of alternative technologies and solutions. The index have been calculated for the three strategic types: (Takala 2007)

- Prospector
- Analyser
- Defender

The objectives are compared pairwise according to their importance, so that the data in each subset (ideally) share some common trait. By combining existing sub-factors into category, (for example combining process improvement, process performance, R&D, knowledge management and customer information into transformation category) it is possible to calculate resource allocation weight needed to implement change. This approach has already been tested in a case study performed with two mobile phone operators for their internet-service providing departments (Toshev et al. 2008).

2.7.2 Operations layer

The resulting priority figures were analysed using a critical factor index (CFI) method, an evaluation tool that indicates which attributes of a business process are of critical importance and require intervention, and which are relatively stable, and is based on questionnaires gathering the experiences and expectations of the company's employees or customers. The CFI was developed on the basis of the Gab analysis and the implementation index. The method reveals mismanagements within the business process and therefore supports the management to form decisions concerning attributes' improvement.

The operations model describes what the business is hoping to achieve (different alternative-energy sources and technologies are evaluated with respect to strategic objectives) and how it measures its progress towards them (key performance indicators analysis).

The critical factor index (CFI) method that was used is a measurement tool that indicates which attribute of a business process is critical and which is not, based on the experience and expectations of the company's employees or customers. The CFI was developed on the basis of the Gab analysis and the implementation index by Rajala and Takala (2009). The method reveals which attributes are critical within the business process, and therefore supports the management to make decisions concerning which attributes should be improved. (Takala 2007)

2.7.3 Execution layer

This layer models management aspects of the process, including competitive and critical factors' indices calculation.

Benchmarking is also a part of the execution layer. It compares the operations and a service offered by the companies and provides information needed to execute them. Data, gathered through interviews and questionnaires, with additional information about manufacturing cycle times, costs, inventory, customer service and product prices tool for selecting potential benchmarking partners. (Ajmal, Helo & Kekäle 2010)

2.7.4 Implementation layer

The implementation model defines the actual information for the realization of the execution. It consists of data-acquisition tools and benchmarking tools. It models the management aspects of the process through simulation using historical data and Monte Carlo randomization for uncertainty

Correlation coefficient enables us to quantify the linear relationship between the variables. This statistic measures both the strength and direction of the linear relationship between the variables and allows us to test how well we can predict a dependent variable on the basis of multiple independent variables.

3 METHODOLOGY

The research methods were selected based on the information required to achieve the research objectives.

3.1 Descriptive statistics and correlation analysis

For macro-level risk evaluation, the volatility of daily electricity prices over a five-year period is used. Descriptive statistics of the electricity price's daily returns are presented. A time series analysis describes the correlation between the regions and countries to answer ***RQ1: What are the volatility levels of electricity market prices in the interconnected Nordic countries?***

Correlation refers to the strength of the relationship between two or more variables. A high correlation means that two or more variables have a strong relationship with each other, while a low correlation means that the variables are barely related (StatSoft 2011).

Longitudinal analysis of the uncertainty and risk factors in the industry was performed. The historical value curve and the correlation matrix of electricity prices describe the following research question: ***RQ2: How does Nordic electricity market affect the volatility of electricity prices?***

3.2 Value at risk

Calculation of Var, to study also ***RQ1: What are the volatility levels of electricity market prices in the interconnected Nordic countries?,*** requires the input of the following variables:

Holding period

The time window for which eventual losses will be projected can be referred as VaR holding period. VaR as a measure is time specific and can indicate both long term, month or quarter portfolio risk, as well as overnight positions risk (Venter 2000:3). General rule is that longer holding period carries greater risk due to the fact that absolute volatility increases over time. Trading VaR, revealed by most of the commercial banks, uses one day horizon. One reason for this is the liquidity and fast turnover in their portfolios, but most important, daily VAR allows to be easily compared with daily profit and loss (P&L) measures (Jorion 1997). As Minnich (1998:42) puts it VaR holding period should correspond to the time required to hedge the market risk. BCBS in Basel II proposed to regulators to scale from one day holding period to 10 days using the square root of time or =3.16.

Confidence level

Confidence level represents the tolerance level for which the loss estimated by VaR value can be surpassed. The Bank for International Settlement recommends 99th percentile, one-tailed confidence interval to be used, but a lot of risk managers prefer to calculate VaR values over a 95% confidence level, such as used in the JP Morgan's RiskMetrics methodology (Duffie & Pan 1997:9). The actual cost of a loss exceeding VAR and the degree of risk aversion are the main criteria when choosing confidence level. The bigger they are, the larger the need for capital reserves to cover possible losses. In such a case higher confidence level should be implied (Jorion 1997; Venter 2000). The choice of the confidence interval may not be so important if VaR is used to compare risk across markets. Researchers provide evidence that 95% confidence interval performs best under backtesting because of the existence of "fat-tails" (Minnich 1998:42).

Data window

When calculating VaR risk professionals have to choose how much historical data to include in the model, or how long the data window should be. Minnich (1998:43) argues that longer periods have return distribution containing more examples of extreme events, while shorter periods allow VaR values to react quicker to changing market.

Return value is calculated by using historical changes in market prices to construct a distribution of potential portfolio profits and losses in the future, and then reading off it the VaR number as the loss that is exceeded only a certain percentage of the time (Linsmeier & Pearson 1996: 7). The behaviour of VaR models with 99 % and 95 % confidence levels, using rolling data windows of 100 and 250 days, is analysed with the help of a range of backtesting procedures. The observed VaR measurement levels are explicated as beta systematic risk in the management of projects for the development of an advanced electrical grid.

3.2.1 Historical and Monte Carlo simulations

Simulating a system with real-world uncertainty requires that uncertainty to be quantified and included in the calculation. This can be done by using probabilistic simulation. In such a simulation, one can explicitly represent uncertainty by specifying inputs as probabilistic distributions. The model is computed multiple times and, each time, all which is run is the uncertain parameters, which are sampled randomly. This system is then simulated over time such that the performance of the system can be computed; these results in a large number of separate independent results, each representing a possible future state of the system that is uncertain, and the result will be in itself a probability distribution. Probabilistic simulation allows a view of the whole range of possible outcomes. The key output of such simulation is the likelihood of any outcome; for example, if you simulate complex projects, one can predict that the likelihood of the project being completed on time and on budget is 15 %. Alternatively, for the new renewable energy generation, a 24 % probability means the system will not be able to meet demands the following year. Probabilistic simulation of complex systems helps us to evaluate how systems will evolve over time and predict their future behaviour, while quantitatively addressing the inherited variability and uncertainty that is present in real-world systems. It also allows decision makers to evaluate, compare and optimize alternative designs, plans and policies in order to minimize risk and make better decisions in an uncertain world.

Commonly used simulations consist of the following steps:

1) Use mathematical equations to model the variables and recognize the interdependencies among them for different time periods.

2) Identify variables' probability distributions.

3) Using Excel's random number generator, create a random sample. Then assess the cumulative distribution function and, in the same way, generate another inverted random variant.

4) Repeat Excel's randomization function numerous times and calculate the statistics of the sample results, such as the mean and standard deviation, to obtain the estimate.

The two simulations that will be conducted — the historical and Monte Carlo, belong to the full-valuation VaR methods. They measure risk by changing the full price of a portfolio over different scenarios. The historical simulation method consists of going back in time and applying current weights to a time series of historical asset returns. This approach is also known as bootstrapping because it involves using the actual distribution of recent historical data (Jorion 2000). Let

$$r_t = \log(\frac{p_t}{p_{t-1}}) \qquad (20)$$

be the returns at time t, where p_t is the price of an asset or a portfolio at time t. $VaR_t(\alpha)$ at the $(1-\alpha)$ percentile is defined by:

$$\Pr(r_t \leq VaR_t(\alpha)) = \alpha \qquad (21)$$

which calculates the probability of returns at time t to be less than or equal to $VaR_t(\alpha)$, α percentage of the time.

3.2.2 Scenario planning

Scenarios are a tool to help identify effects of Technological Uncertainty and Market volatility and study the probable dynamic relations between, operational management and strategic planning. In the phase of the research, technology development scenarios were generated from the collected information in order to inspect companies' management. Scenario planning and strategic-planning methods were used to devise flexible, long-term tactics. When disruptive technology as additive manufacturing comes to maturity phase and reaches exponential growth managers have to be aware with the current state of the art systems and understand what new possibilities there are to diversify company projects portfolio. ***RQ5: How will the progress of additive manufacturing affect "smart grid" technologies?***

Simulation workshops also allow managers to carry out "what if" scenario analyses and assess the impact of decisions before they are implemented. It can perform a historical simulation — a simple approach that requires relatively few assumptions about the statistical distributions of the underlying factors. It consists of using historical changes in market-price rates for energy to construct retroactive distribution of profits and losses based on the current status of operational effectiveness. From the historical simulation, the mean return and volatility of the energy production parameters can be derived. These parameters will be used to describe the stochastic process in Monte Carlo simulation, which introduces a pseudo-random number generator (noise in the system due to an uncertain and volatile environment) and computes a fictitious future path. It combines traditional statistical forecasting techniques with a volatility/uncertainty function visible for the current time period. It improves on baseline forecasts.

3.3 Real options

Net present value NPV and real options were used to calculate the portfolio investment. The same methods already described in the theoretical framework part were used for these calculations in order to analyse the following research question: ***RQ4: What is the value of investment in "smart-grid home" systems?***

A real options approach is chosen to value the investment in a competitive energy-market technology. Other capital budgeting measures, such as the cost of capital and the time value of money, are calculated for smart grid technology project. The Black-Scholes options pricing model uses a risk-free rate and is easy to use through a closed-form equation to estimate the value of European put and call options.

Binomial approximation can model many types of options where the Black-Scholes method is not applicable. It also uses a risk-free rate and delivers a clear decision roadmap for each time period.

These two methods are applied to value real projects and physical assets. After collecting the necessary data for their evaluation, a smart-grid R&D project's value is calculated as a real option.

Market uncertainty affects choices of investment in resources, using the R&D approach to express technological uncertainty, depending on the evolution of the technology.

3.4 Market prices and companies data-collection

3.4.1 Secondary data

Daily system electricity prices were collected from Nordpool Spot database for Finland, Sweden, Norway and Estonia during the period 2012–2014. As an internal source, the Nord Pool Spot market releases hourly price, daily price and day-ahead price reports. External secondary data include the Electricity use per person vs. Gross Domestic Product GDP per person 1960-2010, total generated electricity versus total used electricity, for Finland, Sweden and Norway and Electricity used per person versus electricity generation per person for Finland, Sweden and Norway for the period 1990 till 2008 for Finland, Sweden and Norway, available from World Bank reports on Electric power consumption and British Petroleum statistical review of world energy. (World Bank Group. 2010; BP Group. 2013).

3.4.2 Case companies and primary data

Primary data collection was conducted during the course of a research project lasting two years. A team of five researchers was studying three manufacturing companies. As a means of applied research, analytical surveys with three to five experts from each company were undertaken, with additional information about manufacturing cycle times, costs, inventory, customer service and product prices. The researchers gathered the experts' opinions on grouping factors in the decision-making process. These factors here ordered in hierarchy and AHP questionnaire with a pairwise comparison was generated with "Expert choice" software. In the following workshop sessions the company's managers and employees administered this questionnaire. They filled in the provided questionnaire via either a paper format or by using the online web-based tool. Based on the answers of the pairwise comparison, calculations allowed the determination of an importance weight-value for each factor and the comparison of overall ranked criteria in a complete synthesis. In this way, an AHP permits decision makers to institute a multi-focused strategy, balancing factors as is appropriate for their specific targets (Saaty 2008).

The researchers combined individual judgements in company profiles and ranked the consistency of the answers to validate the logic of the respondents. Importance weight-values are a measure of current resource allocation and a foundation for estimates about the effect of reallocations.

An AHP model was used to represent operations infrastructure, based on dynamic performance targets. Strategic attributes were grouped and compared according to their importance, see Figure 14. The analytical hierarchy process (AHP) is multi-attribute decision instrument that allows consideration of quantitative and qualitative measures and making trade-offs (Saaty 1988). Alternatives and the criteria are compared in pairs with respect to each element of the next level higher, acquiring the priorities and weights of each criterion with respect to the goal. The local priorities are then multiplied by the weights of their respective criteria. The results are summed up to get the overall priority of each alternative. Questionnaire results were analysed using the "Expert choice" software.

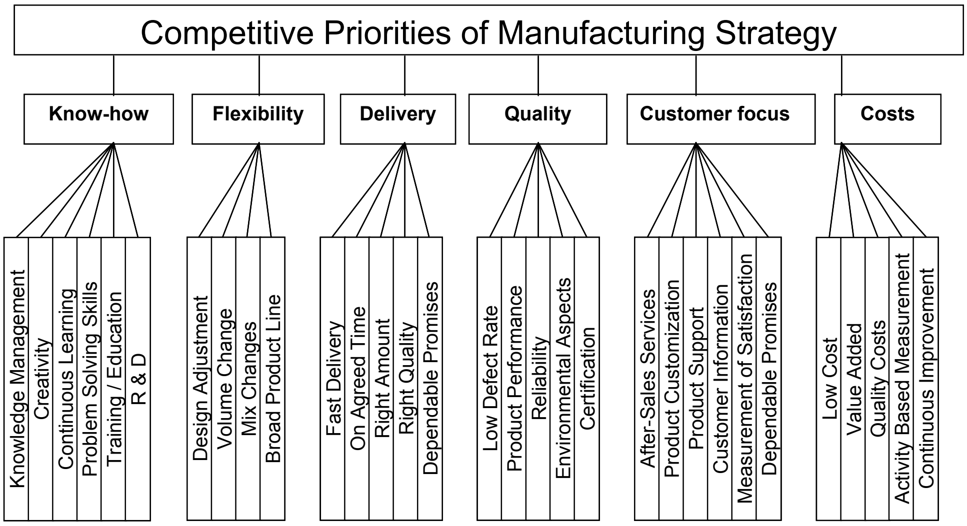

Figure 14. Manufacturing strategy priority structure adopted from (Takala 2002)

Computation of results start with the AHP weights of the major operation criteria cost, quality, time (their normalized values if there are more major criteria) serve as a basis for the calculation a competitive manufacturing index (CMI).

Prospector

(22) $$1-\{(1-Q\%^{\frac{1}{3}})(1-T\%)(1-C\%)\times F\%^{\frac{1}{3}}\}$$

(23) Analyser

$$1-\{(1-F\%)\times(ABS\,(\Delta Q*\Delta T*\Delta C))^{\frac{1}{3}}\}$$

Defender

(24) $$1-\{(1-C\%^{\frac{1}{3}})(1-T\%)(1-Q\%)\times F\%^{\frac{1}{3}}\}$$

These case studies are an empirical enquiry to observe data for the general ways in which the companies operate.

The first company, Company V, is a Finnish manufacturer that develops automation, drives and power-distribution solutions for the energy and process industries, mainly in Europe and mainly for heavy-industry customers such as paper mills and power plants. It offers a range of services aimed at electrification and industrial process applications. The company manufactures control systems according to customers' design specifications, as well as boards, panels and cubicles. Its systems are used by power plants, process industries, cranes and ships worldwide. They manufacture distribution systems; customized, independent line-up and system drives for demanding industrial, offshore and ship applications. The study included market research on the wind-power markets of Sweden and Norway, and workshops on wind-power services roadmaps, business models and partner networks. In addition, two interview rounds with both a general and a more specific focus on network risks took place. The project also included an S&R questionnaire study that looked into operation strategies of Company V, and discussed the issue of transformational leadership. In the questionnaire study, a special focus was also given to the prospects for an energy-storage solutions development.

The second company, Company S, is a Finnish manufacturer of advanced drive-train technology, permanent magnet machines and converter packages. The main areas of expertise are wind, marine and special industrial solutions. The company's innovative drive trains serve power generation and energy operations. Company S has facilities situated in Asia near a wind park. In addition to the company strategic questionnaires, primary data from the company's component performance and secondary data of average wind speed from the local weather sensors were used for part of the study.

Company E develops, manufactures and markets electricity distribution systems. Their products comprise medium-voltage and low-voltage switchboards and related systems for electricity distribution by industries and energy utilities. Transformer products represent their special expertise. They have developed quality products systematically over the past 20 years, relying on proficient personnel. Company E implements demanding projects in the distribution networks of industries, various buildings and energy utilities.

The experience and expectations of the companies' employees were measured using a separate questionnaire, see Table 8. Structured questions were compiled in closed-ended questionnaires, and a scale ranking expectations and experience from 1 to 10 was used.

Table 8. Sample questionnaire adopted from (Takala 2007)

	Expectations	Experiences	Compared with competitors (Please tick your option)			Direction of development (Please tick your option)		
	(1-10)	(1-10)	Worse	Same	Better	Worse	Same	Better
Attribute 1	[ ]	[ ]	☐	☐	☐	☐	☐	☐
Attribute 2	[ ]	[ ]	☐	☐	☐	☐	☐	☐
•	[ ]	[ ]	☐	☐	☐	☐	☐	☐
•	[ ]	[ ]	☐	☐	☐	☐	☐	☐

The direction of the experienced values of the sample during the last three years.

3.4.3 Critical factor index

The critical factor index (CFI) was developed on the basis of the Gab analysis and the implementation index. The CFI was represented by formulae developed by Ranta and Takala (2007), with a modified form as follows:

$$\text{CFI} = \frac{\text{Standard deviation of expectations} * \text{Standard deviation of experiences}}{\text{Importance index} * \text{Gap} * \text{Direction of development}} \quad (25)$$

$$\text{Importance index} = \frac{\text{Average of expectations}}{10} \quad (26)$$

$$\text{Gap} = \left|\frac{\text{Average of the experiences} - \text{Average of expectations}}{10} - 1\right| \quad (27)$$

$$\text{Direction of development} = \left|\frac{\text{Dir. of dev. (better)} - \text{Dir. of dev. (worse)}}{10} - 1\right| \quad (28)$$

The CFI model has been applied in many studies of quality, maintenance, production, knowledge management, etc., for example, in Ranta and Takala (2007) and Takala et al. (2007). Information that had been gathered was analysed, and scaled CFI measurement tools were applied to determine the critical attributes that needed improvement.

Workshops, performed in groups with researchers and selected personnel, were organized to collect information using the constructed questionnaires. The answers to the questions revealed risks. Using comparative metrics, a ranking value was calculated for these factors and the most critical ones are highlighted for debate. ***RQ3: How does prise risk and technological uncertainty affect company strategies?***

AHP and CFI analyses constructed the framework for strategic types' evaluation and the process of re-engineering the organization. Such a framework helps decision-making by systematically assessing the alternatives for a decision over a period of time and the ways in which they affect the overall hierarchical structure. There is a certain amount of uncertainty associated with each outcome. The analysis uses a hierarchy tree model with decision alternatives and chooses the best alternative according to its expected value.

Decision analysis allows multiple decisions and uncertainties over time. The choice between probabilities is a subjective one (De Neufville 1990). Smith and Nau (1995) demonstrate that traditional decision analysis can produce results similar to those of the real-options pricing methods. These two approaches can be combined to extend option-pricing methods.

Hypothesis testing

Four hypotheses were devised by this research to test the significance level between the choices of R&D investments, companies' operational competitiveness and technological uncertainty and risk.

Financial investors in the marketplace evaluate the firm according to its R&D decisions; therefore, market and technological uncertainty, real options and firms' values can be linked within a comprehensive framework.

H1*: An increase in the volatility of electricity market's price will increase the value of technology investment.*

In order to evaluate the amount of R&D investment capital needed over a given time period, companies' real options were calculated to test the following hypotheses:

H2: *Strategic choices of companies are affected by electricity market price volatility.*

H3: *Companies' operational competitiveness is affected by technological uncertainty.*

Correspondingly, the author performed a cross-sectional analysis of the energy market in order to identify operational efficiency and the future outlook of the target company. This allowed me to weigh the target company's efficiency in technological areas and to make the best investment choice from a group of competing emerging technologies within the industry as a whole.

4 RESULTS

4.1 Electricity price analysis

For the first part of the result section daily system electricity prices were collected from Nordpool Spot database for Finland, Sweden regions 1 and 3, Norway region Tromso and Estonia during the period 2012–2014, for which there was matching data sample for the . System price is also known as the 'unconstrained market clearing price. Volatility and correlation coefficients were calculated in order to examine RQ1 ***What are the volatility levels of electricity market prices in the interconnected Nordic countries?*** and generally evaluate if the sector is safe for investments. Figure 15 presents Nordic countries bidding areas and there electricity interconnections. As seen, Finland constitutes a single bidding area that is connected with Norway region 4, Swedish regions 1 and 3 and Estonia. The set of data was extracted from http://nordpoolspot.com/ for the daily electricity system price in these connected areas. A risk-explanatory longitudinal study of energy prices was conducted, together with a VaR risk evaluation, for the collected historical information.

Figure 15. Nordic electric network interconnections map (Source: Nordpool Spot 2010)

When compared in a timeline, el. prices display four sharp peaks, with two cases when price topped 100 euro scale, see Figure 16. We see el. price jump for all the countries on 2.02 2012 with Finland and Swedish Stockholm region 3 experiencing maximum value of 101,3 EUR/MWh. The next peak is 5.12 2012 when Finnish price reached 94,41 EUR/MWh, while other countries does have 53,12 and 46,9 almost double lower. In the following period only Estonia experiences really high peaks on 25.06.2013 and with a price of 103,85 and 93,94 EUR/MWh respectively. The other represented countries do not have abnormal price jumps on that dates.

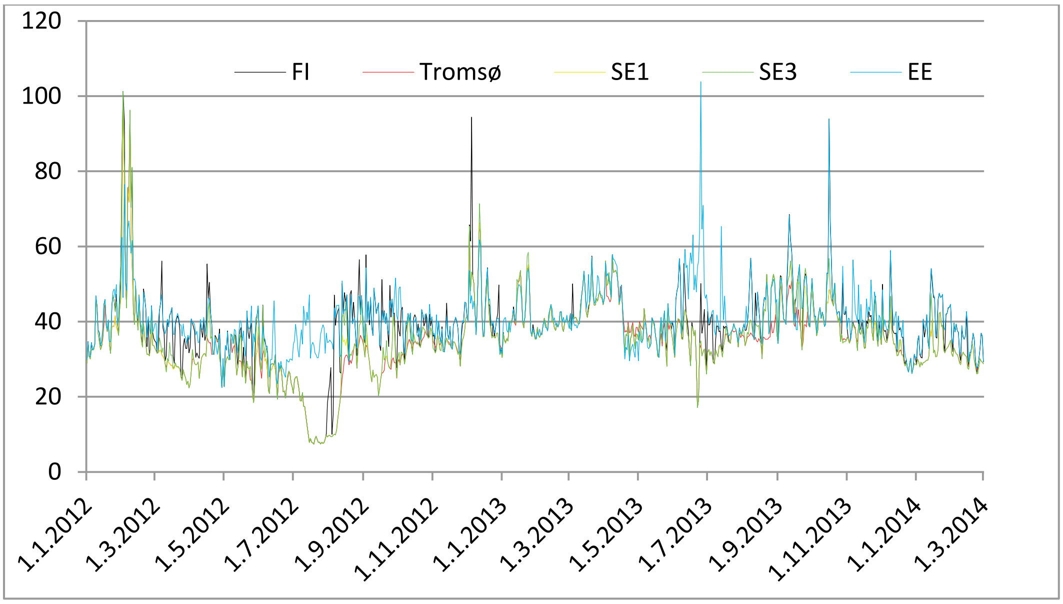

Figure 16. Electricity spot prices for Finland, Sweden, Norway and Estonia 2012-2014 (Source: Nordpool Spot)

The electricity market has a yearly cycle. Factors like climate, external temperatures, population size correlate with electricity prices. Although this is a relatively short observation period, it is long enough to calculate the VaR values for the historical and Monte Carlo simulations later on. It is important to note that peaks appear less systemic and more isolated to single region. This may indicate improvement to the resilience of the market.

Table 9 presents the correlation matrix of the countries and regions' electricity prices. Sweden, region 1 and Norway Trondheim have the closest price match, while Estonia and Sweden, region 3 have the biggest price difference.

Table 9. Correlation matrix electricity prices

Correlation matrix electricity prices					
	Suomi	*Norway*	*Sweden 1*	*Sweden 3*	*Estonia*
Suomi	1				
Norway	0,824046	1			
Sweden 1	0,851359	0,977345	1		
Sweden 3	0,868549	0,961188	0,985646	1	
Estonia	0,706957	0,545099	0,578605	0,598189	1

Table 10 presents the yearly average volatility numbers for the five regions. With the operation of Nordpool market average volatility levels are decreasing for the Scandinavian countries but increasing for Estonia.

Table 10. Average volatility by region for 2012, 2013

Year	Average volatility FI	Average volatility Tromsø	Volatility average SE1	Volatility average SE3	Volatility average EE
2012	5.55	2.76	3.22	3.64	4.03
2013	4.08	2.30	2.82	3.04	4.30

4.2 Risk returns analysis

The Finnish electricity market has a yearly cycle, which is correlated with external temperatures. Seasonality can be observed as during winter we can generally observe hike in el. price (volatility graph shown in Figure 17). Market data was collected for Finland 2011-2013.

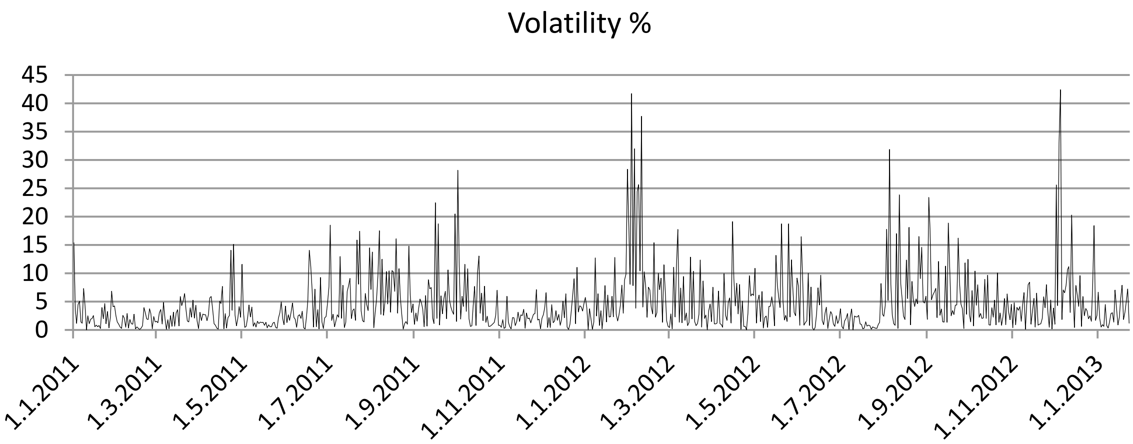

Figure 17. Volatility graph Finland 2011-2013

Based on the daily el prices the author calculates profit and loss over hypothetical electricity portfolio. Histogram of daily profit and loss for the period 1.1. 2011 to 1 1 2013 is presented on Figure 18. In order to provide a graphic comparison between the returns histogram, the normal distribution and Student's t-distribution, a distribution fitting is presented.

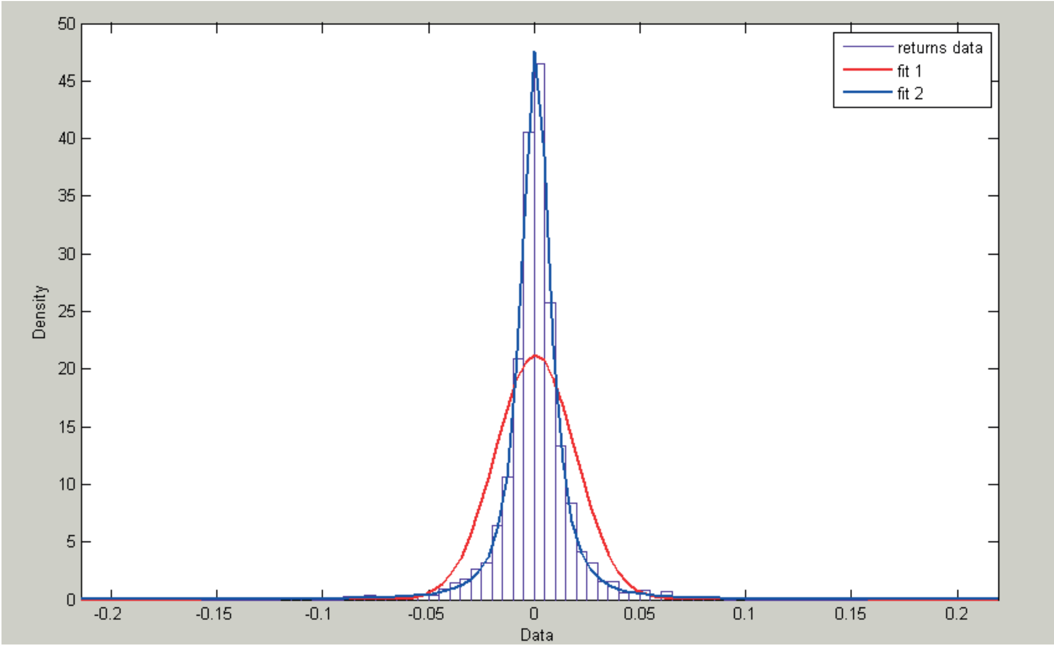

Figure 18. Electricity Daily Profit/Loss Distributions vs. Normal & Student's T

Student's t-distribution fits the realized historical returns much more closely than the normal one do.

Descriptive statistics of electricity-price daily returns are presented in Table 11. The mean value shown in column one is almost zero, with a relatively high standard deviation compared to normal distribution. The kurtosis value of 6.6 is twice as big as the normal distribution, indicating a higher peak (see the histogram in Figure 18) and positive skewness indicates fatter right-tail positive returns.

Table 11. Descriptive statistics of the Finnish electricity prices volatility 2011-2013

Daily Profit and Loss

Electricity Price	*Mean*	*Standard Deviation*	*Kurtosis*	*Skewness*	*Range*	*Minimum*	*Maximum*
Finland	-0.0003	0.1802	6.6124	0.3877	2.1514	-1.0213	1.1301

Over the three years, we observed a volatility of 18.02% in electricity prices. Figure 19 presents a QQ-plot of electricity and fuel returns compared to normal distribution.

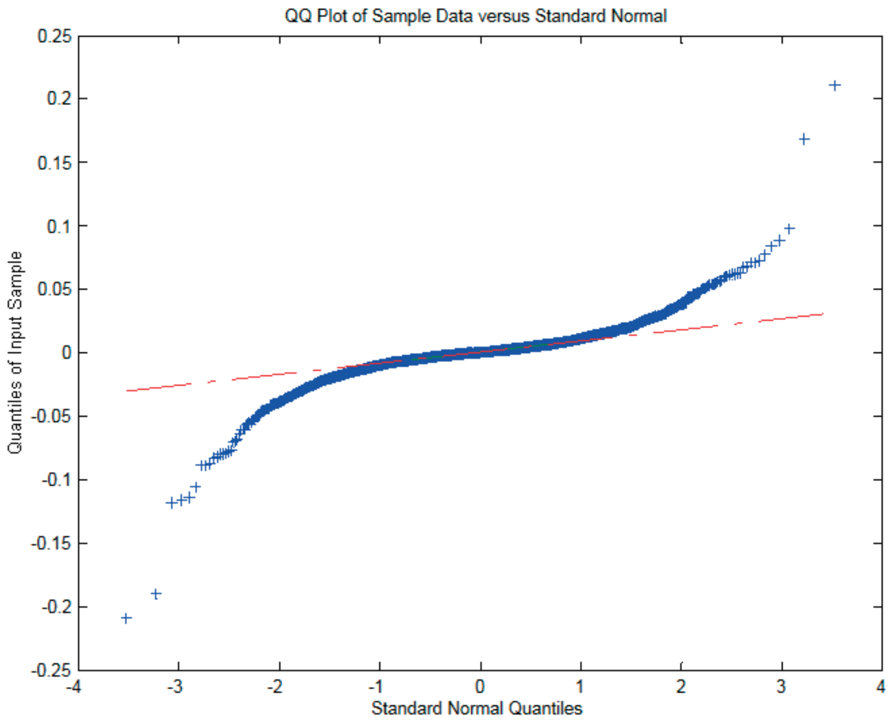

Figure 19. Quantile Quantile plotting of Electricity Returns

The difference from the red line at the extreme positive and negative values, as well as the other results obtained so far show that a normal distribution assumption poorly describes the fat tail and sharp-peak characteristics of the electricity market. In such case Student's t-distribution may work better. It can be said with great certainty that the market's returns are not normally distributed.

4.3 Value at risk analysis

The tested VaR models are a historical simulation with a rolling window of 365 days and a Monte Carlo simulation. To illustrate the rolling window technique, take a window size of 250 days. The time interval is placed between the 1st and the 365th data points. Then, a VaR value forecast is obtained for the 366th day. The window is moved one period ahead to the 2nd and 366th data points in order to obtain a forecast for the 367th day's return, and so on for the whole period under observation.

The realized daily returns values are calculated using HS and MCS with data windows of 365 days at a 95% and 99% confidence level, as presented in Figure 20 and Figure 21. For the MCS procedure, 100 random draws from the normal distribution (with the mean and standard deviation calculated from the previous observed real historical returns) were produced for each trading day throughout the year's historical data. The MCS VaR is calculated as a percentile of these daily pseudo distributions.

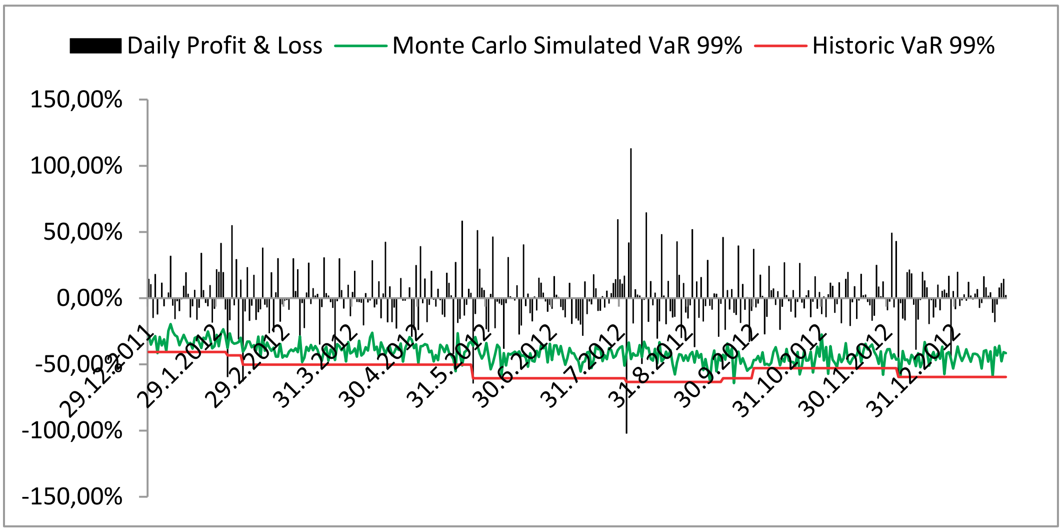

Figure 20. Historic and Monte Carlo simulation for VaR 99%

VaR violations, when the loss is bigger than the VaR level, are clearly visible and they are acceptable in 1% of the time, or 3,65 violations for the Var99%. and 5% or 18,25 violations for Var95%.

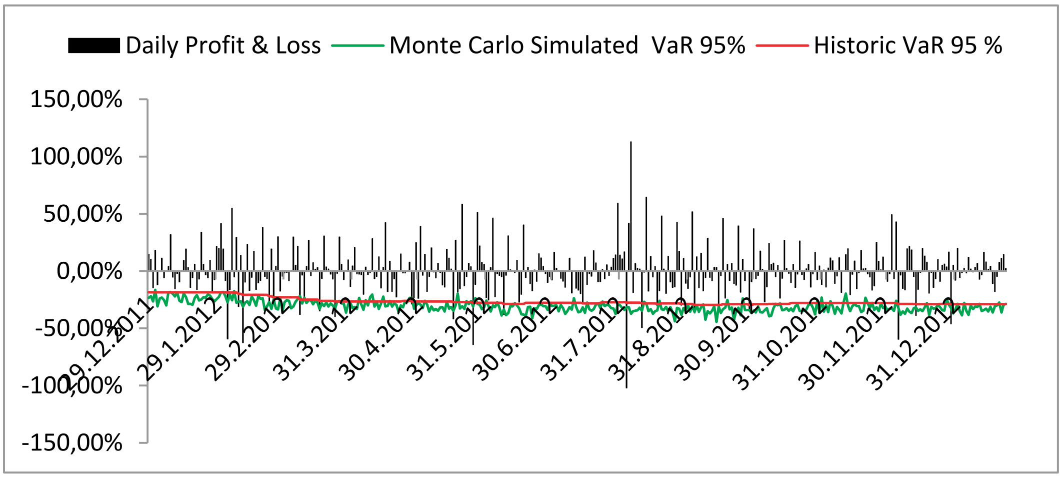

Figure 21. Historic and Monte Carlo simulation for VaR 95%

From the figures, it can clearly be seen that for a 99% confidence level, historical simulation produces fewer violations and has a higher cut-off rate, while for a 95% confidence interval, a Monte Carlo simulation is the prevailing risk model. This can be explained with reference to the relatively high volatility, as mean and standard deviation parameters for MCS calculations are otherwise derived from the historical electricity price returns.

Table 12. Average VaR values

Average VaR over one year	*VaR 99%*	*VaR 95%*
Finland Historical simulation	-54.52%	-26.43%
Finland Monte Carlo simulation	-41.36%	-30.60%

Average values for all calculated VaR models during the whole observation sample are presented in Table 11. These values will be used as a relative risk measure over the period of one year for the purposes of scenario planning.

Different VaR models appropriately capture the electricity market risk in the EU member state of Finland. The biggest possible daily loss form holding electricity portfolio is just over 30% for 95% of the year, and with 99% confidence one can expect loss smaller than 54%. It can be concluded that the electricity sector is generally safe for investment.

4.4 Scenarios in electricity market and smart-grid technology development

Many different scenarios for the future development of the energy market and the economy can be considered, depending on the time horizon and geographical regions. Uncertainty increases with geopolitical factors, including requirements for energy independence, renewable energy integration, natural disasters, technological developments, etc. The global economic situation in the six major regions of the EU, the USA, Japan, the BRIC countries, Asia and the rest of the world for the last 50 years shows a constant growth of the demand for electricity and energy as a whole. Historical data show a clear correlation between population and economic growth and the demand for energy.

In this dissertation two scenarios are described to identify promising technological innovations and study the effects of Technological Uncertainty and Market volatility. In-depth interviews, surveys, questionnaires, case studies and action research were carried out to gather a critical mass of information for the scenarios framework. Using varying methods allows for both cross-sectional analysis of the electricity market's present situation and a longitudinal analysis of the uncertainty and risk factors faced by the industry. The models are organized around the competition between technologies. Analysing key uncertainties and alternative paths for development of technology, we created two different scenarios revolving around the issue of energy.

– Fossil fuel and environment sparked volatility
– Technological innovation

In such a way the author evaluate innovation opportunities and investments and reveal dynamic relations between operational management and strategic planning.

Historical perspective

When looking at the issue from a historical perspective, the share of primary energy sources over a 200-year time span changed from wood dominated to coal, then to oil and natural gas, combined with the rise of Nuclear power after World War Two. The macro-level market analysis of the share of global prime energy for the last 165 years shows a transition between different fossil sources after the wood-burning period. As people become richer they generally use more energy. Prices and technology will drive the transition to smart grid. With the development in technology for generating electricity from renewable energy sources, we expect that diverse sources will emerge at a rapid pace, greater than that of the past.

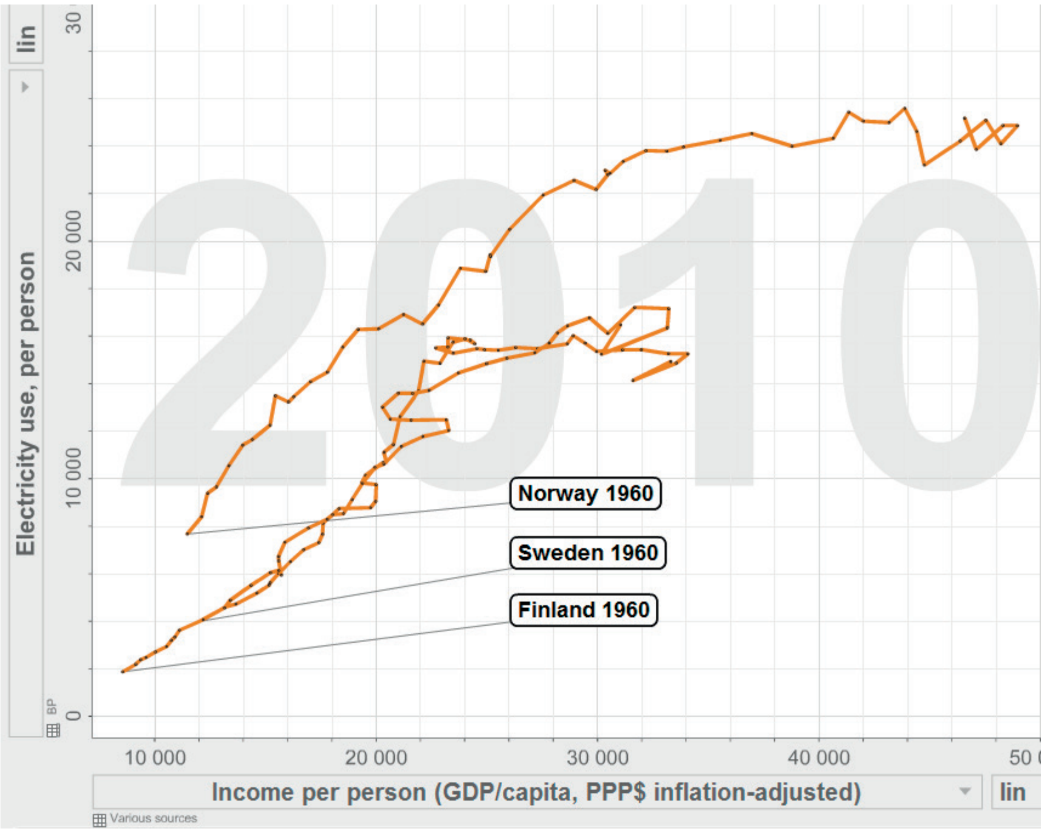

Figure 22. Electricity use per person vs. GDP per person 1960-2010 for Finland, Sweden and Norway. (World Bank Group. 2010; BP Group. 2013)

Considering this Scandinavian group, Sweden and Finland fall into the northern European regional profile, while Norway is an oil- and gas-exporting country. During the 18-year period, these three countries occupied the top right-hand corner of the graph with high levels of both energy usage and energy generation, sharing it with seven other countries, namely Denmark, the United Arab Emirates, Qatar, Kuwait, Canada, Australia and the United States. As developed economies all three countries climb the energy ladder following less energy intensive paths (see Figure 22).

Figure 23 shows a comparison of the total electricity used versus total electricity generated for Finland, Sweden and Norway from 1990 to 2008.

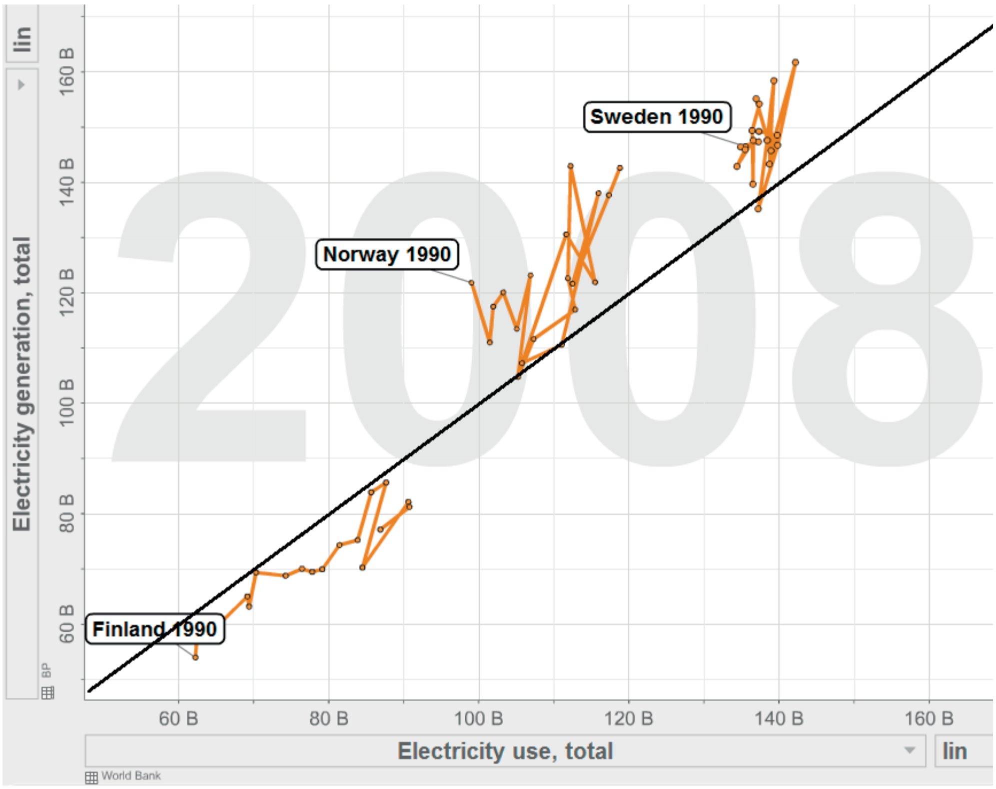

Figure 23. Total generated electricity versus total used electricity for Finland, Sweden and Norway for the period 1990 till 2008. (World Bank Group. 2010; BP Group. 2013)

Sweden has the highest productions and consumption with Norway second and Finland showing lowest values. The equilibrium line presents the balance of use and generation. Norway and Sweden are above it, meaning they produce (and export) more electricity than they consume, except for short time during 1996 and 2004 for Norway, and 2003 for Sweden, when they reach equilibrium. For Finland the opposite is valid.

When comparing el. production and consumption per capita, Figure 24, Norway shows clear lead and Finland taking long path to cluster close together with Sweden 2002-2008. Still clearly Finland used more electricity than it produced for the whole period, coming closest to equilibrium in 1996 and 2003.

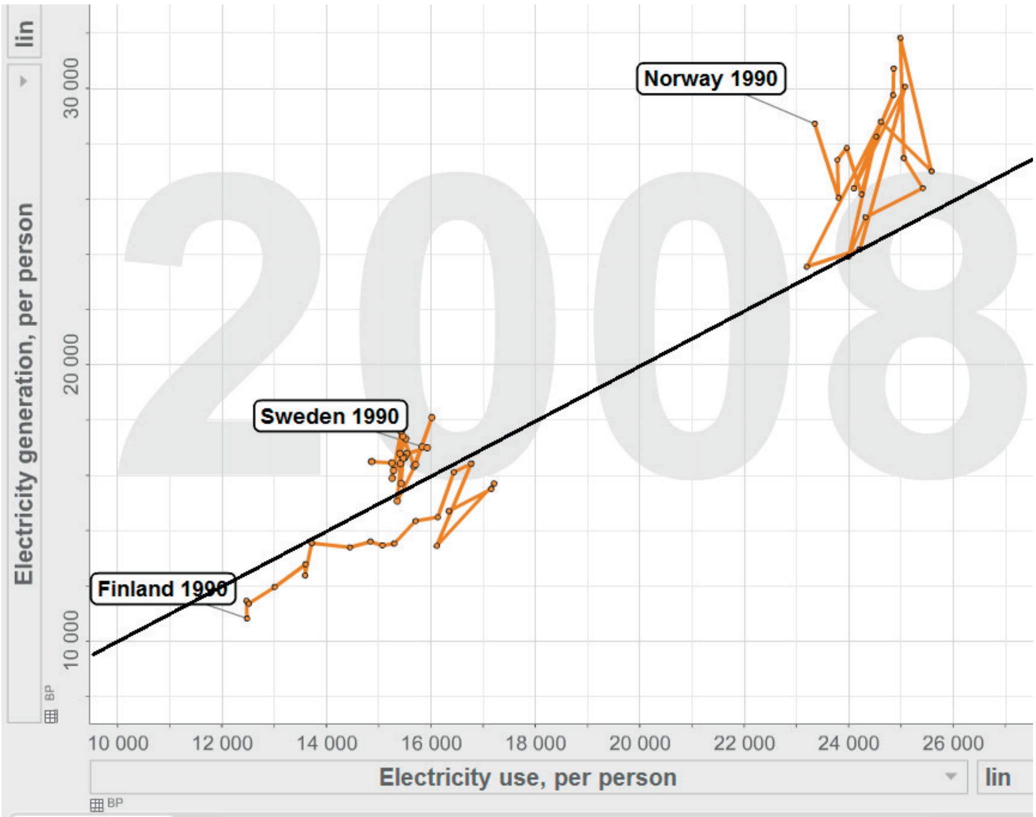

Figure 24. Electricity used per person versus electricity generation per person for Finland, Sweden and Norway for the period 1990 till 2008 (World Bank Group. 2010; BP Group. 2013)

4.4.1 Scenario 1: Fossil fuel and environment sparked volatility

Considering the rise in energy demand, the slowing rate of discovery of new deposits for all fossil fuels, combined with the environmental effects of pollution, we can expect a higher volatility of energy prices in the market in the first scenario. The "peak oil" era and increasing world population, creates a disproportional effect on the socio-economic balance in society. Such challenges require global efforts and consensus that are not possible to reach in turbulent political and market environment. Countries make fragmented efforts to implement smart grid technologies, based on their own energy needs and geopolitical agenda. In such scenario the pace of innovation is slow. Breakthroughs are slow to get to mass market and their effect is weak.

From investment point of view in short term interval of 2 to 5 years there should be little changes in the value of projects and traditional linear forecasting method may produce similar results like the more advanced real option pricing. That's why the author focuses on the second scenario, as it covers viable technology opportunities for the near future.

4.4.2 Scenario 2: Technological innovation

Renewable energy technologies such as wind and solar are long-lasting investments with variable outputs to the grid. Wind power and solar power should provide 20% of Europe's energy by 2020 and 11%–12% of global electricity generation by 2050, according to the ENERGY Map scenarios. With large shares of these technologies, aiming at 20% until the year 2020, steps would need to be taken to ensure the continued reliable supply of electricity. A constant balance of supply and demand is essential to achieve widespread usage of renewable electricity generation (Inage 2009).

To design this scenario, we looked at the alternative routes of innovation, opportunities and threats, bottlenecks and drivers of smart grid business in the Nordic market area. Roadmap work for innovation in the energy sector begins with evaluating factors affecting the business. Scenario 2 also investigates additive manufacturing and energy storage technology needed in mid- and long-term settings. In order to have large shares of variable renewable energies, the power systems must be prepared adequately. The right combination of policy, technology and commitment from governments, industry and society globally is the right way to achieve these goals. As there is no one single solution for energy need of all different regions new technology combinations start to emerge and variable renewable sources are integrated into "smart grid systems"

For longer periods, uncertainty can remain low, assuming the excellent functioning of the Nord Pool Spot market for a project lifespan of 10 years. Electricity generation from renewable sources, intelligent home-energy management systems and smart-grid distribution projects are some of the technologies that can emerge as oysters on the energy-technology roadmap. ***RQ5: How will the progress of additive manufacturing affect "smart grid" technologies?***

The Technological innovation scenario framework consists of:
- Additive manufacturing technique
- Energy storage
- Smart grid and home automation
- Renewable energy integration

Additive manufacturing technological opportunities

In this section, we will consider examples of emerging technologies with the strong potential to offer a disruptive innovation, such as an open-source innovation like AirEnergy 3D — A 3D-printed, open-source, mobile wind turbine that prints solar cells using a metal 3D printer.

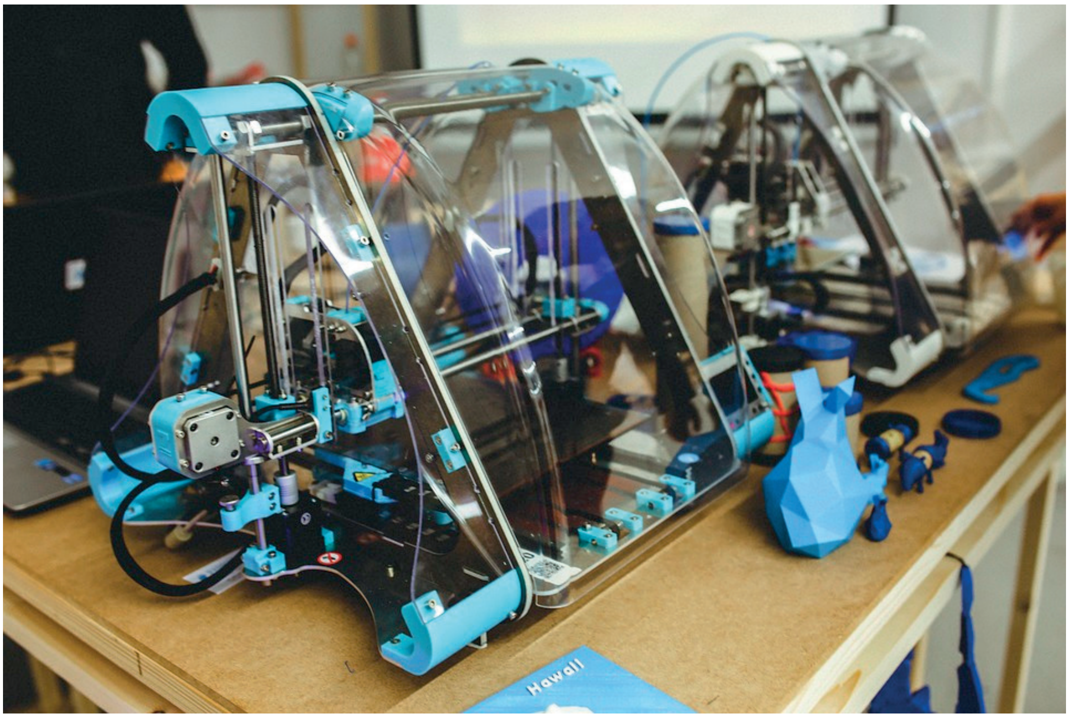

Figure 25. 3D printer REPRAP , self replicating its own plastic parts source:pixabay released under Creative Commons CC0

MetalicaRap is a project for an open-source 3D metal and home solar-cell printer, based on the principles of electron beam welding and vapour deposition. MetalicaRap is in the design phase. If the project is successful, users will have access to affordable home manufacturing of solar cells, key electrical parts and milled-quality metal parts. A direct energy deposition manufacturing method provides the ability to print parts for the machine and fuse metal powder. An electron gun and vacuum chamber are the primary necessities for thin film solar-cell printing. It was recognized that the printer did not require a new technological invention, but did require the existing solutions to become publicly accessible through research and re-engineering. One of the goals is a design that MetalicaRap's creators are designing to be able to print a small solar-cell electricity production plant. For a typical family electrical system, a solar cell's cost may go down from 10,000 euro to 400 euro by using 3D printing (MetalicaRap 2014).

Energy storage

This part of the thesis analyses electricity storage and the prospects for energy-storage solutions' development. Flexible electricity-storage solutions provide buffers that help the energy system to withstand increased variation of renewable generation. To provide for power in periods of low generation, remote households will need to install internal storage solutions. Balance will not be maintained by interconnectors alone, and system designers and operators should look at energy-storage technologies (Inage 2009).

Energy storage is considered to be a business area with high potential. Rather than specific numerical values, it is the relative prospects for which the diversification of energy storage is most important. The current technical potential consists of advances in NaS cells, pumped hydro, redox flow cells, compressed-air energy storage, electric double-layer capacitors, Li-ion batteries, superconducting magnetic energy storage and flywheel systems. Reducing the costs of such storage technologies may be key to expanding the use of energy storage technologies to keep pace with the growth of variable renewables (Inage 2009).

Smart grids and home automation

Zero emission, energy-plus buildings means the total amount of energy used by the building and its inhabitants is higher to the amount of energy generated by the building itself, see Figure 26. Constructing such house is a viable project for a household. Companies like GE, LG and Whirlpool have already announced their commitment to building home appliances that are smart-enabled. Smart-grid sensors will link these appliances with smart meters, providing visibility into real-time power consumption. Power companies can use this information to develop real-time pricing and consumers can use the information to lower their power consumption at peak times.

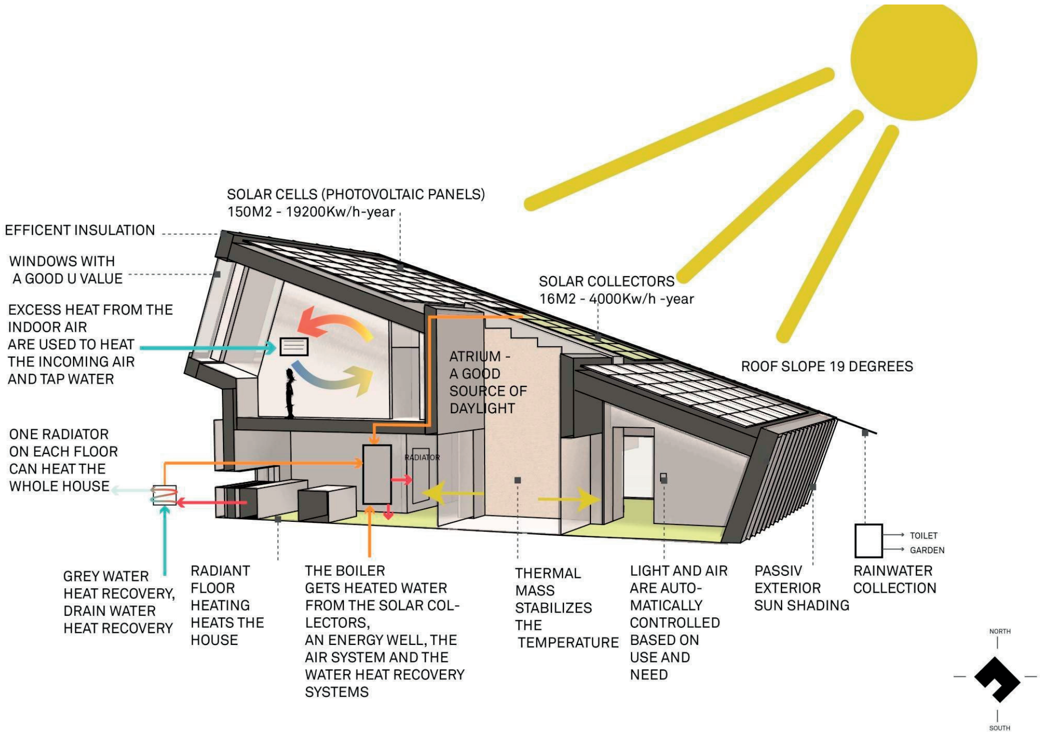

Figure 26. Zero Emission Building pilot energy plus house Larvik Snøhetta (2014).

A state of the art system in the near future may include some or all of the following technologies:

passive heating :WaoSun printed concrete & wooden elements, fence walls etc

active hearing: smart house electronics Termostat with intelligence Shaders and Shutters automation (stepmotors arduino) 3d printed sensors, 3d printed organic carbon Battery, fuel cell or calculate with tesla home storage , solar cells etc.

Smart thermostats

Therecorp, Wevolver and Nest Labs provide currently smart thermostats. Nest Labs is a home-automation company headquartered in Palo Alto, California, that designs and manufactures sensor-driven, Wi-Fi-enabled, self-learning, programmable thermostats and smoke detectors. Co-founded by former Apple engineers Tony Fadell and Matt Rogers in 2010, the start-up company quickly grew to have more than 130 employees by the end of 2012. The company introduced its first product, the Nest Learning Thermostat, in 2011. In October 2013, Nest Labs announced the Nest Protect smoke and carbon monoxide detector. Nest was acquired by Google, and now Nest has acquired Dropcam. They have built a strong technology backbone, which has been integrated with the energy retailer's online services and customer care. The technology is based on energy agents and intelligent sensor networks. They have several patents on the technology. Such technology is very robust and scalable with excellent performance and audited security.

Figure 27. Open Source Thermostat source: Wevolver published under creative common CCO GPL

Renewable energy integration: 3D wind turbine, Cait 3d and cycicle tire**,** 3D printable generators, bicycle home generator in india together with the crowdsource funding site Kickstarter effectively funded a 3D-printed, foldable wind turbine boasting 300W of power. AirEnergy 3D is a 3D-printed mobile wind turbine that you can set up in minutes. It can generate up to 300W of electrical power. Similar one (see Figure 28) can fit it in a backpack, move it and assemble it anywhere without using power tools. Being small and durable, it is also customizable and inexpensive compared to existing wind-based solutions. One can use the power to store it in a battery, plug devices in directly using a USB extension cord and charge your smartphone and power your laptop at the same time, or plug it directly into your wall socket so that your entire household can use the power. The inventors expressed the intent to share the design's prepared production of pre-assembled kits. Made possible by the advances in 3D printing, similar technologies can provide power at very low cost.

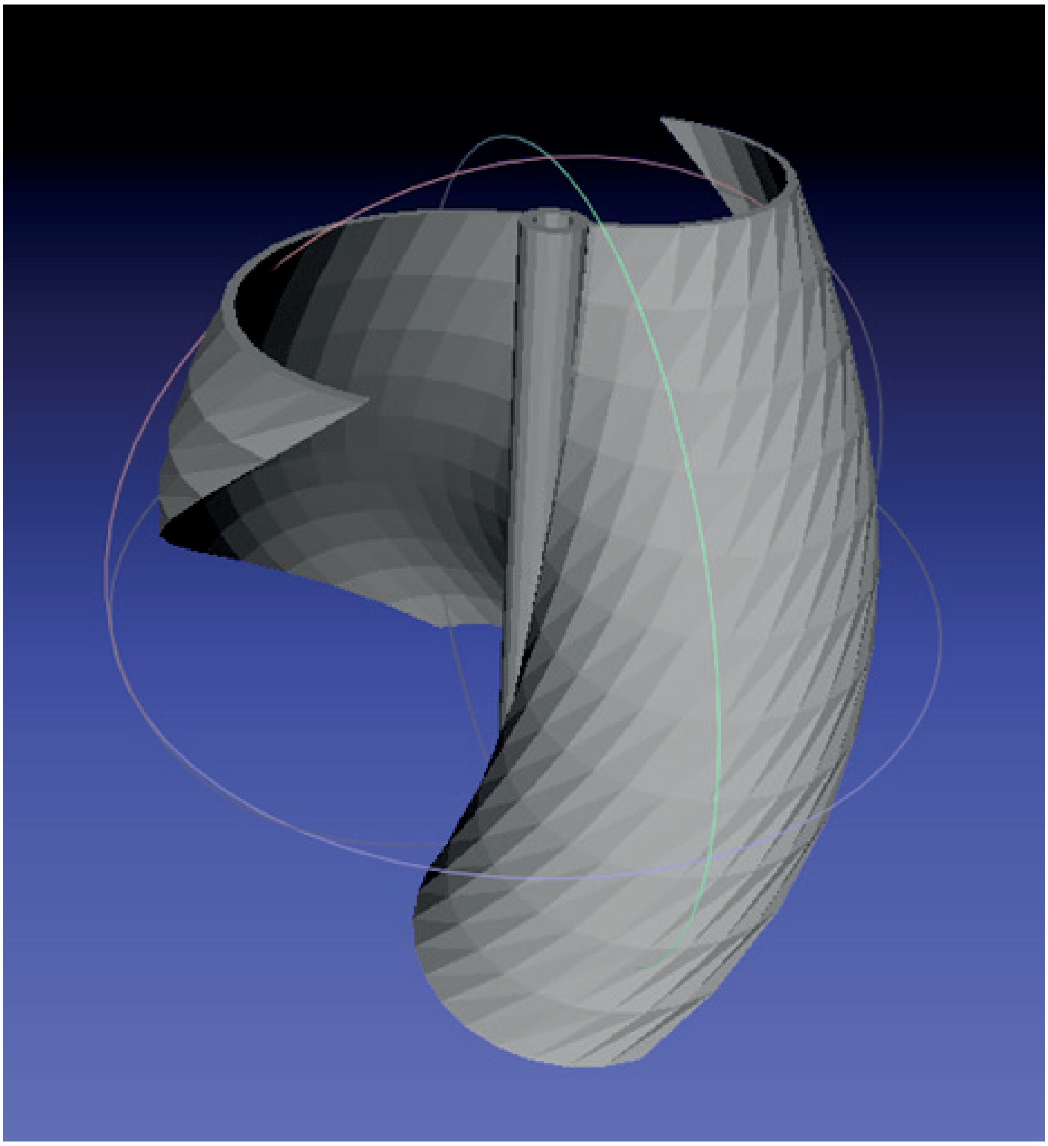

Figure 28. Open source wind turbine 3d printable CAD model

Experts from VTT Finland have developed a prototype of a tree that harvests solar energy from its surroundings (whether indoors or outdoors), stores it and turns it into electricity to power small devices such as mobile phones, humidifiers, thermometers and LED light bulbs, see Figure 29. The technology can also be used to harvest kinetic energy from the environment.

Figure 29. Solar power from energy-harvesting tree VTT (2015).

Renewable Energy integration and Flexibility of power systems

Solid Oxide Fuel Cells (SOFC) have gained increasing attention over the last two decades due to the technology's high efficiency, long-term stability, fuel flexibility and low environmental impact. However, building inexpensive, efficient and reliable fuel cells is a much more complicated process.

Researchers in the Department of Energy Conversion at the Technical University of Denmark (DTU) have transformed an ordinary HP inkjet printer into a printer capable of printing inexpensive fuel cells in 3D, with better quality than the traditional tape-casting methods. Researchers at DTU have modified a 400 DKK HP 1000 inkjet printer to print the fuel cells that offer superior performance. In the future, the 3D-printed fuel cells could be cheap and efficient enough to widely replace traditional ways of generating power, such as coal fire or hydroelectric sources.

A group of 51 scientists in Australia has its own scientific passion to harness the energy of the sun and find affordable ways to design and print solar panels, which they hope will become ubiquitous in the near future, especially for low-power items such as smartphones and tablets. Using ordinary 3D printers, the Victorian Organic Solar Cell Consortium (VICOSC) has developed 3D-printable solar panels that work with solar ink. They hope to have this product commercialized soon, so that they can use their new technology to actually print the panels on the items they want to power, such as rooftops and the windows of buildings. Using concept they call “Factory of the Future,” they are able to use additive manufacturing to move from their inventions from research and design to actual production.

Company 3Dponics provide option when there is surplus of energy in the house to frow your own vegetables. Good technology demonstrations are 3d printed channel house in Amsterdam, European union pavilion, 3d metal bridge printed with robotic hands, German pavilion with fibres.

4.5 Real options and NPV valuation of investments: “Smart grid home” projects

This part presents the investment calculations for R&D project to develop technologies for Zero Emmision Building, energy plus smart house. Trends, interest rates and probabilities associated with the evolution of smart grids are evaluated in context with the Macroeconomic environment for the scenario 2. To address ***RQ4: What is the value of investment in “smart-grid home” systems?***, Table 13 presents the NPV calculation of the R&D project Home Energy Management device, combined with a storage solution and renewable energy generation control, and a comparison with a real-options pricing model. The estimated price per unit is 2,000 euro, the project time is five years and the probabilities of demand follow high, medium and low, respectively 30, 40 and again 30 %. Table 12 represents the traditional NPV evaluation of such a project. We adopted the standard assumption of a constant annual 15 % depreciation rate of previous R&D expenditures for the firm.

Table 13. NPV evaluation of R&D investment in smart-grid components’ manufacture

Demand	Probability	Initial Investment M €	Net Cash Flow for the next Years	NPV	Expected NPV *Prob.
High	0,3	20	12	20,23 €	6,07 €
Medium	0,4	20	8,5	8,49 €	3,40 €
Low	0,3	20	2	-13,30 €	-3,99 €
			Expected NPV		5,48 €

The next Table 14 represents the same scenario evaluation using the real option to “defer” from the project at Time 1 when the probability of low demand for the product is known. The expected NPV of the project is increased and the option price is calculated as the difference between the two methods of evaluation.

Table 14. Real options' evaluation

Demand	Probability	Initial Investment M €	Net Cash Flow for the next Years	NPV	Expected NPV *Prob.	
High	0,3	20	12	16,11 €	4,83 €	
Medium	0,4	20	8,5	5,91 €	2,36 €	
Low	0,3	20	2	-13,04 €	-3,91 €	do not inv
			Expected NPV		7,20 €	
			Option Value		1,72 €	millions

Using the Black-Scholes model, the investment timing option value can be calculated. Table 15 shows the input parameters for the calculation and the binomial event tree, while Table 16 presents the investment project valuation.

Table 15. Evaluation of the American call option

Input parameters		**Calculated parameters**	
Annual risk free-rate	10 %	Up mevement per step	1,5
Current value of the underlying, V0	100	Down movement per step	0,666667
Exercise price, X	250	Risk free rate	7
Life of the option in years	7	Risk neutral probability (up)	0,519881
Annual srandard deviation	0,4055	Risk neutral probability (down)	0,480019
Number of steps per year	1	One plus nominal rate	1,1

Event tree for the underlying

	0	1	2	3	4	5	6	7
0	100	150	225	337,5	506,25	759,375	1139,063	1708,594
1		66,66667	100	150	225	337,5	506,25	759,375
2			44,44444	66,66667	100	150	225	337,5
3			0	29,62963	44,44444	66,66667	100	150
4			0	0	19,75309	29,62963	44,44444	66,66667
5			0	0	0	13,16872	19,75309	29,62963
6			0	0	0	0	8,77915	13,16872
7			0	0	0	0	0	5,852766

American call

	0	1	2	3	4	5	6	7
0	**33,27464**	60,17512	107,4371	188,9694	326,5586	552,5758	911,6408	1458,594
1		11,07915	21,53693	41,53837	79,36078	149,8708	278,9237	509,375
2			2,063309	4,365692	9,237232	19,54477	41,35417	87,5
3				0	0	0	0	0
4				0	0	0	0	0
5				0	0	0	0	0
6				0	0	0	0	0
7				0	0	0	0	0

Table 16. Project valuation with real options

Demand	Probability	PV	NPV	Prob.* PV	Volatility of the cash flow	
High	0,3	12	34,98 €	10,49 €	49,34908854	
Medium	0,4	8,5	24,78 €	9,91 €	2,752945022	
Low	0,3	2	5,83 €	1,75 €	79,93736656	
			Expected PV	22,15 €	11,49083984	Standard d
			Coefficient of Variation	0,52		
			Volatility	0,488123		
			Stock price	22,15 €		
			Strike price	20,00 €		
			Risk free rate	6,00 %		
			Volatility	49 %		
			Time	1	year	
			d1	0,576473		
			d2	0,088349		
			N(d1)	0,717852		
			N(d2)	0,535201		
			Value	5,822187	millions	

Real option model allows us to see how volatility changes influence the value of the whole investment. Testing for ***H1**: An increase in the volatility of electricity market's price will increase the value of technology investment.* As price volatility is increasing, the project value is also growing, and the option to prolong the decision for investment is growing in value, see Table 17. This is consistent with the real options' valuation practices.

Table 17. Effect of volatility levels on the project value

Volatility change	Value change
	5,822187062
20,00 %	3,798060084
25,00 %	4,109393811
30,00 %	4,448089788
35,00 %	4,802834101
40,00 %	5,167263192
45,00 %	5,537526849
50,00 %	5,911136859
55,00 %	6,286389098
60,00 %	6,662055375
65,00 %	7,037210037
70,00 %	7,411127741
75,00 %	7,783220744
80,00 %	8,152999069

4.6 Case companies

A key point for companies is to closely examine the economic value of implementing a smart-grid solution before committing to actual deployment. These deployments are capital intensive and impact multiple departments within the organization, so there strategic importance has to be evaluated. ***RQ3: How does prise risk and technological uncertainty affect company strategies?***

4.6.1 Analytical framework of the process of re-engineering the organization

As it was stated in the theoretical framework, for a company to become an adaptive system it is highly convenient to use a DSS tool, allowing flexibility for its decision makers and advanced learning. S&R model's implementation complements existing planning applications and enables proactive monitoring of CFIs. Based on the trends and special situations identified through analysis, it helps to prevent future violations of process flows due to turbulent changes. The analytical framework of the process of re-engineering the organization via implementation of the S&R concept is summarized in the following Figure 30:

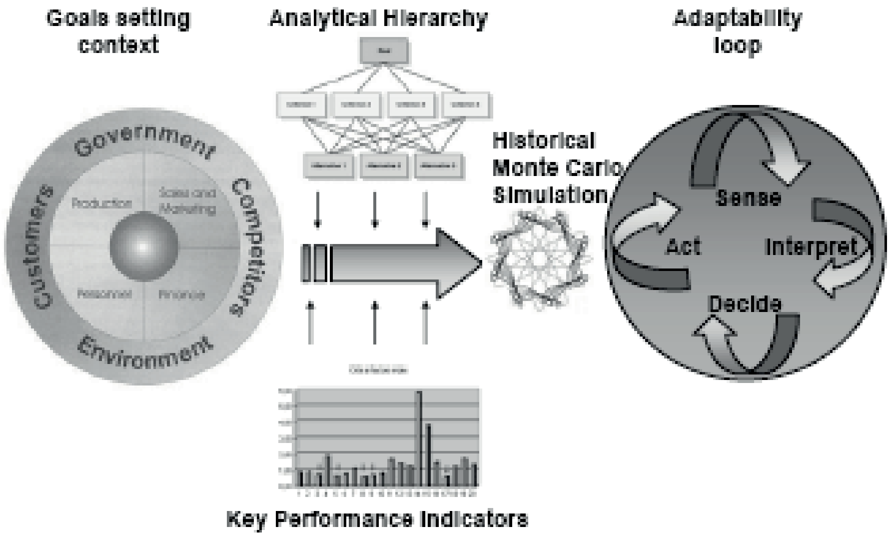

Figure 30. Strategic re-engineering with implementation of SaR

The process of re-engineering a company's business segments requires a structured approach. Using an AHP model, we tried to determine how the resource allocation should be developed and what would be "the price" of implementing a sense-and-respond design in the operations network, at the "expense" of the already existing capabilities. Computation of this result starts with the AHP weights of the major operation criteria (for example cost, quality, delivery (time), flexibility, know-how and customer focus, see Figure 31.

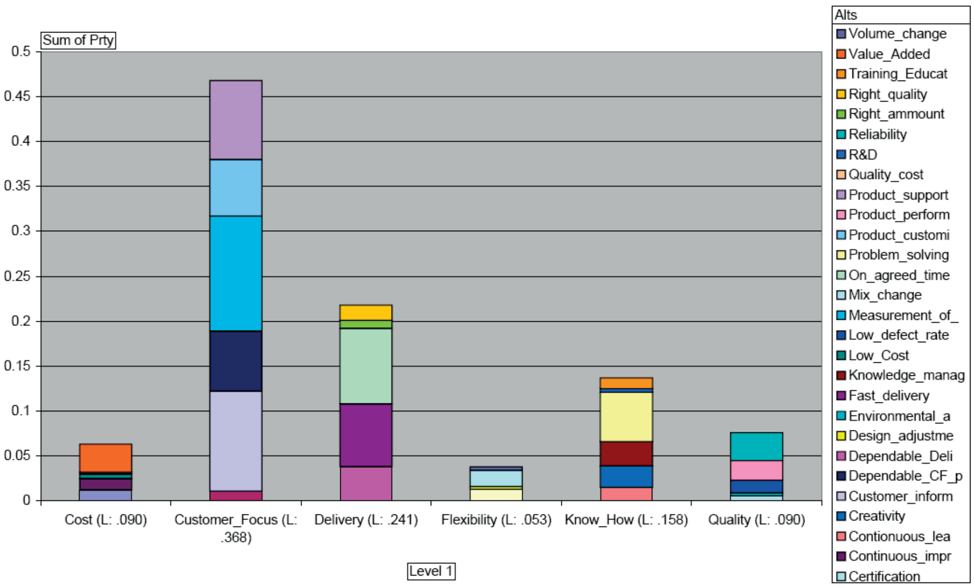

Figure 31. Manufacturing criteria with priorities weight

This section contains an analysis of companies' performance in addition to the assessment of risk factors associated with the transition towards adaptive enterprises and intelligent grid systems. Primary data for identifying the major factors influencing the structure of service designs were collected. Structured interviews with decision makers in the company, managers and operators were conducted. The case study was carried out in three companies from the electrical manufacturing sector. Collaboration with the companies of a high and medium-high technology level was the basis for data collection and information-archive building for strategic priorities, based on the key components of mission, vision, strategic goals, value proposition matrix (products/services by market segments), critical business processes, technologies and organizational aspects such as motivation, employee satisfaction, etc.

The data gathering processes used in the case study included interviews, working groups and workshops. Structured interviews with decision makers in the sector, managers and operators were conducted. The topics of discussion were the current policies and future development. The key personnel within the companies were interviewed first to establish the current status and the key development areas. Initially, in-depth interviews were conducted with senior management to outline the major issues inside the companies, followed by an exploratory study of the management and engineers' opinions by talking to experts in the industry and conducting focus-group interviews. The interviews were recorded and transcribed. The data of the initial interviews were used for familiarization with the companies and its current practices, as well as key development targets. They were analysed to create an overview of the main challenges and strengths related to the value network and new service-business development.

After constructing empirical knowledge about corporate strategy, the competitive priorities model was constructed and the questionnaire was generated. It consists of a pairwise comparison between the main factors that were administered by employees connected to the project.

The questionnaire's results were analysed by using analytical hierarchy process (AHP) software by Expert Choice and S&R methodology to reflect the multi-focused decision-making process. A participant evaluates each particular factor. A tailored AHP was constructed to assess the importance of major strategic decision factors. ***H3:*** *Companies' operational competitiveness is affected by technological uncertainty.*

4.6.2 Company V

The case study's special focus was to discuss and extend the understanding of wind-power services and prospects for energy-storage solutions' development for Company V. The study included market research on the wind-power markets of Finland, Sweden and Norway, and workshops on wind-power services' business model and networks.

Two interview sessions focused on network risks taken, and a critical factor index (CFI) questionnaire evaluated operational strategies of Company V. Another discussed topic was the issue of transformational leadership (Takala et al. 2008). ***H2:*** *Strategic choices of companies are affected by electricity market price volatility.*

Recognizing the development needs, knowledge and service offerings of Company V, the management expected the wind-power business and related electrification and automation solutions to bring a 30 % growth of the turnover in the business area of smart electric grid within the next two to four years.

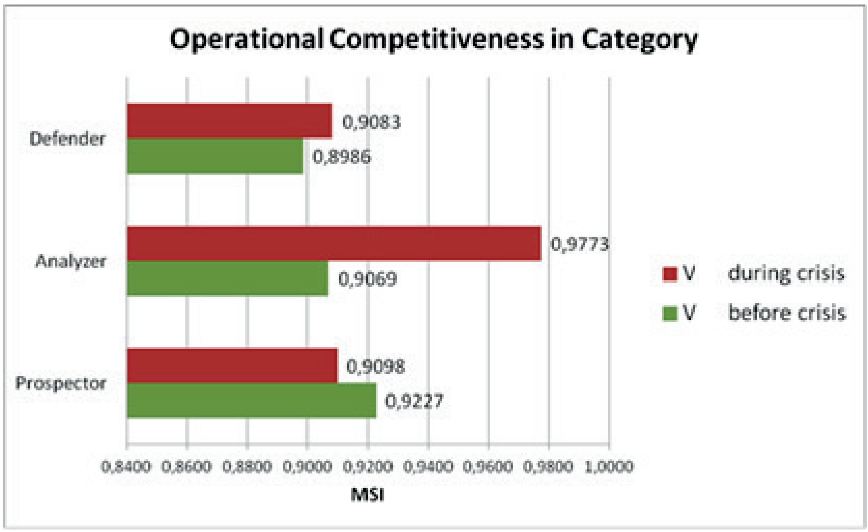

Figure 32. Operational competitiveness in category

Figure 32 shows that before the crisis, V was a prospector, and that during crisis, V was an analyser. This can also be seen when analysing the company's manufacturing strategy. Prospectors adopt the most aggressive type of strategy, but it is a natural one for a highly competitive technology company when normal or favourable conditions prevail. They have to be constantly seeking new markets and new product innovations in order to maintain their competitive ability. During the crisis, prospector companies tended to shift their statuses towards being analysers, giving them more balanced cost, quality, flexibility and time attributes. The analyser strategy is less risky than that of the prospector and, rather than constantly seeking new markets and creating new products, analysers seek to strengthen their existing competencies and products. This is a natural mode for corporations to adopt during a crisis, when they have to concentrate on optimizing their vital processes and minimizing the effects of the crisis (Si et al. 2008).

On Figure 32 we can see that the change between analyser and prospector is quite significant for before and during the crisis. We can also see that the prospector and the defender are almost at the same level. Change can be seen in Figure 4, in which the proportion of quality as a factor has clearly been lowered against cost, time and flexibility during the crisis situation. One can argue whether this transformation is too extreme or too convenient. The risk is that, during a crisis, a company changes from being a prospector to a defender. A company should maintain appropriate degrees of flexibility, time and quality in its manufacturing strategy. Jumping from the status of a prospector to that of a defender is a huge leap, and it can be very difficult to transform back.

Different attributes were selected and used for the evaluation of the customers' expectations, experiences, the direction of the company's development and its position in relation to its competitors. The S&R method is based on the reflection that the business is operating in a less familiar environment (Ranta & Takala 2007).

4.6.3 Critical factor index

This part of our analysis looks closely at the energy-storage business opportunities for Company V. We rank the operation's performance and construct a critical factor index analysis for the company's development of competitive advantages in the market sector. Attributes from four major categories — knowledge and technology management, processes and work flows, organizational systems and information systems — were evaluated for the future one to five-year period. CFI methodology was used to analyse the set of critical parameters for the company, describing the weaknesses and strengths of the operating area (Takala & Uusitalo 2012: 62).

For the company's effort to implement energy-storage solutions in the line of business, past attributes, knowledge and technology diffusion, short and prompt lead-times in order-fulfilment processes and the control and optimization of all types of inventories are highly critical, and related to processes and workflows' business processes.

From the collected answers, we determined a CFI value and compared the ranking of factors in a complete synthesis. We combined the individual judgments in company profiles and calculated CFI values based on the modelling equations corresponding to the time-specific resource allocation (for both past and future). The results lay the foundation for estimates about the consequences of reallocating resources in periods of global economic turbulence (Belay et al. 2013).

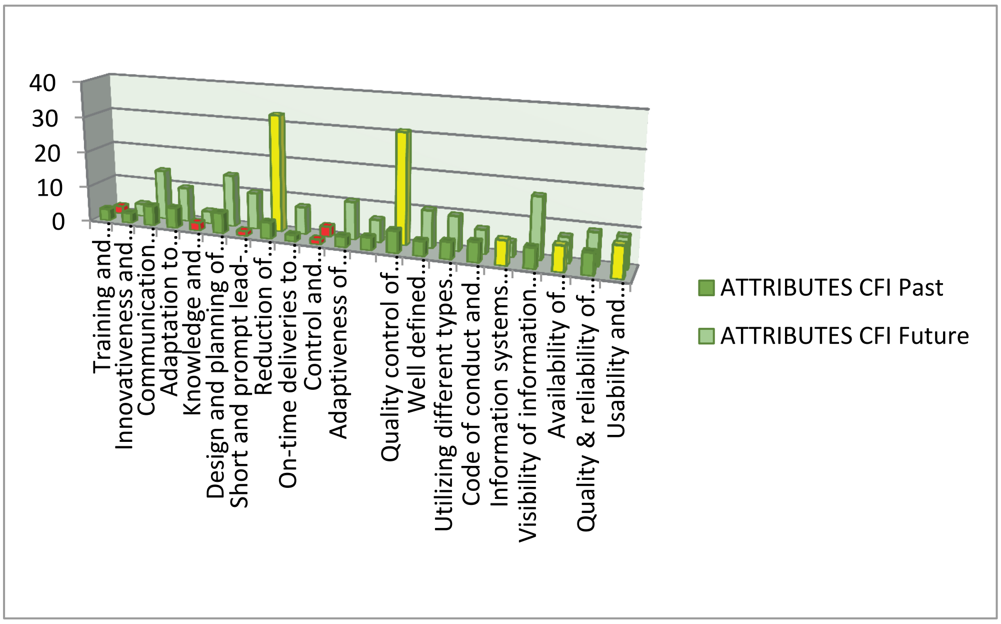

Figure 33. Operations attributes and comparison results using CFI method.

Compa*ny* V has relatively lower value attributes for the past period (see Figure 33). When they are compared to what should be the main focus in the future, the critical factors shift to the training and development of the company's personnel, while the control and optimization of all types of inventories remain the same.

A critical factor index was also analysed for the future, meaning that experiences were not included in this calculation. Trends of the CFI future-oriented route can thereby be understood. The training and development of the company's personnel is the most critical attribute. Innovation and performance are also at critical levels, and leadership and management remain in the red zone. It can be stated that the performance of high-value attributes occupies an adequate level when compared to that of other attributes. From such a point of view, the new critical factors are information systems that support the business processes, and control and optimize all types of inventories.

Possible actions fall into a number of categories, including:
– Notifying the appropriate managers,
– Reallocating resources,
– Invoking exception processes,
– Initiating improvements of ineffective processes or strategies.

4.6.4 Sustainable competitive advantage (SCA)

The case study indicates how we might implement a sustainable competitive advantage (SCA), which is the highly competitive operational strategy for managing new business situations through a fast strategy, by integrating manufacturing and technology strategies with transformational leadership profiles of the decision makers (Takala & Uusitalo 2012).

Analysing factors' rankings can generate multipurpose signals, indicating both positive progress and negative development (Toshev, Forss & Takala 2011). It helps to minimize information gaps and inefficient decision-making, from strategic goals to day-to-day operations. Management has to make decisions for the future of the company/organization based on information concerning the level of service needed (Forss & Toshev 2010).

4.6.5 Conclusions for the energy-storage analysis

Company V's analysis revealed a need to emphasize the development of analysis tools for electricity network decision-making and data management, as these factors become key for successful business development. Different technologies can be harmonized, and the best option would depend on the selected grid management strategy, and the system's cost and efficiency.

Results from V showed in Figure 33 the issues for the knowledge and technology management and processes and workflows groups. The company's quality and time orientation of operation processes are of major significance for the service and product-innovation process, as related to the responsiveness concept for energy-storage business development. Essentially, it can be seen that the importance shifted over time towards implementation problems. This indicates a commitment to change and that the company is trying to adapt to the industrial environment.

CFI results suggest that past problems with information system support have been resolved and that the business' processes are at an acceptable level, despite their different manners of calculation. From this perspective, it might be reliably stated that the processes and workflows group's attributes are critical to Company V and that this fact should be further considered inside the company.

4.6.6 Company S

The second company, Company S, is a Finnish manufacturer of advanced drive-train technology, permanent magnet machines and converter packages. The main areas of expertise are wind, marine and special industrial solutions. The company's innovative drive trains serve power generation and energy operations. Company S has facilities situated in Asia near the wind park. In addition to the company's strategic questionnaires, for part of the study, primary data from the company's component performance and secondary data of average wind speeds from the local weather sensors were used.

Model digital factory concept — Company S's model factory concept for production flexibility and volume production, thanks to fast prototyping and repeatable quality.

Table 18. Manufacturing strategy comparison of company S model vs. real factory

Manufacturing Strategy Index (MSI)

		Operational Cometitiveness in category			
		Prospector	Analyzer	Defender	note
SWI	during crisis	0.9324	0.9657	0.9167	2/3 informants, ICR < 0.25
Model Factory	-	0.9201	0.9300	0.9010	
China Factory	-	0.9211	0.9145	0.9359	

	Normalised Scale			
Company	Quality (Q%)	Cost (C%)	Time (T%)	Flexibility (F%)
SWI during crisis	0.4525	0.2396	0.3079	0.1351
Model Factory	0.4188	0.2086	0.3727	0.2026
China Factory	0.2000	0.4000	0.4000	0.1000

The main criteria values show that the focus on quality remains the most important criterion for a successful business, in the Model factory though a crisis situation. Also timeliness and flexibility expanded their importance. That gives high ranking in Analyser strategic type. For the China factory Cost and Time issues are equally important, making it good Defender.

4.6.7 Company E

Company E develops, manufactures and markets electricity-distribution systems. Their products comprise medium-voltage and low-voltage switch boards, and related systems for electricity distribution by industries and energy utilities. Transformer products represent their special area of expertise. They have developed quality products systematically over the past 20 years, relying on proficient personnel. Company E implements demanding projects in the distribution networks of industries, various buildings and energy utilities. These results, compared with a longitudinal study of the technological level factors (before, during and after the economic crisis), visualize the sensitivity of the factors involved.

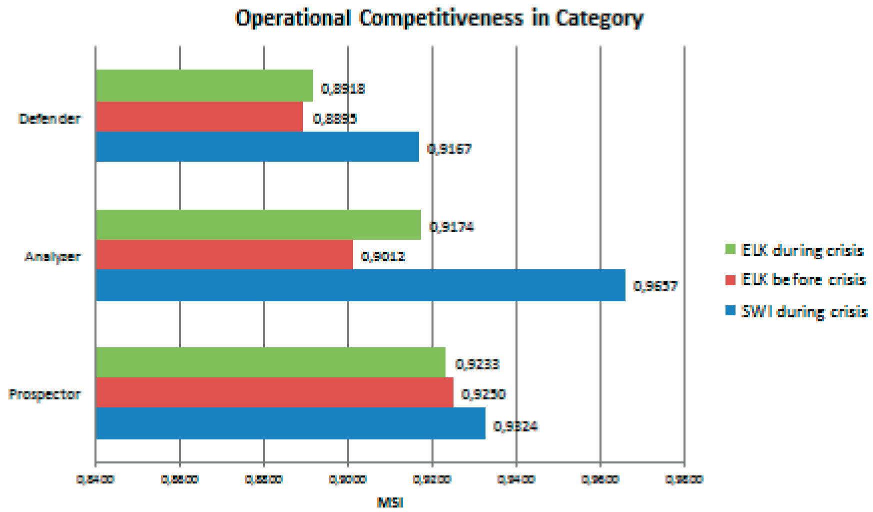

Figure 34. Operational competitiveness is the three strategic categories

Sensitivity of the Main criteria is presented on Figure 34, where future estimated values of Cost, Quality, Delivery and Flexibility are set up in the model and consecutive ranking of sub-criteria was performed simultaneously.

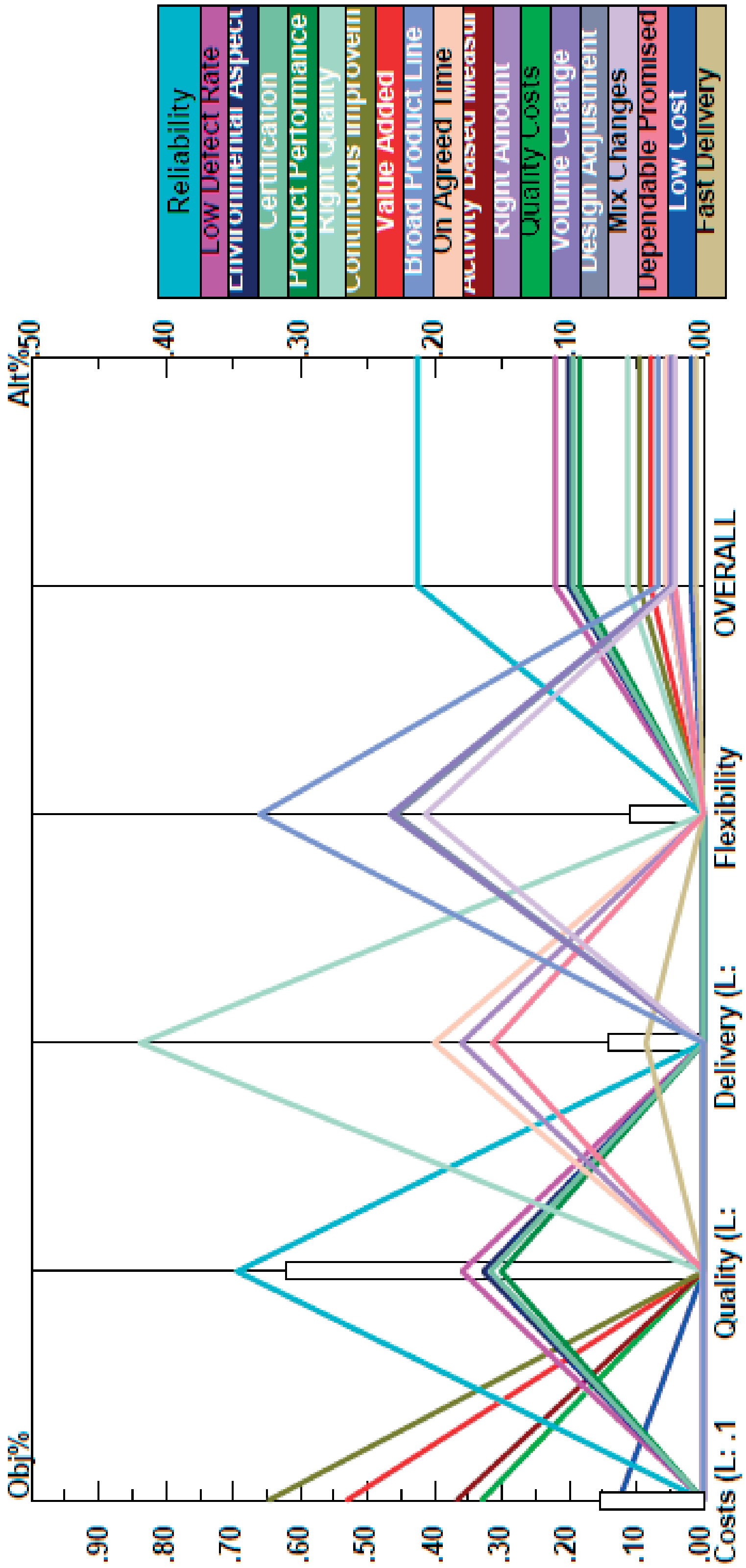

Figure 35. Performance Sensitivity for nodes below: Goal: Competitive Priorities of Manufacturing Strategy

5 THEORETICAL AND PRACTICAL IMPLICATIONS

5.1 Validation and verification

Modelling consists of translating the real-world functions with concern to the different actors, changing market conditions and complicated decision guidelines. Simple models are easier to understand and involve fewer effort and time to analyse. However, they tend to oversimplify matters and might not be a convincing representation of the actual situation.

The electricity-price data cover the period over which the case studies were conducted. This is a relatively short observation period, but it is long enough to calculate the VaR values for the historical and Monte Carlo simulations. Also it provides a long enough interval to extrapolate volatility in the analysis of scenarios, and the market data passed consistency checks.

When referring to the case studies the results were presented in workshop and there was open discussion between the research team members and the company experts, which verified the findings. It must be noted that some strategic-evaluation questionnaires of earliest informants did not fulfil expectations and their results cannot be compared with those of their competitors. The values were given in a later stage of the project. Individual judgements in company profiles and ranked the consistency of the answers to validate the logic of the respondents. Some of the companies' personnel's answer-inconsistency levels were too high, so separate synthesis models were used: one including and one excluding them.

The results of the analysis for Company V are at the semi-strong market-test stage, as the decisions made on the basis of the results have already been applied.

The results of Company S have gone through weak market testing. The test was carried out by asking the management to commit to proposing an improvement (in terms of efficiency and effectiveness) of the attributes found to be critical, for example: '*Communication between different departments and hierarchy levels*' and '*Utilizing different types of organizing systems (projects, teams, processes...)*'.

During the Course Operation Strategy organized for the master students in Industrial management at University of Vaasa, student groups have independently performed parallel analysis of the data and have achieved the same AHP and CFI calculation results. The Department of Production have created a database with case studies for the Strategic types of various industry branches, which gave additional depth to the research, comparing and analysing strategic priorities as well as connections between the factors. Benchmarking verified the operations and services offered by the companies.

5.2 Research Limitations

It is challenging to exploit the structure of a developing energy market and to manipulate strategic behaviours to ultimately develop a set of competitively proven market rules. The forecasting of smart-grid technology development is quite complex, since it combines numerous new technologies, such as energy storage cells or 3D-printed personal wind generators and electronics. More trend studies and comparisons with comparable emerging technologies are needed to acquire better information on the topic. R&D engineers could have superior knowledge on how technologies are evolving, but they can be biased towards a specific project or company's agenda.

The Black-Scholes option-pricing model was originally designed for valuing financial options. The unique characteristics of electricity prices provide some challenges to real options valuation. Real options models are as reliable as the methodology and data that they use. In a dynamic scenario with electricity-pricing information approaching real time, it is unrealistic to expect that a totally accurate real options model might be produced.

In this work, competition between companies, and mergers and acquisitions, are assumed to have no influence on the choice between technologies. Though the model represents the Nordic area, it does not represent the transmission system within the Nordic countries, assuming that transmission constraints will not significantly influence the issues of concern in this study. If we were to analyse issues in the short-term, transmission constraints would be more important for the results. While uncertainties are addressed through Monte Carlo simulations, the model is a descriptive simulation model and thus does not prescribe an optimal solution.

As for the CFI method, a limitation of the research is the small sample (few cases were tested), when compared to the broad area of information analysed for risk assessment. It is in the early stage of development and has only been tested with a few participating companies. Further development and validation is required for obtaining stronger data about trends and correlations existing in the proposed method.

Qualitative risk assessment can be subjective and inconsistent. Analysing decision hierarchies for diverse companies can generate versatile signals. Management have to make decisions for the future of the company/organization using information for the capital flows and the level of supply and demand, while balancing risk for the organization and uncertainty factors. If they make incorrect risk assessments and rank risks too highly, they might prevent companies from starting a project. Spending too much time and effort measuring all sorts of risk factors can lead to resource waste. Highly unlikely events will occur, but risk retention can be as good strategy as spending a lot of money to cover them. On the other hand, planning for them and the simulation of them is inexpensive.

Although the Nordpool Spot data for the Finnish electricity prices had short observation period 2011-2013, it was long enough to calculate the VaR values for the historical and Monte Carlo simulations.

5.3 Managerial implications

This work helps decision makers to compare diverse operational strategies for managing new business situations through a flexible approach, integrating manufacturing and technology strategies.

Analysing factors' rankings can generate multipurpose signals, indicating both positive progress and negative development. It helps to minimize information gaps and inefficient decision-making in pursuit of strategic goals and to translate them into practical choices in day-to-day operations. Management have to make decisions for the future of the company/organization based on information for the levels of uncertainty they face. Critical factor indexation assists the management of business processes, acting as decision-making support systems.

As indicated by Industrial Management team's previous studies (Kohtamäki, Takala & Toshev 2008), even companies with the same kinds of business branch, technology and many strategic similarities may show remarkable differences in prioritizing objectives' sub-criteria — meaning that companies can reach a high degree of competitiveness via different archetypal strategies. Simulations allows decision makers to evaluate, compare and optimize alternative designs, plans and policies in order to minimize risk and make better decisions in an uncertain world.

The results support choices to implement flexibility in companies' strategic approaches and corresponding resource allocation activities. That allows for proactive monitoring and the modelling of market and technological risks. Analysing trends within the available market information produces signals for effective strategic design. These ideas support a company to move towards a more analytical decision-making process, and foster increased confidence in economic projections. Operational benefits from this type of modelling include improved information flow and efficient technology management.

Possible actions fall into a number of categories:
- Notifying the appropriate managers,
- Reallocating resources,
- Invoking exception processes,
- Initiating improvements of ineffective processes or strategies.

6 CONCLUSIONS

This work was focused on the short- and long-term scenarios that influence the development of smart-grid technologies and the companies' strategic choice.

The presented approach attempts to maintain a balance between oversimplifying the problem and increasing the complexity unnecessarily. It is vital for investors to ensure that projects for innovative electricity-grid technologies have commercial merit. Economic modelling with risk assessment is vital for justifying investments to managers, engineers, regulators and other possible stakeholders. They can apply it and tailor it for their specific issues and environments, once they have sufficient information and good knowledge about the modelling approach to determine their smart-grid strategy.

Smart-grid technologies can be presented as unconventional, futuristic and complex exotic options, which is why they require a mixture of modelling techniques to describe them and correctly value the options.

The essential steps to complete the valuation involve plain and intermediate modelling knowledge for price-volatility mapping, value at risk calculations and NPV and real options analysis. Managers and engineers need to go through the implementation using Monte Carlo simulation to mimic demand and net profit for different technologies. The estimations of a future period's electricity-price volatility support real options valuation for the appraisal of possible scenarios by using a binomial lattice. It makes forecasts on the basis of the assumed volatility observed from the standpoint of today.

There is no guarantee for a faultless prediction. New information comes with the passing of time and the world will certainly change, so we have to remodel the project evaluation and market volatility dynamically. The analysis results delivered in this thesis allow the case companies to better understand the investment in various emerging smart-grid technologies, given today's volatility and demand estimation, serving as a decision-support mechanism for strategic planning.

Taking data from the stock market helps us to model the fluctuation of electricity prices. The NPV of projects is used as the underlying factor in the proposed real options approach, which allows for flexibility in project management. In such a way, real options valuation is a better fit for modelling projects' uncertainties than is DCF.

In conclusion, it can be stated that there is no one universal method to address all of real options' shortfalls. The discussed tools are as reliable as the methodology they use and the data that are fed into the calculations. In a dynamic scenario, with electricity-pricing information approaching real time, it is unrealistic to expect 100% accurate real options models. The process of going through the problems and causes, collecting information and modelling scenarios is important to managers and engineers. In such a way, great ideas for the technological flexibilities and value dynamics can be generated.

Within electricity markets, VaR measures can be used to quantify the maximum electricity price changes associated with a likelihood level. This quantification forms a starting point when designing risk-management strategies.

During the last phase of the work, it was proposed to the participating companies that they compare their situations with the results of the case companies in order to find similarities in critical areas, thereby detecting possible trends in the energy market's development. Operation-level company analysis showed that one of the major threats for new grid-service businesses is coming to the business too late, and that despite V's strong technical expertise, it does not have the references, networks and resources needed for operating in the new business field. In order to achieve the vision developed in the roadmap process, the companies have to take many steps. These include resource allocation relating especially to marketing and product development, setting clear goals for the new business area, establishing innovative partnerships and building up networks. Other choices have to be made, such as what expertise it is crucial to have in-house and what processes can be outsourced, besides determining a geographical expansion strategy and product development.

Energy storage, wind power and photovoltaic-electricity generation was seen to have enormous potential. The new business field would help the case companies to attract new partnerships and, thus, new opportunities. Maintenance and service business would offer long-term possibilities.

Competition has been proven to be an effective way to spur innovation. This dissertation develops our understanding of the capabilities and limitations of modelling scenarios for the management of a future energy network that includes a variety of distributed, sustainable sources. Models allow such structures to be evaluated in a risk-free environment, under a variety of real-world scenarios and conditions, within a state of market and technological uncertainty.

The company case studies revealed the necessity of emphasizing the development of tools for electricity network decision-making and data management, as these factors become key for successful business development. Different technologies can be harmonized, and the best option would depend on the selected grid-management strategy, and the system's cost and efficiency measures.

The company's quality and time positioning of operation processes are of major significance for the service and product innovation process, related to the responsiveness concept for energy-storage business development. Essentially, it can be seen that, with time, the importance has shifted towards implementation problems. This indicates a commitment to change and that the company is trying to adapt to and industry environment.

The benefits of a fast and comprehensive method for gathering important risk information in order to make knowledge-based decisions at the operational level are self-evident. CFI ranking helps electric-component manufacturer companies to identify the most critical attributes, and allocate and balance resources based on the critical level.

The analysis showed increased volatility and stronger correlation among energy risk factors. Sensitivity modelling supported increased flexibility in resource allocation, especially as it related to marketing and product development, and the building up of additional partnerships and networks as efficient methods for companies to hedge risk and manage uncertainties in their strategic shifting process. Maintenance and service businesses offered the best long-term business possibilities. Attributes found critical in the operations' evaluation were the communication between different departments and hierarchy levels, utilizing existing organizations' projects and teams and the control and optimization of inventories.

The analysis revealed how market-risk measures can be used as tools for decision-making operation management, as these factors become key for successful business development. Different strategies can be harmonized according to technological development, and the best option would depend on the selected management approach and the system's flexibility.

A body of valuable research and statistics are provided, along with a raised level of confidence that an electricity-price market-risk evaluation mechanism could be used by a real company to develop a smart-grid systems business.

Demonstrations from this work can be used to bridge the gap between a successful demonstration of innovative technologies and their mass deployment in the market.

The methodology suggested here allows for systematic planning and the evaluation of innovation initiatives on an operational level by validating and verifying the constituting elements of technology and also coherency among different scenarios and strategies.

6.1 Recommendations for future research

The author makes a call that the proposed models be used as experimental laboratories for researchers and business practitioners, policymakers and authorities to address long-term and short-term developments of smart energy projects.

Since the prices in developed electric markets are subject to variability and fluctuation, a research topic could be how smart-grid technical-infrastructure changes affect customers' behaviour and how these changes can be balanced in real time. Ultimately, the test of relevance will be that the resulting research helps bring about a more sustainable energy future. The market modelling can be extended to include market indices' volatility behaviour.

Further research questions can be:

How do we further transform electricity generation and distribution systems?

Can the provided model be used to change real-world customers' behaviour?

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8 APPENDIX

Table 1 Sample questionnaire

	Expectations	*Experiences*	*Compared with competitors (please tick your option)*			*Direction of development (please tick your option)*		
	(1–10)	*(1–10)*	*Worse*	*Same*	*Better*	*Worse*	*Same*	*Better*
Attribute 1	[ ]	[ ]	☐	☐	☐	☐	☐	☐
Attribute 2	[ ]	[ ]	☐	☐	☐	☐	☐	☐
•	[ ]	[ ]	☐	☐	☐	☐	☐	☐
•	[ ]	[ ]	☐	☐	☐	☐	☐	☐

Notes: Expectation – what is the expectation to the attributes.
Experience – what is the experience of the attribute.
Compared with competitors – compare experienced value to the values of all other providers.
Direction of development – direction of the experienced values of the sample during the last three years.

Sample AHP questionnaire

1	Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Functionality
2	Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment
3	Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation
4	Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Society_and_Custor
5	Safety	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic_value
6	Functionality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Environment
7	Functionality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation
8	Functionality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Society_and_Custor
9	Functionality	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic_value
10	Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Reputation
11	Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Society_and_Custor
12	Environment	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic_value
13	Reputation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Society_and_Custor
14	Reputation	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic_value
15	Society_and_Custor	9	8	7	6	5	4	3	2	1	2	3	4	5	6	7	8	9	Economic_value

Operations attributes evaluation.

ATTRIBUTES	CFI Past	CFI Future	BSFI Past	BCFI Future
Knowledge & Technology Management				
Training and development of the company's personnel	3.34	2.22	1.72	1.15
Innovativeness and performance of research and development	2.85	3.56	1.17	1.46
Communication between different departments and hierarchy levels	5.61	14.02	1.23	3.07
Adaptation to knowledge and technology	5.77	9.62	1.55	2.58
Knowledge and technology diffusion	2.34	3.51	1.02	1.53
Design and planning of the processes and products	5.83	14.57	1.44	3.59
Processes & Work flows				
Short and prompt lead-times in order-fulfilment process	1.46	10.19	1.01	7.04
Reduction of unprofitable time in processes	4.66	32.64	0.96	6.75
On-time deliveries to customer	1.90	7.58	0.88	3.51
Control and optimization of all types of inventories	1.44	2.89	0.84	1.67
Adaptiveness of changes in demands and in order backlog	3.01	10.53	0.85	2.97
Organisational systems				
Leadership and management systems of the company	3.59	6.27	0.78	1.37
Quality control of products, processes and operations	6.15	30.75	1.36	6.79
Well defined responsibilities and tasks for each operation	4.14	10.34	1.29	3.22
Utilizing different types of organizing systems (projects, teams, processes...)	4.78	9.57	1.78	3.55
Code of conduct and security of data and information	5.55	6.65	1.30	1.57
Information systems				
Information systems support the business processes	6.80	4.08	2.64	1.58
Visibility of information in information systems	5.65	16.96	2.10	6.30
Availability of information in information systems	7.05	7.05	2.86	2.86
Quality & reliability of information in information systems	6.05	9.07	2.08	3.12
Usability and functionality of information systems	8.70	8.70	3.36	3.36

Research process

Meeting	Description
Interview meeting	Interviews of
Work group meeting	Wind power markets in Sweden and Norway. PEST analysis for wind power business.
Work group meeting	Network description of the wind power business of V. Wind power business roadmap.
Interview meeting	Interviews Mid-term reporting meeting. Mid-term reporting of the achieved results.
Questionnaire study	Sense & Respond questionnaire study about energy storages.
Work group meeting	Wind power service business, and business model.
Work group meeting	Business model, business related opportunities and threats.

Reported values:

	S_Combined	Average of expectation	STDEV of expectation	Average of experiences	STDEV of experiences	Direction of Development		
	ATTRIBUTES					Worse (%)	Same (%)	Better (%)
1	Knowledge & Technology Management	9.00	1.00	6.67	1.53	0%	0%	100%
2	Training and development of the company's personnel	9.00	1.00	6.00	2.00	0%	33%	67%
3	Innovativeness and performance of research and development	9.67	0.58	7.00	1.00	0%	0%	100%
4	Communica-	8.67	0.58	5.00	3.61	0%	67%	33%

	tion between different departments and hierarchy levels							
5	Adaptation to knowledge and technology	9.00	1.00	6.67	0.58	0%	33%	67%
6	Knowledge and technology diffusion	8.67	1.15	7.00	1.00	0%	33%	67%
7	Design and planning of the processes and products	9.33	0.58	6.00	3.61	0%	0%	100%
8	Processes & Work flows	8.33	0.58	5.67	3.51	0%	0%	100%
9	Short and prompt lead-times in order-fulfilment process	8.67	0.58	7.00	1.00	0%	33%	67%
10	Reduction of unprofitable time in processes	8.67	1.15	6.33	0.58	0%	33%	67%
11	On-time deliveries to customer	9.67	0.58	7.67	0.58	0%	0%	100%
12	Control and optimization of all types of inventories	9.33	0.58	7.33	1.53	0%	0%	100%

13	Adaptiveness of changes in demands and in order backlog	9.33	1.15	6.67	0.58	0%	33%	67%
14	Organizational systems	8.67	1.15	7.00	1.00	0%	33%	67%
15	Leadership and management systems of the company	9.67	0.58	7.67	0.58	0%	0%	100%
16	Quality control of products, processes and operations	9.67	0.58	7.33	1.53	0%	0%	100%
17	Well defined responsibilities and tasks for each operation	9.33	1.15	6.00	1.00	0%	0%	100%
18	Utilizing different types of organizing systems (projects, teams, processes...)	9.00	1.00	7.00	1.73	0%	33%	67%
19	Code of conduct and security of data and information	9.00	1.00	6.67	1.53	0%	33%	67%
20	Information systems	9.33	0.58	5.67	3.21	0%	0%	100%
21	Information systems sup-	9.33	0.58	5.33	2.89	0%	33%	67%

	port the business processes							
22	Visibility of information in information systems	9.33	0.58	5.00	2.65	0%	0%	100%
23	Availability of information in information systems	9.33	0.58	5.33	3.06	0%	0%	100%
24	Quality & reliability of information in information systems	9.33	0.58	5.67	4.04	0%	33%	67%
25	Usability and functionality of information systems	9.33	0.58	5.00	3.61	0%	33%	67%

	E_Combined	Average of expectation	STDEV of expectation	Average of experiences	STDEV of experiences	Direction of Development		
	ATTRIBUTES					Worse (%)	Same (%)	Better (%)
1	Knowledge & Technology Management	7.80	1.14	6.10	2.42	0%	20%	80%
2	Training and development of the company's personnel	7.60	0.84	5.10	1.29	0%	60%	40%
3	Innovativeness and performance of research and development	7.80	1.32	5.80	2.30	10%	10%	80%
4	Communication between different departments and hierarchy levels	7.80	1.48	4.50	1.84	10%	80%	10%
5	Adaptation to knowledge and technology	8.10	0.88	6.30	2.41	0%	40%	60%
6	Knowledge and technology	7.90	0.99	6.00	1.70	10%	60%	30%

	diffusion							
7	Design and planning of the processes and products	8.30	0.95	5.40	1.96	20%	40%	40%
8	Processes & Work flows	7.90	1.45	6.10	1.37	10%	50%	40%
9	Short and prompt lead-times in order-fulfilment process	8.40	1.51	6.00	1.89	10%	50%	40%
10	Reduction of unprofitable time in processes	8.00	1.05	6.00	2.00	20%	40%	40%
11	On-time deliveries to customer	9.00	1.05	6.80	1.81	20%	20%	60%
12	Control and optimization of all types of inventories	8.00	1.63	6.60	1.07	0%	70%	30%
13	Adaptiveness of changes in demands and in order backlog	8.30	1.16	7.00	1.56	0%	50%	50%
14	Organizational systems	7.50	1.35	6.50	1.18	0%	70%	30%
15	Leadership and management systems of the	8.40	1.17	7.00	1.41	0%	40%	60%

	company							
16	Quality control of products, processes and operations	8.60	0.84	6.50	1.18	10%	70%	20%
17	Well defined responsibilities and tasks for each operation	8.70	0.95	5.60	1.71	20%	50%	30%
18	Utilizing different types of organizing systems (projects, teams, processes...)	8.20	0.79	6.50	1.78	10%	70%	20%
19	Code of conduct and security of data and information	8.20	1.23	7.10	0.99	0%	70%	30%
20	Information systems	8.60	0.97	7.00	1.94	0%	0%	100%
21	Information systems support the business processes	8.20	0.92	6.90	1.52	0%	30%	70%
22	Visibility of information in information systems	8.20	1.48	6.70	1.57	0%	50%	50%
23	Availability of information in information systems	8.80	0.92	7.10	2.08	0%	0%	100%

24	Quality & reliability of information in information systems	8.70	0.95	6.20	1.81	0%	10%	90%
25	Usability and functionality of information systems	8.60	0.84	6.70	1.77	0%	20%	80%