Norwegian University of
Science and Technology
NTNU

Faculty of Social Science and
Technology Management

Department of Industrial Economics and Technology Management

MASTER THESIS

for

STUD.TECHN. TOR OLAV SEIM AND OLE RONNY THORSNES

Field of study	**Financial Engineering** Investering, finans og økonomistyring
Start date	15th of January 2008
Title	**Analysis of Investments in Renewable Energy - the Significance of Uncertainty** Analyse av investeringer i fornybar energi – virkningen av usikkerhet
Purpose	Investments in renewable energy are characterized by irreversibility, uncertainty and often the investment decision can be deferred. The importance of the investment as part of a larger portfolio of projects is another aspect, this being analyzed from a corporate or at a national perspective.

Main contents:

1. Modeling and analyzing investment projects by using standard discounted cash flow approaches. Data collection and quality control. It will also be natural to discuss how the effects on energy production and effect capacity, environment and supply uncertainty are handled in the standard framework.

2. Modeling and analyzing investment projects with important underlying stochastic processes and the portfolio perspective integrated.

Tim Torvatn
Department Management

Stein-Erik Fleten
Stein-Erik Fleten
Supervisor

Declaration

Stud.techn. ____________Tor Olav Seim _________

Institute of Industrial Economy and Technology Management

I hereby declare that I have written the above mentioned
thesis without any kind of illegal assistance

______________________________ ____________________

Place Date

____

Signature

In accordance with Examination regulations § 20, this thesis, together with its figures etc., remains the property of the Norwegian University of Science and Technology (NTNU). Its contents, or results from them, may not be used for other purpose without the consent of the interested parties.

Declaration

Stud.techn. ________Ole Ronny Thorsnes __________

Institute of Industrial Economy and Technology Management

I hereby declare that I have written the above mentioned
thesis without any kind of illegal assistance

______________________________ ____________________

Place Date

____

Signature

In accordance with Examination regulations § 20, this thesis, together with its figures etc., remains the property of the Norwegian University of Science and Technology (NTNU). Its contents, or results from them, may not be used for other purpose without the consent of the interested parties.

Preface

This master thesis is prepared at the Norwegian University of Science and Technology, Department of Industrial Economics and Technology Management during the spring of 2008.

We would like to thank our teaching supervisor, Associate Professor Stein-Erik Fleten for good support and discussions during this semester. Additionally, we would like to thank Åsmund Jenssen at Econ Pöyry for providing us with the problem statement and solutions to all thinkable problems that occurred along the way.

We would also like to express our gratitude to the individual partners of the Discount Rates for Energy Investments project: Econ Pöyry, Enova, Statnett, StatoilHydro, The Government Agency for Financial Management, Møreforsking Molde and The Research Council of Norway, for constructive feedback on the presentation held in Oslo May 20th 2008.

NTNU, Trondheim, June 5th 2008

Tor Olav Seim

Ole Ronny Thorsnes

Investments in renewable energy
The significance of uncertainty

June 2008

Master Thesis for

Stud.Techn. Tor Olav Seim and Stud.Techn. Ole Ronny Thorsnes

NTNU Trondheim

Abstract

The recent global attention of achieving a sustainable development for future generations has stimulated investments in renewable energy projects. These projects are characterized by a high degree of uncertainty, but also a great amount of flexibility in the managerial decisions as the project evolves. Traditional valuation techniques such as the net present value fail to incorporate this flexibility when evaluating the projects. Valuation methods based on real options however are well suited for such conditions. Real options techniques are considered more complex than traditional valuation techniques and the threshold for users makes them less applicable. This thesis uses real options methodology to analyse three renewable energy projects with technologies based on wind, biomass and biowaste respectively. By focusing on an applied approach, we are attempting to bring theory closer to practice. The actual method and processes in relation to the use of real options is therefore also considered as an important part of the thesis and a complete valuation model is developed and revised. Results obtained from the model indicate the importance of valuing flexibility arising from uncertainty, illustrated through high option values and recommended investor behavior that deviates from those advocated by standard valuation techniques. The analysis also illustrates how the uncertainty in relation to the future support system may lead investors to postpone their investments, the opposite of the support system's intention. Valuations methods based on real options are recommended as they provide users with more accurate project evaluations, and decision support for timing of investments.

Contents

1 Introduction

The increased global attention on the environmental consequences of today's energy consumption has led to a growing focus on renewable energy sources. This focus has inter alia resulted in country specific targets on the share of electricity generated from renewable energy sources, as well as support schemes stimulating investors to engage in renewable energy projects. In most countries support schemes are necessary to initiate new projects, since most renewable energy projects still have a long way to go before grid parity is reached. Renewable energy projects are in general characterized by high uncertainty about future cash flows dating from e.g. fluctuating power prices, uncertainty about support schemes and an uncertain resource base. This uncertainty gives rise to flexibility in management's decision as information evolves, especially since planning and lead time can be very long in such projects. The flexibility can be the opportunities to wait for new and better information, expanding the project if things turn out favorable, switching between operating mode and in worst case abandoning the project. This flexibility is of value to the project owner, but traditional valuation techniques fails to include it. The need for more sophisticated valuation approaches are therefore necessary.

This thesis develops and compares two valuation models. The first is a traditional net present value (NPV) approach, where no flexibility is included, and the second based on the real options analysis (ROA) framework presented in Copeland and Antikarov (2003). The real options approach includes managerial flexibility by modeling it using options, and the following options are analyzed in this thesis: wait-and-see option; abandon option; expand option. Based on these two valuation techniques, the underlying uncertainties' impact on the valuation of renewable energy projects are analyzed. The analysis is conducted for three different investment projects with technologies based on wind, biomass and waste (hencehforth named biowaste). These are reffered to as the base cases and are evaluated over a 20 year project life. All three projects considered are located in Norway and all the data is given in real numbers unless else is specified. Our investor is assumed to be internationally well-diversified and situated in Norway, and the projects are analyzed from an investor's perspective. Real options are increasing in popularity when it comes to valuing physical assets, although considered more complex than standard valuation techniques such as the net present value. This thesis is therefore focusing on an applied approach, bringing theory closer to practice.

The thesis is divided into 10 sections, starting with an overall description of renewable energy focusing on the bio- and wind technologies analyzed. The following sections presents the standard framework of valuing investment projects, and the real options procedure including managerial flexibility. Section 5 discusses the different portfolio perspectives that may be considered when valuing investments in renewable energy. Section 6 presents the method used for valuing real options in this thesis and the model that was created for valuation of renewable energy projects. In section 7 the results obtained from the model is presented together with analysis and a short discussion. The next section discusses the results and assumptions made, together with the paramount implications of the findings in the previous section. The last two sections present the conclusions drawn from the analysis and suggestions for further work.

2 Renewable Energy

The focus on renewable energy sources has been given much attention in media the latest decade due to the climate changes the increasing use of fossil fuels has caused. The impact of increasing CO2 emissions on the global climate has been an intense discussion, but there is now a common acceptance that many of the climate changes seen today are most likely caused by humans (Intergovernmental Panel on Climate Change (2007)). The concerns about climate changes in addition to high dependency and volatility of oil prices have led to an increasing government support of power generation based on renewable energy. The need for a sustainable development has been widely accepted by the international society and is an important part of the UN's agenda. Support schemes are introduced by governments all over the world to stimulate the commercialization and growth of power generation based on renewable energy.

Renewable energy is regarded as energy generated by a natural resource that replenish itself in a relatively short time. It is considered as clean energy as it produces few or no emission or pollutants, and having minimal impact on the global ecosystem.[1] There are several energy resources that are considered renewable and they involve technologies comprising among others: wind, biomass, geothermal, solar and hydro.

Renewable energy constituted about 18% of the worlds global energy consumptions, and 18,4% of the world's total electricity generation in 2006, as can be seen from figure 1 (Martino (2007)). Fossil fuels are still the dominating part, although experiencing increasing regulations related to emission of CO2 and other climate gasses.

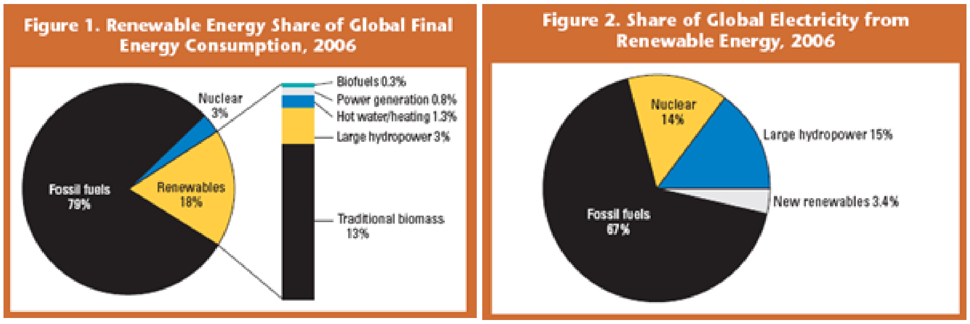


Figure 1: Global energy consumption and global electricity consumption

Large hydroelectric power and biomass have traditionally been the most significant among the renewable energy sources, but other technologies have experienced large growth in recent years (such as wind and solar power). In Norway the large hydro power plants have been the dominating source of electric energy covering about 99% of the total demand, but also here investments in other forms of renewable energies are being carried out.

In 1972 the United Nations held their first conference on the human environment where international environmental issues were discussed.[2] The problem related to transboundrary pollution was discussed in detail and conclusions made about pollution being a global problem affecting the entire planet. 15 years later the Brundtland-commission published

---

[1] There is however a local impact on the ecosystem from certain renewable energy sources e.g. hydro power production.

[2] The Stockholm Conference.

the report "Our Common Future", which was the first holistic and global political analysis of the international environmental issues the world is facing (Brundtland et al. (1987)). The report introduced the term *sustainable development* and a common understanding among nations that they need to change their energy generation and consumption to a way that is sustainable also for future generations.

In 2006 the International Energy Agency (IEA) published the "World Energy Outlook 2006" describing several possible development scenarios towards 2030 (IEA (2006)). It states that if no effort is made to change our energy consumption, the World will double its energy consumption in 2030 relative to its 2004 level. The positive outcome of this report is that it describes an optimistic, yet realistic, scenario where the world's total energy consumption stagnates and that the climatic threat faced can be handled by among others replacing fossil fuels with renewable energy. This conclusion is drawn in many other reports analyzing international environmental challenges and is part of the reason why there has been a significant increase in realized energy projects based on renewable energy sources in the latest years. These projects are usually not commercial viable and so support schemes need to be in place for these technologies to become realized. Support systems are further discussed in the next section, followed by a description of the renewable technologies analyzed in this thesis.

2.1 Support

In 2007 Norway joined the European Union's RES-directive which encourage electricity production from renewable energy sources. The goal is to make 22.1% of the EU's total electricity consumption based on renewable energy. Each individual government that is part of the directive specifies its own national indicative goals and establish support schemes to reach these. These support schemes differ between the member states in both form and size and a short description of some of them are given below.

2.1.1 Fixed price systems

In fixed price systems the government sets the relevant price and the market decides the quantity of renewable energy generated.

Investment subsidies
Investment subsidies can be used as an incentive to the investors where either a percentage of the total investment is subsidized or the investor is paid an amount in relation to rated production. In the early days of wind power development, grants were given based on installed capacity instead of annual energy production, which often lead to overdimensioned and less efficient turbines (EWEA (2002)). Investment subsidies can also be combined with other incentives as in the UK where offshore wind energy projects are given an extra investment support to compliment the ROC to make it competitive with onshore wind projects (EWEA (2002)).[3]

Fixed feed-in tariffs
The fixed feed-in tariff involves payment of a fixed price per kWh electricity delivered from the renewable energy producers. This removes the price risk from the energy producers and has been a widely adopted support scheme throughout continental Europe, in for example Germany, Denmark and Spain. The shift of price risk from the producer to

---

[3] ROC is an obligated renewable quota system

the subsidizing part is probably some of the reason why investors consider these countries as favorable to invest in, additional to the relatively high level of support (Haas (2002)). The cost of the mechanism will be the difference in the fixed tariff and the electricity price, and is borne by the tax payers or the electricity consumers. The size of the support is therefore difficult to predict and it can also result in negative support (income to the subsidizing party) if the electricity price surpasses the tariff, as have occurred in Scandinavia. This result in a temporary situation where owners of coal powered plants receive higher prices for their electricity than owners of wind turbines. If however this situation should occur, it do not necessarily mean that the margin for coal power plant increases. The shift in power prices can be due to e.g. discrete jumps from introduction of CO2-quotas, increasing the costs for a coal fired power station.

Guaranteed minimum price
This system mends some of the flaws of the model above and guarantees the producers of energy a minimum price for their renewable energy. If the electricity price is high the producers receives no support, but if the electricity price drops below a fixed level the government subsidizes the difference between the fixed level and the electricity price. The producer is then shielded from the downside risk of the electricity price movements.

Fixed premium systems
A fixed premium system provides the producers of renewable energy with a fixed premium per kWh generated in addition to the varying market price. This support scheme makes it easier for the government to predict the cost per kWh renewable energy generated (the subsidizing amount), but shifts the price risk of the electricity market back to the producer. The principle of the mechanism is to make the fixed premium reflect the additional cost of renewable energy power generation to make it competitive in the electricity market. The system will also stimulate producers to increase production in periods were the price of electricity is high.

Tax credits
Tax credits is another variant of the fixed price mechanism and it can in some cases be politically important whether the incentive is paid by the electricity consumer as a levy or by the taxpayer through general taxation. This is more a discussion of allotment of costs, and the mechanism is used in among others the US.

2.1.2 Fixed quantity systems

In fixed quantity systems the government sets a quota for the amount of renewable energy that should be generated and traded in a given time interval and it is up to the market to set the price. Some form of regulation is however needed and the most common forms is described below.

Tendering system
In a tendering system (also known as competitive bidding) the developers of the renewable energy projects submit their wholesale price for the electricity they deliver, and the bid with the lowest price wins and typically enter into purchase agreements for the next 15-20 years. The difference between the bid price and the electricity price represents the extra cost of producing renewable energy and is paid by the consumers through a levy.

Tradable green certificate systems
In a tradable green certificate system (TGC) producers of renewable energy are given

green certificates in relation to the amount of electricity they generate which they can sell in addition to the electricity. These certificates are traded in a separate market and prices are settled daily like the spot price in the electricity market. The TGC mechanism works as follows (EWEA (2002)):

- The Government sets a specific and gradually increasing quantity or minimum limit for the amount of electricity in the supply portfolio to create a demand for TGCs.
- An obligation is placed on either the end user or the supplier of electricity.
- The producers, wholesalers, retailers or consumers (depending on who is deemed obligated by the Government) are obligated to supply/consume a certain percentage of electricity from renewable energy sources.
- At the settlement date the operators have to submit the required number of certificates to demonstrate compliance.

Certificates can be obtained by either owning a renewable energy plant or buying certificates from another renewable energy plant or in the market. A price cap is usually set on the green certificates by allowing obligated parties to buy-out of the obligation by paying a fine for lack of compliance. The price of the certificate will therefore never exceed this fine.

2.1.3 Indirect promoting strategies

In addition to the strategies aimed directly at a certain type of technology as described above, there are also ways of indirectly affecting the amount of renewable energy that is being generated. The most important of these are different types of environmental taxes that are imposed on production from non-renewable sources, or tax exemption or reduction on renewable energy sources. Taxes and permits on CO2 emission and other climate gases can also increase the cost of using fossil fuels, thus making renewable energy more competitive. Soft loans are also a way of subsidizing investors in renewable energy.

2.1.4 Support schemes in Norway

The support schemes for renewable energy in Norway are managed by Enova SF, which is a public enterprise owned by the Ministry of Petroleum and Energy. Enova SF's main mission is to contribute to environmentally sound and rational use and production of energy, relying on financial instruments and incentives to stimulate market players and mechanisms to achieve national energy policy goals (Enova (2008)). It receives its funding from a levy on the electricity distribution tariffs and governmental support. The Norwegian Government decided in 2007 to create a "Grunnfond" for renewable energy and energy efficiency. The profit from this fund will enter into the Energy Fund managed by Enova. The total amount of support at Enova's disposal to foster renewable energy and energy efficiency will reach 1.5 billion NOK per year from 2010 (Enova (2008)).

The current support scheme in Norway is an investment scheme set to be a temporary solution during the transition phase to a potential green certificates market with Sweden. Depending on the outcome of the negotiations between the Norwegian and Swedish government about a common market for tradable green certificates, there are two likely outcomes of support schemes in Norway, according to Musum (2008). If the negotiations turn out favorably there will be a traded green certificate system for those technologies that are included in the system. If however the negotiations break down, as happened in 2006, the government will most likely introduce an updated version of the fixed premium system that was created after this disagreement (St.meld nr.11 (2006-2007)). The outcome of these negotiations is still to be determined and a source of uncertainty in this thesis. Other potential support systems can also occur, but this is not included in this thesis.

2.2 Wind energy

About one percent of the sun energy that hits earth is used to put air in motion thus creating wind. This energy amounts to 100 times the world's energy consumption, but only a small part of this can be utilized for wind power production. Norway has large onshore wind resources mainly located in Finnmark due to large uninhabited areas along the coast with good wind conditions (Fornybar Energi (2007)), illustrated in figure 2. The offshore wind potential is also great, but only a onshore case it treated in this thesis.

Figure 2: European wind map

2.2.1 Wind power

Wind is air in motion and contains kinetic energy which can be transformed into electricity by a wind turbine. The wind accelerates the turbine blades transforming some of the kinetic energy of the wind into mechanical energy. The energy is then transferred from the turbine trough the drive shaft to a generator inside the nacelle. The generator generates electric energy which is then transferred to the electric grid system through transformers. The power the turbine is able to draw from the wind is given by equation 1.

$$P_{turbine} = \frac{1}{2} C_p A \rho_{air} \nu^3 \tag{1}$$

Here C_P is the turbine's effect factor, A the size of the circular area covered by the rotor blades, ρ_{air} the density of air, and ν the velocity of the wind. The effect factor shows the ratio between generated electric energy and the kinetic energy in the wind. This factor will vary from different turbine types and wind velocities. The maximum theoretical level is constrained to 59% (the Betz-criteria) and a good wind turbine will have an effect factor of about 45% in the most promising wind areas. The power increases with the wind velocity cubed, and so the total energy production and profitability of projects is sensitive to this parameter, and therefore subject to extensive testing before final investment plans are initiated. Total energy production (Wh) can be found in equation 2.

$$E_{wind} = 0.615 C_p A \nu^3 T \tag{2}$$

Here T is the time interval of the period in hours and ν the average wind velocity over the period. A modern wind turbine operates when the wind velocity is in the area of 4-25 m/s. Maximum power typically occurs at 12-15 m/s while production is stopped when it surpasses 25m/s to avoid unnecessary wear of the equipment. A typical effect curve for a wind turbine is given in figure 3.

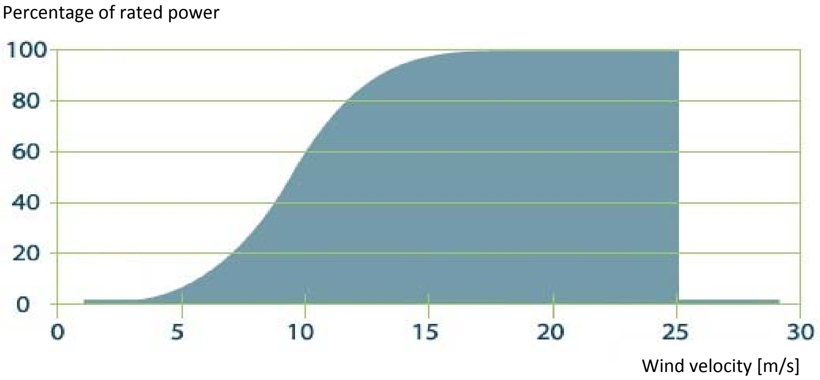


Figure 3: Effect curve for wind turbines

Wind power is a varying source of energy and can not be regulated in the same way as hydro power stations with large reservoirs. The wind turbines are shut down for large periods of time and normal utilization time in Europe is about 2000h.[4] In Norway the average is 3000h due to better wind conditions, and up to 4000h in exceptionally good areas (Fornybar Energi (2007)). A wind park can thus not be the sole supplier of electricity to an area due to supply uncertainty, but could do so in a portfolio of several wind parks in different geographical areas or in connection with other production units such as hydro power. One advantage of having several production units (wind turbines) in a wind park is the flexibility of having turbines out of production due to maintenance or failure. This will only effect a small fraction of the wind park's total power capacity, e.g. 2-3MW, whereas maintenance of a turbine in a gas fired or a nuclear plant could result in a loss of e.g. 1000 MW. Wind also has a favorable seasonal profile with more wind during the winter months resulting in higher production when the demand for electricity is high. There is also less variation in wind resources compared to hydro power which dominates the electricity production in Norway (Undeland (2008)). A seasonal profile for the average wind velocity of a wind park is given in figure 4 (collected from Krossøy and Torgersrud (2004)).

---

[4] Utilization time is defined as the number of hours the plant have to run at full capacity in order to generate the total annual generation.

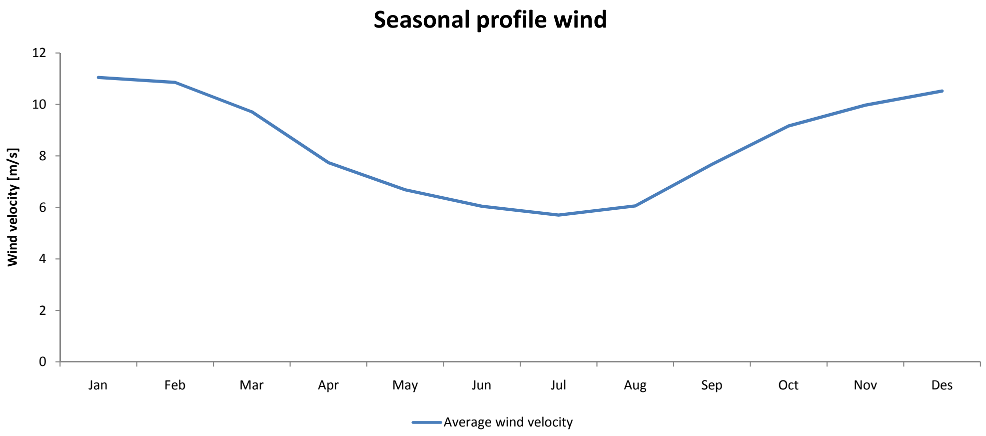


Figure 4: Seasonal wind profile

2.2.2 Wind power industry in Norway

Norway has, as pointed out earlier in this thesis, very good conditions for electricity generation from wind. There has been an increasing activity within this field, resulting in a growing wind energy industry in Norway. The Norwegian government quantified a target of 3 TWh generated energy from wind in 1999 (St.meld nr.20 (1998-1999)), and today several Norwegian companies are involved in the wind energy value chain (Fornybar Energi (2007)). Many integrated power companies have or are planning development and operation of large wind parks, and several companies only focusing on wind power production have also emerged. In 2006 the total electricity production from wind was 670 GWh and the total installed capacity was 325 MW (NVE (2006)).[5] This thesis considers investments in onshore wind projects, since this is the most mature part of wind power industry in Norway today and therefore provides high quality data for our valuation model.

2.2.3 Cost structure wind

Investments in wind power projects are characterized by large initial investment costs. The cost structure of a typical investment in a wind park is given in figure 5 (Muhlbradt (2007)).

---

[5] Divided by 18 wind power fields and 163 wind power turbines.

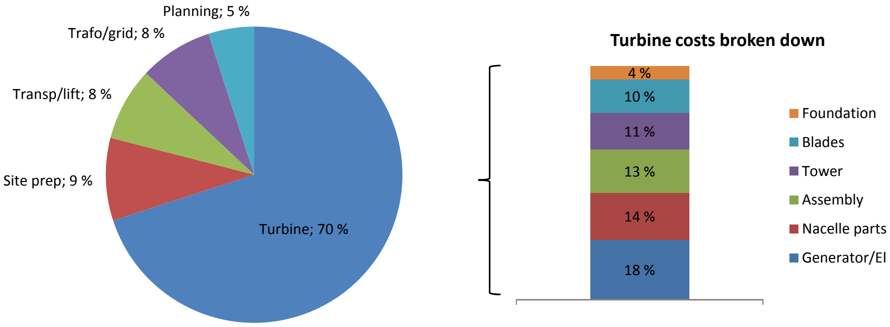


Figure 5: Cost structure in wind projects

The turbine cost represents approximately 70 percent of the total investment cost, and have been subject to a substantial growth in the latest years due to an increasing demand for wind turbines. Site preparations, transport of the wind turbines, and connection to the electricity grid are also comprehensive parts of the total investment cost. The costs of the wind turbines are further broken down into different parts, also illustrated in the figure.

2.3 Bio energy

Bio energy is a common term for use of biomass or waste for energy production.[6] The different types of biomass are diverse in both quality and properties, but they all have their origin in the photosynthesis. It is still the most important energy resource for more than half the world's population, although industrialized countries have moved in direction of using fossil fuels. The most common use of biomass is for producing hot water for district heating, but it can also be used to generate electric power, liquid biofuel, biogas and hydrogen.

2.3.1 Bio power

Biological material, such as plants, uses the energy from the sunlight to bind carbons from the air together with water. This creates oxygen that is released to the atmosphere and sugar that is used by the plant as building blocks or energy storage. The chemical reactions occurring in the photosynthesis can be described as follows:

$$6CO_2 + 6H_2O + (energy) \rightarrow C_6H_{12}O_6 + 6O_2 \tag{3}$$

The combustion of biomass is the opposite of the photosynthesis and releases energy:

$$C_6H_{12}O_6 + 6O_2 \rightarrow 6CO_2 + 6H_2O + (energy) \tag{4}$$

Commercial bioenergy resources mainly stem from forestry, agriculture or waste, and the biomass is usually refined into fuels before the energy is used. The regrowth of biomass that can be used as fuel in Norway is estimated to about 140 TWh per year (Hohle (2001)). Many of the biomass resources used today occur as by-products from industry

---

[6] Biomass is defined as living or recently dead biological material used as fuel, for example plant matter.

and households, and so if the demand for biomass increases, the fuel prices will probably follow. When using bioenergy for heating, it is a great advantage if it is part of a larger district heating system. This increases the efficiency of the combustion process and removes the need for individual biomass storages.

Electricity generation from biomass creates waste heat and so combined heat and power (CHP) plants are often placed in the vicinity of industry with large heating demand or in connection with a district heating system. Traditional production of electricity from biomass has been done through production of high-pressure steam that is expanded in a conventional steam turbine. If some of the energy in the biomass is to be used for heating, a counter-pressure turbine is used to ensure that the steam is expanded to a pressure that is suitable for the district heating system.

The demand for heat typically has a seasonal profile and so it is important to dimension the power plant according to this. A bio fueled plant will typically cover the base load as showed in the figure 6, due to high investment costs and relatively low fuel prices compared to for instance electricity or gas.[7]

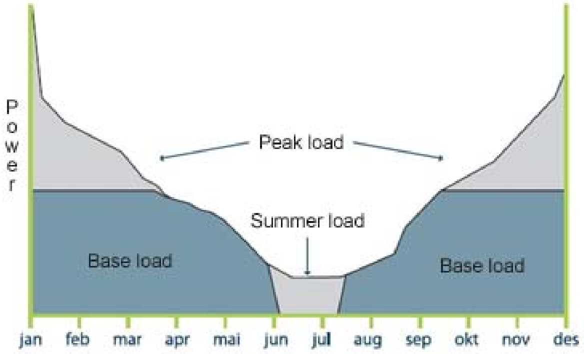


Figure 6: Seasonal profile for household heat demand

A bio fueled plant can normally not be regulated down to 20-30% of max capacity due to incomplete combustion and unnecessary tear of the equipment. It will typically be dimensioned to cover approximately 30-50% of the maximum power demanded from consumers (the base load), and thus covering approximately 80-85% of the total energy demand (Fornybar Energi (2007)).

2.3.2 Bio power industry in Norway

The value chain in the Norwegian heat-sector can be described as in figure 7 (Econ Pöyry (2008)), ranging from the collection of the waste and biomass, to the distribution of heat and energy to end users.

---

[7] This thesis assumes a case that covers the base load.

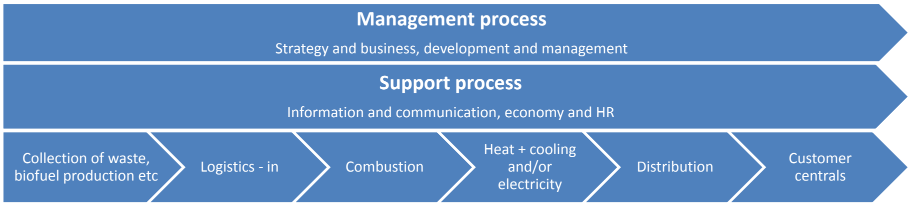


Figure 7: Value chain of Norwegian heat sector

This thesis focuses on companies operating heat centrals combusting biomass or biowaste. The plants generate power sold to end users through the grid and heat trough district heating systems. The value chain covers many distinct technologies and different parts of it are naturally exposed to different types of risks and uncertainties. In Norway there are several different constellations of market players operating in different parts of the value chain and the rate of return demanded by investments in the different sections differs.

2.3.3 Cost structure bio

Investments in biomass and biowaste projects are on average more expensive than investments in wind power on a per kWh base. In addition to the heat central itself, it is also necessary to invest in infrastructure to distribute the heat produced. Figure 8 displays how the investment costs are divided between the central and infrastructure for the biomass and biowaste plants (Grønli (2008)).

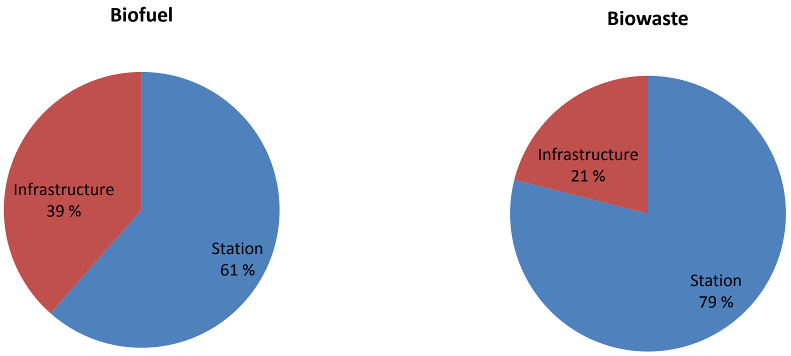


Figure 8: Distribution of costs between infrastructure and heat for power producing plants fueled on either biomass or biowaste

The figure shows that investments in infrastructure accounts for a larger share in the biomass case compared to the biowaste case. The reason for this is that the investment cost for a plant fueled on biowaste is significantly higher than for a plant fueled on biomass, while the cost of infrastructure is relatively constant in the two cases.

Figure 9 gives an overview of the cost structure for the combined heat and power plant itself, together with the detailed costs for the electromechanical equipment (Energy Act (1990)).

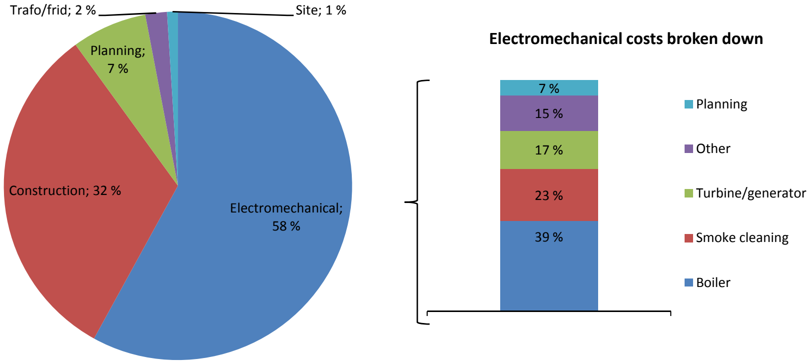


Figure 9: Cost structure for the combined heat and power plants based on biomass and biowaste

It is assumed that the cost structure presented in figure 9 is representative for both the biomass and biowaste plants, only the total cost for the biowaste case is higher.

2.4 Investment cases evaluated

This section presents the key figures for the three investment cases analyzed in this thesis, referred to as the base cases.

Table 1: Key figures for the three investment cases considered in the thesis.

	Wind	**Biomass**	**Biowaste**
Installed capacity [MW]	40	10	10
Investment cost [NOK/MW]	11.8	14.8	30.5
Utilization time (electricity) [h/year]	2650	4000	8000
Utilization time (heat) [h/year]	-	4000	4500
Fuel price [NOK/kWh]	-	0.237	-0.343
Economic lifetime [years]	20	20	20
Weighted average cost of capital (real after tax)	4.78%	4.28%	3.78%

The investment costs for the bio cases includes infrastructure. Fuel prices for the bio projects are fixed assuming long-term contracts with local suppliers, discussed later in the thesis. Further details about specific data for the individual base cases are given in appendix A.12 and calculation of WACCs are presented in section 3. All the investment cases are assumed to be eligible for investment support from Enova.[8]

---

[8] Investments in both power and heat capacity for the bio cases.

3 Standard valuation framework

What drives a company or a project's value is its ability to earn a return on invested capital greater than the weighted average cost of capital (WACC) (Koller et al. (2005)). By use of this procedure, management maximizes the shareholders' wealth undertaking projects that earn at least the opportunity cost of capital. This principle is known as The Separation Principle, and states that shareholders will agree in the management's decision as long as the last dollar invested yields greater or equal to the market-determined opportunity cost of capital (Copeland and Antikarov (2003)). The traditional way of valuing companies or projects is the net present value approach. The value is then given by the future expected net cash flows discounted at a suitable discount rate. This discount rate is intended to reflect the risk of those cash flows, and is therefore risk adjusted. A positive net present value is equivalent to a green light for the investment. The cash flows that are being discounted are free cash flows payable to both sources of funding, debt and equity. If the NPV is zero, the investment provides just enough free cash flows to pay back providers of debt and equity their expected return on the investment. The formula for the NPV is given in equation 5, where I is the initial capital outlay, C_i is the expected free cash flow in year i and r is a suitable risk-adjusted discount rate.

$$NPV = -I + \sum_{i=1}^{N} \left[\frac{C_i}{(1+r)^i} \right] \tag{5}$$

Calculation of the risk adjusted discount rate can be difficult, and an alternative method is to make the adjustment for risk to the cash flows. These certainty-equivalent cash flows can then be discounted at the risk-free interest rate. Equation 6 shows this procedure.[9]

$$NPV = -I + \sum_{i=1}^{N} \left[\frac{C_i - \lambda cov(C, R_m)}{(1+r_f)^i} \right] \tag{6}$$

Here, λ is the market price of risk, $\mathrm{R_m}$ the market return and r_f the risk-free rate of return. This technique is in particular attractive for investments in commodities, but also in relation to real options using risk-neutral probabilites to value options. For this investment class, the certainty-equivalent cash flows can be easily obtained from forward or futures prices (Schwartz (1998)).

In the last decades the net present value approach has been the single most used tool for valuing investments. A survey by Schall, Sundem and Geijsbeek (1978) showed that in a sample of 424 large firms, 86 percent used NPV as their decision tools evaluating investment projects.

3.1 Weighted average cost of capital

The cost of capital for an investment is defined as the expected rate of return the capital market offers equally risky investments. This represents the alternative cost of capital decided by the market, and varies from project to project depending on the risks associated with each project. A discount rate reflecting the risks associated with the investment is used in the NPV approach described in the previous section. The weighted average cost of capital (WACC) represents the opportunity cost faced by investors if they should

---

[9] Consult Copeland and Antikarov (2003) page 72 for derivation

choose to invest in one particular project instead of another with similar risk. As stated above, the free cash flows generated by an investment must cover the opportunity costs of all the financial investors (debt, equity, hybrid securities), and hence the calculation of the WACC must include all this. Koller et al. (2005) lists four important criterias that the cost of capital must satisfy:

1. The opportunity cost of all sources of capital must be included, since the free cash flow is available to all investors.
2. Each capital provider's required return must be weighted by its market-based value.
3. It must be computed after capital taxes.
4. It must be denominated in the same currency as the free cash flows

Equation 7 gives the expression for the WACC.

$$WACC = \frac{E}{E+D} r_e + \frac{D}{E+D}(1-t) r_d \tag{7}$$

Here r_e is the cost of equity, r_d is the cost of debt, E and D the market value of equity and debt, and t the tax rate. It is important to notice that use of WACC assumes a relatively stable capital structure. If this is expected to change significantly, a constant WACC can understate (or overstate) the effect of tax shields. Table 2 summarizes the WACC calculated in this thesis, while the rest of this section is dedicated to present the parameters in equation 7 and how they are estimated. For an in-depth discussion on calculation of WACC, see Brealey and Myers (2006).

Table 2: Summary of WACCs (real after tax).

Wind	4.78%
Biomass	4.28%
Biowaste	3.78%

The WACC values calculated are somewhat lower than results from relevant studies, e.g. Gjølberg and Johnsen (2007) and Haas (2002). These differences will be discussed later in the thesis.

3.1.1 Cost of equity

A common procedure to calculate the cost of equity is to use the Capital Asset Pricing Model (CAPM), which translates risk into expected return. By use of CAPM, three variables are used to determine the expected return of a stock: the risk-free rate of return; the market risk premium; the beta of the stock. The CAPM states that the expected return on a security equals the risk-free rate plus the market risk premium times the security's beta, as given in equation 8 (Sharpe (1964)).

$$E(r_i) = r_f + \beta_i \left[E(r_m) - r_f\right] \tag{8}$$

Based on equation 8 and parameters presented later the cost of equity is calculated and presented in table 3.

Table 3: Summary of cost of equity.

Wind	7.75%
Biomass	6.75%
Biowaste	5.75%

3.1.2 Beta

Beta is a measure of an asset's correlation with the market and a measure of the asset's systematic risk. It can not be observed directly, and must therefore be estimated. Equation 9 gives the mathematical expression for beta.

$$\beta_i = \frac{\rho_{r_i,r_m}\sigma_i}{\sigma_m} \tag{9}$$

Here σ_i and σ_m are the standard deviation of the stock and the market respectively, while ρ_{r_i,r_m} is the correlation coefficient between the stock and the market. The market in this setting is considered a value-weighted well-diversified portfolio. In CAPM the market portfolio is a portfolio consisting of all assets, both traded (e.g. stocks, bonds) and untraded (e.g. private companies, human capital), but of course this portfolio is not observable, and an index will have to suffice. Since an international well-diversified investor is assumed, MSCI World Index is used as the market index. Consult appendix A.1 for a description of this index and the investor. The market portfolio will have a beta of 1.0, and companies with beta larger than one are to be considered more risky than the market overall, while companies with lower beta are considered less risky. The beta is a measure of the systematic risk that can not be diversified, and hence a risk that investors are demanding an extra return to carry.

Companies typically obtain financing from debt and equity and the capital structure of companies determines the risk of the different stake holders. The beta of a company is the weighted sum of both the equity and the debt beta as given in equation 10.

$$\beta_A = \frac{D}{D+E}\beta_D + \frac{E}{D+E}\beta_E \tag{10}$$

The formula can be used to convert between equity and asset betas by leveraging and deleveraging the betas.[10] Interest to debt holders are to be paid before any dividends can be given to the equity owners, and they are also first in line in case of financial distress. This reduces the volatility of the cash flow to debt holders and lowers the risk and thus also the debt beta. Most of a creditors risk in a normal corporate loan (medium to good rating) is also company specific and can therefore be diversified. This means that debt holders typically hold much less risks than stockholders in firms, and so debt betas are much less than equity betas. Typically, if the debt rate is reasonable, the debt beta can be disregarded (Gjølberg and Johnsen (2007)). Thus, a debt beta of zero is used in the calculations.

Valuing renewable energy projects or companies can be difficult since they are typically not traded on a stock exchange and so it is difficult to estimate their beta values. A common way to cope with this problem is to find traded "copies" of these projects or companies with equal risks and cash flows. This is typically firms operating in the same industry with the same size and market share etc. A large number of copies should be

---

[10] Book value of debt is used.

found and the average beta value of these used. When doing this one have to calculate the asset beta of the different companies and then leveraging the resulting beta to the correct capital structure for the company or project that is being valued.[11] In new and developing technologies such as electricity production based on wind and bio it can be difficult to find domesticaly traded companies, and it is necessary to look for copies in countries all over the world. It is also possible to use industry betas to approximate a specific company's beta. This is funded on the fact that companies within the same industry will face a rather similar operating risk, and hence should have similar operating betas. Unleveraged betas incorporate solely operational risk and can therefore be averaged across an industry (Koller et al. (2005)). This assumes of course that the operating characteristics across the industry is similar. The technique described above is well suited in mature and sizable industries. If however very few comparables exist, other methods can be used such as the Blume method and the Vasicek method. These methods will not be used in this thesis and we confine ourselves to just mentioning them here without any further elaboration.

Wind

As pointed our earlier, the lack of domesticaly listed companies in the wind industry makes it necessary to use an international peer group. Companies in our peer group are located in different parts of the wind energy value chain, and an overview is given in table 4.

Table 4: Table listing the peer group used to calculate beta for a wind project.

Company	**Description**
Vestas [Denmark]	World's largest manufacturer of wind turbines
Greentech [Denmark]	Development, construction and operation of wind farms
Plambeck [Germany]	Development and operation of wind farms
Gamesa [Spain]	Maufacturer of wind turbines and operator of wind farms
Western Wind [Canada]	Producer of electricity from wind energy

Not all of these companies are exposed to power price- and support uncertainty directly. It can however be argued that wind projects have a risk profile that partly resembles wind mill manufacturers (related to support), and partly conventional power producers (related to power prices). Figure 10 shows a time series of the stock price for the companies listed in table 4 relative to the MSCI index.

---

[11] See Brealey and Myers (2006) for description on leveraging and unleveraging betas.

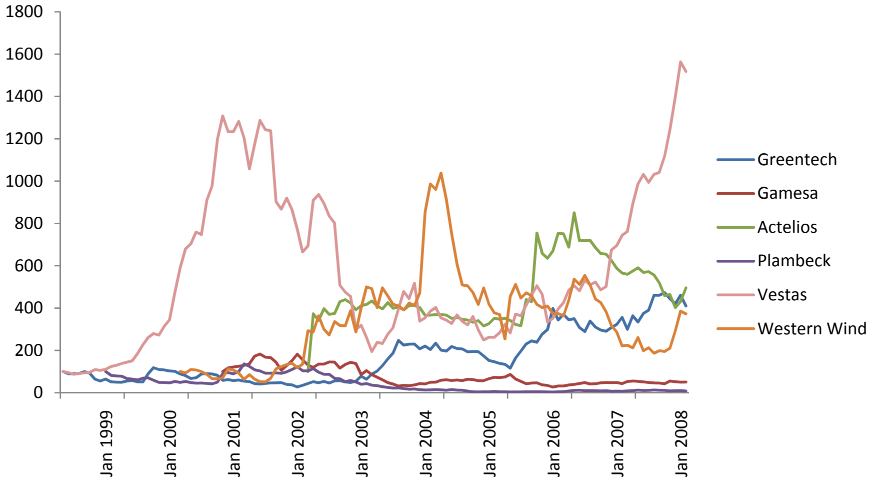


Figure 10: Stock price for the peer group companies relative to the MSCI index from 1998 to 2007

As can be seen from figure 10, companies in the peer group have, except from Gamesa and Plambeck, outperformed the market, illustrating abnormal returns of wind related companies the recent years. The procedure by using listed companies as copies of the relevant project to be valued are not unproblematic. Gjølberg and Johnsen (2007) list some important factors to be aware of when this procedure is used to calculate beta values.

- It can be challenging to find listed copies with corresponding business risk as the current investment project.
- Many of the companies are not operating solely within the same business area as the project.
- Many projects (particularly within renewable energy) are within markets and technologies that can expect significant structural changes in the future. It can therefore be problematic to use historic numbers to predict future betas.
- CAPM has, based on empirical tests, been criticized for not being a sufficient model. Examples of models challenging CAPM is e.g. APT (Arbitrage Pricing Theory) and Fama & French Three Factor Model, which includes several beta values (for different factors) and not just a single for the whole market.[12]

Based on these drawbacks by using copies to determine betas, we will in this thesis determine beta for wind projects based on a comparison between our own calculation of the asset beta for the companies in our peer group, and relevant work and papers previously done on this area. Table 5 displays an overview of the calculated asset beta values found for the peer group.

---

[12] See Ross (1976) and Fama and French (1993) for a description on APT and the Three Factor Model respectively.

Table 5: The table displays the asset beta calculated for the peer group for the periods 2000-2007, 2000-2004 and 2004-2007.

Vestas			**Greentech**			**Plambeck**		
00-07	00-04	04-07	00-07	00-04	04-07	00-07	00-04	04-07
1.22	1.17	1.32	0.86	0.67	1.64	0.59	0.50	0.62

Gamesa			**Western Wind**			**Average**		
00-07	00-04	04-07	00-07	00-04	04-07	00-07	00-04	04-07
0.88	0.93	0.65	0.78	1.03	0.37	0.87	0.86	0.93

Our calculations show an asset beta in the range 0.8-0.9. Gjølberg and Johnsen (2007) are using slightly different time periods, but are also finding asset betas in approximately the same range. Gjølberg and Johnsen do further calculate asset beta for integrated energy companies involved in wind energy development and production. Table 6 repeats their findings.

Table 6: Asset beta for integrated power companies for the periods 2000-2004, 2002-2007 and 2004-2007. The results are collected from Gjølberg and Johnsen (2007).

E.ON			**Scottish & Southern**			**MVV**		
00-04	02-07	04-07	00-04	02-07	04-07	00-04	02-07	04-07
0.46	0.83	1.11	-0.10	0.01	0.37	0.16	0.35	0.89

A comparison between table 5 and table 6 shows that integrated power companies do in general experience a lower asset beta than companies in the wind energy value chain. Statkraft SF is the most significant developer of wind power in Norway and it can therefore be interesting to include estimates of its asset beta in our assessments. Johnsen (1996) estimate Statkraft's asset beta to be 0.40, while Lehman Brothers (2006) estimates Statkraft's Merchant Energy division to have an asset beta in the range 0.43 to 0.61. The fact that Johnsen (1996) finds a lower asset beta than Lehman Brothers (2006) can be ascribed that Johnsen (1996) is an older estimate than Lehman Brothers (2006) and that Johnsen (1996) includes Statkraft's network infrastructure in his calculation.[13] This is in contrast to Lehman Brothers (2006) who only considers the merchant energy part.[14]

The fact that imperfect copies are needed to determine beta, together with the general difficulties stated earlier and the spread in the asset beta calculations presented in this section, shows that it is not straightforward to decide the asset beta for wind projects. The betas presented earlier indicate an asset beta in the rage 0.50-0.90. Based on this, an asset beta of 0.60 will be used in this thesis as a best estimate.

Bio

In the previous section an asset beta of an investment in a wind project was calculated based on tradable copies, using the CAPM model to find the equity beta and then deleveraging it using the company's debt ratio. The rate of return demanded by investors in bio energy projects vary depending on where in the heat-sector value chain the project being evaluated is located and on the type of technology used. It is therefore difficult to find

---

[13] Statkraft's grid activities were however limited in 1996 compared to the current situation.

[14] Network infrastructure business are regulated monopolies, while merchant energy activities are competitive activities exposed to commodity price risk.

tradable copies of the cases evaluated due to the specific nature of the projects. A more qualitative analysis is therefore conducted in order to find an asset beta and the WACC.

According to Econ Pöyry (2008) the risk premium for investments in the sector should lie above The Norwegian Water Resources and Energy Directorate's (NVE) risk premium for grid services and below the average companies on the stock exchange. Further Gjølberg and Johnsen (2007) also find the risk for district heating (and implicit renewable combined heat and power project) to be lower than other power producers and higher than regulated grid services. The reason for this being that district heating are characterized by more or less regulated prices, in addition to stable demand and long-term costs. Based on these arguments, a qualitative assessment of the asset beta of different investments in the heat sector can be performed by spanning out a set of possible asset betas of the investment based on these endpoints, as given in figure 11.[15]

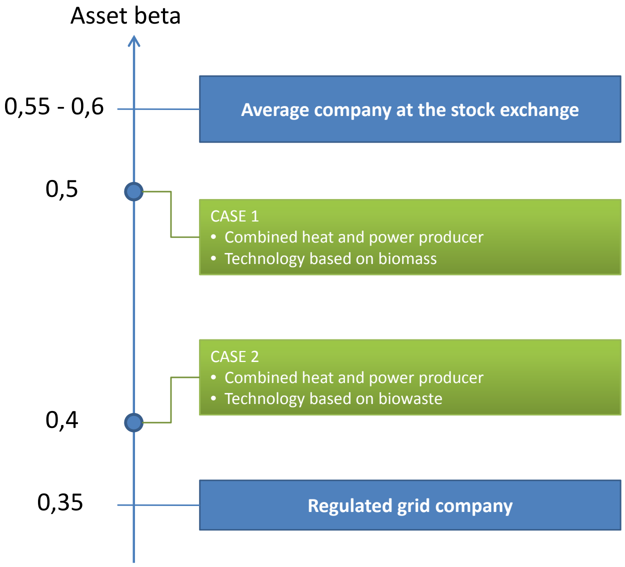


Figure 11: Asset betas for bio projects

In this thesis two different bio cases are considered, where the power plant is either fueled with biomass (case 1) or biowaste (case 2). Both cases delivers heat to households and it is assumed that since the project has a concession to deliver heat within an area, customers within this area have an obligation to connect to the system. This secures a heat demand for the investor.[16] The different fuel types do however lead to different risk profiles for the two cases. Biowaste is a fuel type that is characterized with a stable supply and at the same time has a negative cost for the heat producer. It is also a local resource that is produced wherever people are living. Centrals fueled on biomass do experience more uncertainty around the logistics and supply. This fuel resource is not available everywhere, and hence a biomass central may be dependent on supply from more distant suppliers. The fact that waste has a negative fuel cost do also lead to electricity generation during the whole year since it will always be profitable to operate the boilers even if there is no demand for heat. The opposite is the situation for the biomass fired central. Based on

---

[15] The asset beta of 0.35 for regulated grid companies stems from "inntektsrammereguleringen" by NVE (NVE (2008)).

[16] Obligation to connect is equivalent to "tilknytningsplikt" in Norwegian.

this discussion, case 1 is given an asset beta of 0.5 and case 2 an asset beta of 0.4.

3.1.3 Inflation

Inflation is an important factor to consider when valuing projects. As described more thorough later in the thesis, income and expenses are in real terms in the cash flow calculations. This is done assuming that all elements affecting the cash flows in the projects are experiencing the same inflation. Since all income and costs occur in Norway, Norges Bank's inflation target of 2.5% is used (Norges Bank (2008)). The price movements on different cost- and income component will however vary over time, but this thesis makes no assumptions on individual inflation levels.

3.1.4 Risk-free rate of return

Default-free government bonds are commonly used as an estimate of the risk-free rate of return. The risk-free rate is defined as the return provided by a portfolio with zero beta, i.e. no covariance with the market. In a project, free cash flows are spread over the life time of the investment. Ideally each cash flow should be discounted using a government bond with the same maturity, since the interest rates change over the yield curve. This is however rarely done by practitioners, in addition to the fact that the Norwegian yield curve is relatively flat at present.[17] It is therefore common to use a maturity that matches all the cash flows from the project. In this thesis government bonds with 10 years to maturity are used as a proxy. Since the investor is assumed to be international and well-diversified, a set of Eurobonds, US government bonds and Norwegian government bonds are used to decide on the risk-free rate of return. These are presented in table 7.[18] All countries used have AAA rating. Only these countries are included since a composite benchmark will include lower rated countries, which is considered to be irrelevant for the investor.

Table 7: Yield on government bonds.

Bond	**Effective yield**
Norwegian government bond (10 y)	4.55%
French government bond (10 y)	4.15%
German government bond (10 y)	4.18%
UK government bond (10 y)	4.73%
US government bond (10 y)	3.82%

In appendix A.2 the one year historic development in government bonds for Norway, EU and US are included. An equally weighted average of the selection above gives a risk-free rate of return of 4.29% (nominal), as showed in table 7. Since free cash flows are denoted in real terms later in the thesis, a risk-free rate has to be denominated in real terms.[19] This gives a real risk-free rate of return of 1.75%. It can however be argued that 10-year government bonds can be a wrong estimate of the risk-free rate of return, due to the fact that they can be illiquid and include an extra risk premium for future inflation (Johnsen (1996)).

---

[17] Effective yield on Norwegian government bonds per 05.05.2008 collected from Norges Bank: 4.69%, 3 year maturity; 4.55%, 5 year maturity; 4.54%, 10 year maturity.

[18] All data collected 05.05.2008 from the following sources: Agence France Trèsor (2008); Bloomberg (2008); Norges Bank (2008).

[19] Real risk-free rate of return is calculated by $\frac{r-p}{1+p}$, where r is nominal rate and p is inflation rate.

3.1.5 Market premium

Since most investors are characterized by being risk-averse, they demand a premium for holding stocks rather than bonds. The market's future return is unknown, and hence the calculation of the market risk premium must be done through models. Dimson, Marsh and Staunton (2006) advocate the use of a forward-looking world risk premium rather than using historic and country-specific premiums. They find a forward-looking arithmetic mean risk premium in the range 4.5% to 5.0%.[20] Campbell (2008) argues that world equity premium is approximately 5%. Based on these findings, a market premium of 5% is used in this thesis.

3.1.6 Cost of debt

Cost of debt is simply the effective rate the company is paying on its current debt. This can be defined as the yield to maturity on the long-term bonds of a company with investment-grade debt (Brealey and Myers (2006)).[21] Lenders are requiring a debt premium over the risk-free rate to lend money to corporations, due to default risk. This is also known as credit risk premium. Huang and Huang (2003) reports a credit risk premium in the range 50-100 basis points for companies with BBB+ rating, which is assumed that projects in this thesis will hold, and a debt premium of 75 basis points is therefore used.[22] This is also in accordance with Lehman Brothers (2006).

3.1.7 Tax

A common way to calculate net present value through discounted cash flows, is to calculate the free cash flows as if the project is all equity financed. Previous derivation of WACC calculations assumes that this approach is used. The share of the free cash flow going to debt holders is then treated in the WACC (see equation 7), together with tax advantages. The tax rate is necessary in order to calculate after tax cost of debt since interest payments are tax deductible. Since it is assumed that the investor is located in Norway, the marginal corporate tax rate of 28% is used.

3.1.8 Capital structure

Mjøs (2007) finds an average debt ratio for listed companies in Norway of about 60%. Traditionally, Norwegian power producers have had a lower debt ratio than other industries (Jenssen (2008)).[23] In the calculation of WACC it is most appropriate to use the targeted capital structure, and the investment projects are assumed to be financed with 50% debt and 50% equity.

The sections over have presented the WACCs used in this thesis. By doing so we have relied on the Capital Asset Pricing Model and accepted the simplifications and assumptions it makes. The CAPM model assumes for instance frictionless markets, meaning that securities can be traded without costs. Another important factor it ignores is the

---

[20] On an arithmetic basis

[21] Debt is considered Investment-grade if it is rated BBB or better by Standard & Poor's or Baa3 or higher by Moody's

[22] Statkraft AS do currently hold a long-term rating of BBB (Standard & Poor's) and Baa1 (Moody's)

[23] E.g. a valuation of Statkraft conducted by Lehman Brothers assesses Statkraft's merchant energy division to have a net debt/equity ratio in the range 25-30%.

cost of illiquidity in the market. The liquidity of an asset is defined as the ease and speed with which it can be sold at a fair market value in a timely fashion (Bodie, Kane & Markus (2005)). A part of this is the cost of engaging in a transaction, especially the bid-ask spread and the price impact.[24] For short term investors valuing energy projects, the need to be able to sell their share of the project quickly at a fair market value may be important, and so they might demand a liquidity premium for holding the asset. This thesis assumes a long term investor and will therefore not add an extra liquidity premium to the cost of equity.

As a concluding remark it is worth mentioning that the calculation of discount rates traditionally has been given too much attention compared to a critical evaluation of the cash flows generated from a project (Johnsen (1996)). This is avoided by using updated data about investment, operational and maintenance costs from NVE, in addition to crosschecking these numbers with industry players in the Norwegian market.

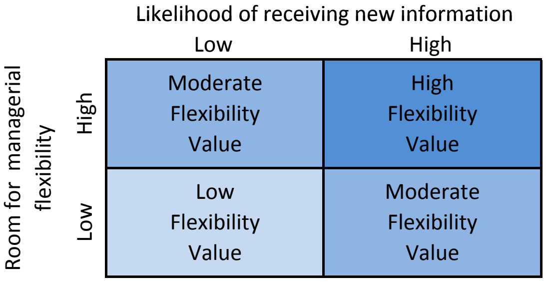
---

[24] The adverse movement in price one would encounter when attempting to execute a larger trade.

4 Valuation including flexibility

The discounted cash flow methodology described earlier in this thesis has been the dominating decision support technique regarding investment projects for several decades. One of the main drawbacks using the DCF techniques is that no flexibility is incorporated into the valuation. This lead users to valuing a rigid project which only uses the information available today and ignores all future flexibility, an example of which is given in Myers (1984). Suppose a firm can invest in a negative-NPV project in order to gain the opportunity to enter an attractive market. This first investment is associated with high risk, but can be justified by the possible valuable second-stage investment in the new attractive market. At first glace the natural thing might be to just forecast the expected cash flows and discount them at suitable discount rates reflecting the risk for each project. This will however not lead to the right answer. The traditional DCF technique fails to see the second-stage investment as an option. This investment is an option because the firm can wait and see the outcome of the first investment before they choose to undertake the second. The first-stage investment results in the purchase of an intangible asset: a call option for stage two. If the value of this call option and the first-stage investment has a positive NPV, the first investment can be justified.

The above example illustrates how the standard DCF approach fails to consider the value of managerial flexibility, and therefore undervalues the project. A decision is forced based on today's expectation of future knowledge (Dixit and Pindyck (1994)). Managers have the opportunity to react to changes in the economic, operational and technological environment by adjusting plans and strategies. This flexibility is associated with a certain value that needs to be found in order to capture the total value of an investment project (Koller et al. (2005)). Figure 12 is collected from Koller et al. (2005) and shows how the value of flexibility is connected to managerial flexibility and degree of uncertainty. As one might expect, the value of flexibility is at the highest when both uncertainty and room for managerial flexibility is high.



Likelihood of receiving new information

Room for managerial flexibility		Low	High
	High	Moderate Flexibility Value	High Flexibility Value
	Low	Low Flexibility Value	Moderate Flexibility Value

Figure 12: Managerial flexibility matrix

Two of the most popular decision-making techniques which incorporates and values flexibility in a project is decision tree analysis (DTA) and real option analysis (ROA). These are both discussed in the following.

4.1 Decision tree analysis

Decision trees maps all possible alternative actions contingent on the possible state of nature in a hierarchical manner. All available choices that a decision maker can choose from are displayed together with the estimated outcomes for each possible state. The contingent future cash flows are discounted at the project's cost of capital and each branch is associated with a probability. It is however not straightforward to use this approach. The correct cost of capital must be used, and since a project with contingent cash flows are evaluated, the cost of capital from the original project without flexibility can not be used. The reason for this is that the contingent cash flows are associated with a totally different risk profile. When flexibility is included, the cash flows are changed and so are the risk profile and the discount rate. A decision tree analysis assumes a constant discount rate throughout the tree, even if the risk of cash flows is dependent on the position in the tree and hence changing (Copeland and Antikarov (2003)).

4.2 Real options analysis

The real option approach uses techniques developed for valuation of financial assets and extend them to be used on real assets like e.g. land, plants, buildings and equipment. Further development also makes it possible to use real options to value flexibility in contracts (e.g. opportunity to re-purchase, maintenance) and R&D-programs. Common for all these examples are options embedded in the investment opportunities (Hull (2006)). Like financial options, a real option's value is dependent on six variables.

1. Current value of underlying risky asset.
2. Strike price.
3. Time to expiration.
4. Standard deviation of underlying risky asset (volatility).
5. Risk-free rate of return.
6. Dividends

When using ROA to value investment projects, the flexibility can be divided into four different option types, seen in table 8. Further elaboration on the different real options used in this thesis are discussed in section 6.4.

Table 8: Summary of real options

Option to defer	Equivalent to a call option.
Option to abandon	Equivalent to a put option.
Option to adjust (expand/contract, extend/shorten, switch)	Equivalent to options on options
Option to follow-on (compound)	Equivalent to financial put and call options

Two main techniques used for valuing real options are the replicating portfolio approach and risk-neutral valuation, both discussed in the following sections.

4.2.1 Replicating portfolio approach

In many cases it can be difficult to calculate the appropriate risk-adjusted discount rate. An alternative is to find a "twin-security" with cash flows perfectly correlated with the current project. A portfolio can then be composed of securities with exactly the same payoffs as the project in mind. To avoid arbitrage, the law of one price states that the portfolio and project must provide exactly the same payouts in every state of nature. This procedure is referred to as the replicating portfolio approach. This is also the fundamental foundation in option pricing models by Black, Scholes and Merton (Black and Scholes (1973); Merton (1973)). The option's payoff can be replicated by use of the underlying stock and riskless debt. Since the replicating portfolio exactly matches the option's payoff at expiration, to avoid arbitrage, the initial cost must be equal to the option's price (Campbell, Lo, MacKinlay (1997)).[25]

4.2.2 Risk neutral probability approach

In contrast to the replicating portfolio approach, which uses a risk-adjusted discount rate, the risk-neutral probability approach uses the risk-free rate to discount cash flows. This approach applies the probabilities of the underlying value either going up or down, in contrast to the replicating portfolio approach which do not need the probabilities since the option is replicated whichever way the stock moves. By constructing replicating portfolios, it can be shown that the option value is given by equation 11.

$$C_0 = \frac{\left[C_0\left(\frac{(1+r_f-\delta)-d}{u-d}\right)+C_d\left(\frac{u-(1+r_f-\delta)}{u-d}\right)\right]}{(1+r_f)} \tag{11}$$

Here u and d are the respective up and down movements of the underlying, r_f is the annual risk-free rate, δ the annual dividend yield, and $\mathrm{C_u}$ and $\mathrm{C_d}$ are the option values in the up and down states respectively. The expressions in the parentheses are called risk neutral probabilities and denoted by p and (1-p).

$$p = \frac{(1+r_f-\delta)-d}{u-d} \tag{12}$$

$$(1-p) = \frac{u-(1+r_f-\delta)}{u-d} \tag{13}$$

When valuing real options, the annual dividend yield, δ, is equivalent to the lease rate for investments in physical assets. By use of the risk-neutral approach, probability mass is altered so that cash flows can be discounted using the risk-free rate of return. The risk-neutral probability is a function of the up and down movements, the risk-free rate, and the dividend yield, and hence independent of the present state of the underlying. This is one of the great advantages of the risk-neutral approach, in contrast to the replicating portfolio approach where the risk-adjusted rates and hedge portfolios change. The real options approach also makes it possible to estimate the correct cost of capital to be used in a decision tree analysis, cf. the discussion under the DTA section.

The calculation of up and down movements, u and d, relies on the work by Cox, Ross and Rubinstein (1979), which gives the relationship between up and down movements in a binomial tree and the underlying risky asset's annual standard deviation of rates of return. The up and down movements are given by equation 14 and 15 respectively.

$$u = e^{(r_f-\delta)+\sigma\sqrt{\frac{1}{h}}} \tag{14}$$

---

[25] Assumes that the investment in the portfolio is self-financing, i.e. only cash outlay at the start of the investment and no withdrawal until expiration.

$$d = e^{(r_f - \delta) - \sigma\sqrt{\frac{1}{h}}} \tag{15}$$

Here σ is the annual standard deviation of the underlying and h the number of steps per year.

4.3 Use of binomial trees to value real options

Binomial trees have proven to be a very efficient and elegant way of pricing real options. Underlying is the binomial model where the asset price is monitored over consecutive (short) time periods, and where it is assumed that only two price movements can occur in each time period. This approach was first used by Sharpe (1978), and further developed by Cox, Ross and Rubinstein (1979), and hence often referred to as the "Cox-Ross-Rubinstein pricing model". The binomial tree is the graphical representation of the asset price and shows the different paths the price may follow over the life of the option (Hull (2006)). In each time period there is a given probability of moving up by a certain percentage, and likewise a certain probability of moving down a given percentage. Letting the time steps become infinitely small leads to the Black, Scholes, Merton model for pricing financial options. Construction of the binomial tree relies on the techniques for risk-neutral valuation, and the underlying formulas necessary to construct the tree is presented in section 4.2.2. Equations 12 and 13 give the probabilities for up and down movements, while equation 14 and 15 gives the percentage up and down movements per step respectively. The risk-free rate is used as the discount rate since the formulas assumes a risk-neutral world. This, in addition to the base case present value (PV) of the project, is all the information needed to construct the binomial tree.[26] Binomial trees can be either recombining or non-recombining. The tree is recombining if an up movement followed by a down movement gives the same price of the underlying as a down movement followed by an up movement. After the binomial tree is constructed, options can be incorporated into each node of the tree, transforming it into a decision tree. This way options can be priced when the lifetime of the option increases beyond one time step in the binomial tree.

It can be shown that it is never optimal to exercise an americal call option on a non-dividend paying asset before expiration. There are however three economic considerations governing the decision to early exercise options (McDonald (2006)):

- Dividends received from holding the asset.
- Interest cost from paying the strike price before expiration.
- Insurance provided by the option against an undesirable asset price at time of expiration.

Dividends from the underlying asset can make it profitable to exercise the option prior to expiration in order to receive these dividends. Larger dividends will therefore stimulate early exercise of options. Exercising a call option entails paying the strike price in order to obtain the underlying asset, and so holding the option postpones this payment. The option can also be considered to provide implicit insurance protecting against the possibility that the option may end out-of-the-money at expiration. A lower volatility of the underlying decreases the value of this insurance, and by exercising the option the insurance value is lost.

---

[26] This binomial tree is equivalent to an event tree.

5 Portfolio perspective

As described earlier, the thesis analyzes investments from an internationally well-diversified investor's point of view. This resulted in the choice of MSCI World Index as a benchmark index for the market. This section will elaborate on some of the underlying assumptions necessary in order to deem our investor as well-diversified and further discuss the portfolio perspective in renewable energy as seen from both the investor's point of view, a corporate point of view and a social point of view. The portfolio perspective will not be explicitly considered in the valuation of the project, other than through use of CAPM to calculate the investor's cost of capital. It is however included here to give a wider perspective of how investments in renewable energy projects can be assessed.

Portfolio perspective from a corporate and investor point of view

Most investments are characterized by a certain amount of risk that can be divided in two categories, systematic and unsystematic risk. Unsystematic risk is regarded as company specific risk, which is the risk an investor is undertaking if he/she only invests in one company. The risk can be related to e.g. the risk of a company going bankrupt or risk of recession localized in one sector of the market. Investors can however remove all unsystematic risk by diversification, since factors leading to unsystematic risk are company specific and hence not correlated with each other. The investor is then left with a portfolio containing only systematic risk, which is common for all securities of the same general class. The Separation Theorem states that shareholders' wealth is maximized if managers invest in projects with the highest NPV compared to other mutually exclusive alternatives. Managers following the Separation Theorem will make investments in renewable energy highly relevant for investors looking for "new" investment vehicles for diversification. Theory further states that diversification should not take place at a corporate level (Berger and Ofek (1994)). Explanation of this can be higher agency costs than single-business companies and that it is usually easier and cheaper for investors to diversify than for companies (Brealey and Myers (2006); Jensen (1986)). Investors considers the risk-spreading qualities of well-diversified companies as of no value and will hence not pay a premium for them. Some empirical data do however show that some well-diversified companies outperform the market and do have lower risk from being diversified to a certain degree, among others due to distress cost (Kaye and Yuwono (2003)). From a generation economics point of view it also makes sense to talk about portfolios, namely generating portfolios. Traditionally, if a generation alternative is evaluated, the "least cost" alternative has been the way to perform energy planning. When holding a portfolio of different generating alternatives, it is however common to talk about portfolio cost instead of stand-alone cost. What is interesting is the source's cost contribution relative to the risk contribution in the portfolio, which is in accordance to the way financial portfolios are evaluated (Averbuch and Berger (2003)). Averbuch (2000) shows that adding fixed cost generating alternatives to a portfolio of conventional generation units reduces overall portfolio cost and risk, even though stand-alone generating cost can be significantly higher than conventional alternatives. Averbuch and Berger (2003) points out that in situations where portfolios of real assets are to be constructed, "variation and covariation of the holding period returns of costs of technologies considered" can be used as a measure analogous to market risk in financial portfolios. It is then possible to construct efficient frontiers based on the different generation classes, where "riskless" resources (i.e. passive renewable technology that is not exposed to fuel risk) act as riskless assets (cf. financial portfolios).[27] Market imperfections in form of suboptimal market design may further imply that an integrated producer controlling several generation technologies can

---

[27] Consult Markowitz (1952) for details on portfolio theory.

make better decisions than stand-alone producers. These decisions may comprise both production and allocation between technologies on a short- or long-term basis, based on price signals in the market.

So far we have only discussed the impact of diversification seen from an investor's and corporate point of view . The discussion has shown that diversification through different generation technologies at company level can be natural and valuable for investors and companies. Portfolios do however in addition impact other factors than pure economical ones. Some of these are not properly captured by standard investment models and will be discussed for investments in renewable energy in the following.

Portfolio perspective from a social point of view

For the consumers and the society it is important to avoid energy and power shortage and at the same time generate in an environmentally friendly way. Electric energy can be generated in several ways. In Norway hydro power is totally dominating, while conventional thermal power plants are mainly prevailing throughout the rest of the world. Power systems dominated by hydro production is energy dimensioned. These systems have plenty of power, but a very volatile energy source. Thermal energy systems on the other hand are power dimensioned, and the energy source (coal, oil, gas) can be considered more or less limitless. What is important for customers is to be supplied with the demanded amount of energy. Investments in new renewable energy will lead to a broader production portfolio as seen from a power consumer's perspective, and hence contribute in a positive way. Norway's dependency on hydro power has led to vulnerability to precipitation, something that was confirmed during the winter 2002/2003 when there was a serious threat of electricity shortage and rationing. This led the Norwegian Ministry of Petroleum and Energy to prepare St.meld nr.18 (2003/2004), which points out several initiatives and plans of action. Many of these initiatives are of an advantageous character for investments in renewable energy as they have led to an increase in economic support and a more “smooth” bureaucracy when it comes to applying for concession. In time this probably leads to a more diversified portfolio of generating technologies in Norway, and hence reduce the dependence on hydro power. More transmission capacity to continental Europe will also improve the security of supply. However, from an investor's point of view, the main objective is still to maximize profit. Inclusion of several energy sources can contribute to that, since many combinations of different technologies can benefit from the flexibility of generating when prices are at the highest or reduce the need for expensive regulation. Another question that arise is whether use of policy instruments is able to realize the social optimal portfolio of different technologies from market based signals. This will require a more thorough evaluation of how different generation technologies are compensated in the market to give investors and producers an incentive to construct economically efficient portfolios (Jenssen (2008)).

Sustainable development has as previously discussed become an important factor especially in the energy industry. Based on the last decade's focus on environmental issues, several directives, incentives and laws are putting restrictions on power generation, influencing producers and consumers of energy. As more economic incentives are coming in place (feed-in tariffs, green certificates, etc.), renewable energy is getting more interesting for investors as these become economically sound projects. Even though economic incentives historically has been the main driver for investors to implement renewable energy production in their portfolio, it is also becoming more and more important for corporations and investors to give an outwards impression that they operate and invest in agreement with social acceptable guidelines. Further, as the significance of environmentally friendly behavior is increasing, this can lead to investors using renewable energy projects as a way to cope with these guidelines. The high focus on environment and renewable energy can also result in consumers being more willing to buy green power voluntarily. Another point worth mentioning is that generating portfolios that contains a mix of e.g. thermal and hydro power will lead to lower demand for regulation of the thermal units. This will again lead to less pollution since rapid changes in production from these units are expensive and extra pollutive.

6 Model

Section 4 presented the importance of incorporating flexibility in the valuation of projects. In this section the real options framework developed by Copeland and Antikarov (2003) is presented. This framework will be used to value investment projects with flexibility in this thesis. The technique is described by a four-step process, and considered as a user-friendly and highly adaptable approach. The valuation model developed in this thesis is built in Microsoft Excel and Visual Basic for Applications (VBA) and is enclosed on a CD in appendix A.12.

6.1 A four-step process for valuing real options

The four-step approach presented in Copeland and Antikarov (2003) is illustrated in figure 13.

Figure 13: Four-step approach for valuing real options

The first step consists of creating a standard DCF model for valuation of the respective project without including any flexibility. Different uncertainty factors that affect the project value are identified and the ones considered most prominent are modelled, either using historical data or other more qualitative assessments. All these uncertainties are combined in a Monte Carlo simulation to estimate the volatility of rates of return, referred to as the consolidated approach in Copeland and Antikarov (2003). The different managerial flexibility of the projects evaluated are then identified and modelled through options, with the project value as the underlying asset. In the final step, the event tree and the options identified are combined in a decision tree through a real options analysis, either by using the replicating portfolio technique or risk-neutral probabilities as used in this thesis.

The replicating portfolio approach requires a market-priced underlying asset that is perfectly correlated with the current project in every state. This is practically impossible as many of the options needed to be valued are not written on assets that have a market-priced security with the same characteristics. To avoid this problem, Copeland and Antikarov (2003) recommends using the present value itself (without flexibility), as the underlying risky asset i.e. the twin security. They argue that the best unbiased estimate of the market value of a project, if it was a traded asset, is the present value of the cash flows of the very same project without flexibility. This is called the Marketed Asset Disclaimer (MAD), and is in accordance to valuation of financial options, where the underlying risky asset is usually a traded asset and so the parameters easier to estimate. This is not the situation for real options and hence the MAD assumption is used.

Copeland and Antikarov (2003) also assumes that properly anticipated cash flows fluctuate randomly. This implies that changes in the present value of projects will follow a random walk with constant volatility, independent of the expected cash flow patterns. This assumption builds on Samuelson's proof (Samuelson (1965)). In briefness the theorem can be stated as follows. "The rate of return on any security will be a random walk regardless of the pattern of cash flows that it is expected to generate in the future as long as investors have complete information about those cash flows" (Copeland and Antikarov (2003), page 222). This implies that all information about future expected cash flows are already incorporated in the considered asset's price, and investors will hence receive their expected cost of capital if expectations are met. However, deviations from the expected future cash flows will produce price changes that deviate from the expected ones. Deviations like these can only be caused by random events, and therefore the deviations from the expected rate of returns are also to be considered as random.

By making the assumptions mentioned above it is possible to combine any number of uncertainties in a project valuation by use of Monte Carlo techniques. These uncertainties may be auto- and cross-correlated with each other and by using a high number of simulations an estimate of the volatility in shareholder returns can be found. This can further be used as the volatility of the underlying project value when constructing a binomial lattice for pricing the real option, as described in section 4.3.

6.1.1 Further elaboration on estimating volatility under the consolidated approach

As described earlier, the output from the consolidated approach is a single estimate of project volatility, built up by using all relevant underlying uncertainties considered to have significant impact on the project. To use this approach, the stochastic properties of the underlying drivers of project volatility need to be estimated and modelled in advance.[28] Figure 14 displays the approach.

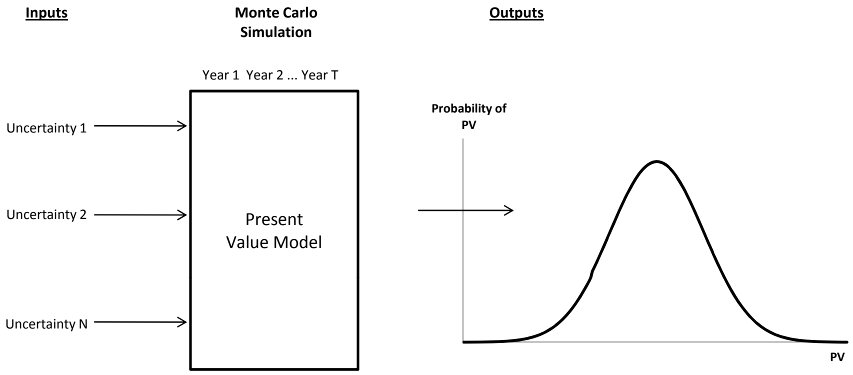


Figure 14: Illustration of the Monte Carlo simulation process. The figure is taken from Copeland and Antikarov (2003), page 245.

Each Monte Carlo simulation generates an estimate of the present value of the project. For a project that reinvests all the free cash flows, the rate of return is given by equation 16.

$$PV_t = PV_0 e^{rt} \tag{16}$$

$$ln \frac{PV_t}{PV_0} = rt \tag{17}$$

---

[28] It is here important to stress the fact that the volatility of a project is not the same as the volatility of any of the input variables or the company equity volatility.

By setting t equal to one, equation 17 gives a simple way of finding the project's rate of return for one simulation. Repeating this procedure gives a measure of the standard deviation of the rates of return for the project.[29] For a project that do not reinvest the free cash flows, the rate of return is given by equation 18, again setting t equal to one.

$$r = ln\left(\frac{PV_1 + FCF_1}{PV_0}\right) \tag{18}$$

Copland and Antikarov's four-step approach starts with a present value calculation based on expected values of the uncertain factors and no flexibility included, presented as PV_0. In equation 17 and 18 PV_0 is held constant while the present value at t equals 1 is changing due to different realizations of the uncertain inputs for each simulation. The volatility of the resulting rates of return is then used as the volatility of the underlying asset when analyzing the real options.

6.2 Link between theory and model

This section describes how Copeland and Antikarov's Four-Step method is used to value investment projects in renewable energy. The valuation model developed in this thesis is built in Microsoft Excel and Visual Basic for Applications (VBA). A more thorough description of the model's user interface and input parameters is given on the readme file found on the attached CD in appendix A.12. A principal drawing of the valuation model is given in figure 15.

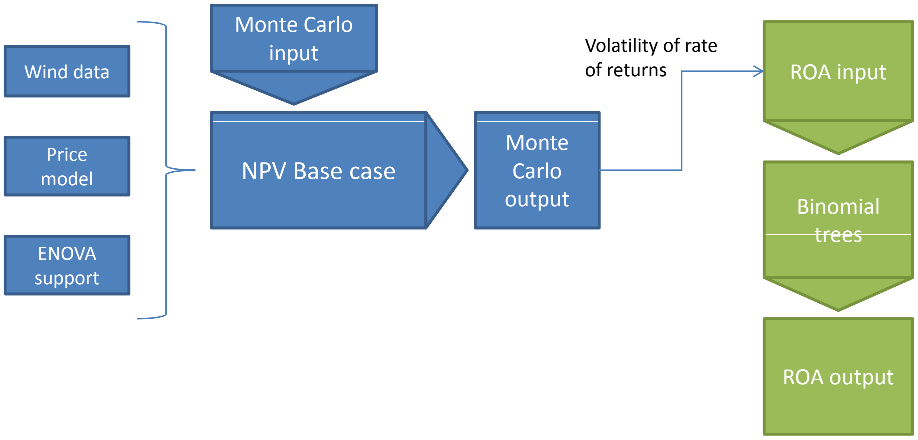


Figure 15: Overview of model

The model is separated in two parts, one using Monte Carlo simulation to estimate the volatility of the underlying project value, and the second constructing binomial lattices and including the managerial flexibility in a real option analysis. The first part is centered round a DCF model (NPV base case) created for the different base cases using publicly available data and other relevant sources as input.[30] The different parameters of the uncertainty factors are then specified and the Monte Carlo simulation initiated, in order to obtain the volatility of the underlying project value. This volatility is then exported

---

[29] This is the annual standard deviation of rates of return.

[30] Grønli (2008); Musum (2008); NVE (2006, 2007)

into the second part of the model, where the managerial options are specified together with the expected annual dividends from the project. The value of the investment project including flexibility is found using the binomial valuation approach described in section 4.3.

In section 4.2the dividend yield (lease rate) was incorporated into the equations for the risk neutral probabilities and the up and down movements in the binomial tree. It is also possible to include the dividends directly in the binomial tree, as is suggested in Copeland and Antikarov (2003). By assuming that dividends paid each year is proportional to the project value, the three becomes recombining, as illustrated for the wind project in figure 16. The free cash flow's share of the projects value increases towards the end of the project life due to a low continuing value.[31] This technique is used when pricing the contingent options in this thesis. The wait-and-see option on the investment will incur a lease rate since postponing the project one year will also shift all cash flows from the project by one year. The difference in present value of these two cash flow series are calculated and divided by the initial investment to obtain an estimate for the annual lease rate. This lease rate is used for pricing the wait-and-see option.

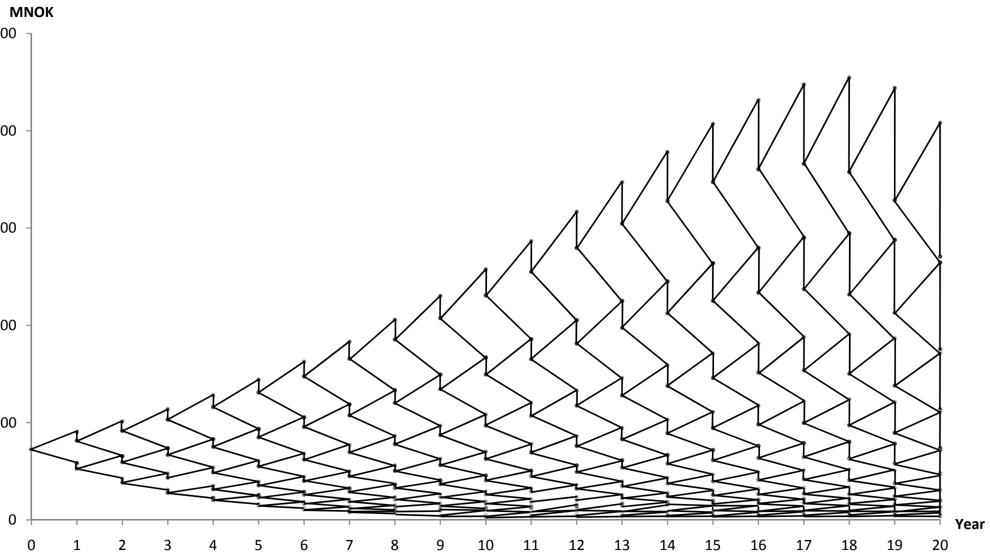


Figure 16: Recombining binomial tree used for pricing the abandon and expand option in the wind case.

In the next section the underlying stochastic factors included in the model are discussed, followed by a description of how the managerial flexibility is modelled.

6.3 Modeling uncertainty

This section discusses and models the underlying processes that drive the uncertainty of a project's value. The different parameters of the models used are estimated, and assumptions made for the cases where no empirical data exist.

---

[31] Non of the free cash flows are retained in the project and all are paid to the debt and equity holders.

6.3.1 Power price

This section presents the model used for the electricity spot price, together with estimation of parameters and simulations to verify the results.

Model

The Nordic electricity prices are characterized by seasonality (annually, weekly and daily), mean reversion and high volatility (Fleten and Ringen (2006)). This thesis uses a two-factor model based on Lucia and Schwartz (2002) to capture these properties. The stochastic price behavior of the spot price is modelled with one short-term mean reverting component and one long-term equilibrium price level component given in equation 19.

$$P_t = f(t) + X_t + \epsilon_t \tag{19}$$

Where

$$dX_t = -\kappa X_t dt + \sigma_x dZ_x \tag{20}$$

$$d\epsilon_t = \mu_\epsilon dt + \sigma_\epsilon dZ_\epsilon \tag{21}$$

$$dZ_\sigma dZ_\epsilon = \rho dt \tag{22}$$

Here, f(t) describes the seasonality in the electricity prices, while the stochastic term $\mathrm{X_t}$ is the short-term component which follows a mean reverting Ornstein-Uhlenbeck process, and ϵ_t is the long term equilibrium and follows an arithmetic Brownian motion.[32] The two stochastic processes (dZ_X and dZ_ϵ) are correlated through equation 22. κ is the speed of reversion of the short term factor, μ_ϵ the drift of the long term factor and σ_X and σ_ϵ the volatility of the short and long term factors respectively.

In order to use the model for security valuation purposes, the risk-adjusted process for the stochastic terms in the two factor model is needed. The corresponding risk-adjusted processes are given by equation 23 and 24.

$$dX_t = \kappa(\alpha^* - X_t)dt + \sigma_X dZ_X^* \tag{23}$$

$$d\epsilon_t = \mu_\epsilon^* dt + \sigma_\epsilon dZ_\epsilon^* \tag{24}$$

Where

$$\alpha^* = -\frac{\lambda_X \sigma_X}{\kappa} \tag{25}$$

$$\mu_\epsilon^* = \mu_\epsilon - \lambda_\epsilon \sigma_\epsilon \tag{26}$$

λ_X and λ_ϵ are the market prices of risk for each state variable and assumed to be constant, dZ* is an increment to a standard Brownian motion, Zt*, under the risk-neutral probability measure.[33] It can then be shown that the futures prices are given by equation 27.

---

[32] See Dixit and Pindyck (1994) for a detailed description on the stochastic processes.

[33] See e.g. Hull (2006) chapter 25 for a more thorough description of market price of risk.

$$F_0(P_0, T) = E_0^*(P_T) = f(T) + e^{-\kappa T} X_0 + \epsilon_0 + (1 - e^{-\kappa T})\alpha^* + \mu_\epsilon^* T \tag{27}$$

Electricity needs to be delivered over time, and equation 27 therefore gives the theoretical price for a contract with maturity date T. The seasonality is captured by the deterministic component in the model, f(T), and is given by equation 28.

$$f(t) = \alpha + \gamma \cos\left[(t + \tau)\frac{2\Pi}{52}\right] \tag{28}$$

Here α determines the level, γ is the amplitude of the seasonality, while τ adjusts the time for the annual peak in power price given by the model. The model estimates weekly electricity prices and captures seasonal patterns through a sinusoidal term. Since only long-term price movements are of essence for valuing long-term projects, short-term patterns are less relevant for the results.

Estimation

The parameters in the price model are estimated based on historical weekly spot prices and prices of futures and forwards traded at Nord Pool between January 1996 and February 2008, giving 10 260 observations. The parameters are estimated using the procedure presented in Lucia and Schwartz (2002) and Cortazar and Schwartz (2002). This is a numerical nonlinear least squares procedure, which is considered a more flexible and user-friendly approach than the rather complex Kalman filtering. After running 40 iterations in Excel, the improvements per run are approximately zero and the parameter estimations obtained are presented in table 9. The excel file used for estimating the two factor price model is enclosed on the CD in appendix A.12.[34]

Table 9: Estimated parameters of two factor model for electricity prices

Parameter	**Value**
Mean reversion speed κ	0.033
Long term drift factor μ_ϵ^*	-0.024
Volatility short term factor σ_X	6.39
Volatility long term factor σ_ϵ	0.20
Level α	151.2
Amplitude γ	25.4
Phase angel τ	-2.17
Correlation between short-long term ρ	-0.23

The parameters can be compared to the values obtained in the original paper by Lucia and Schwartz (2002), presented in appendix A.3. These values were however computed using daily prices from the period January 1993 to December 1998, and a seasonal variable correcting for weekend and holiday effects. Despite these differences the parameters estimated in this thesis are very similar to the ones found in the original paper. Both the level (α) and the amplitude (γ) of the deterministic part of the model are approximately equal, with a slightly higher amplitude in Lucia and Schwartz (2002). This suggests that the annual price variation has diminished since the late 90s. The original paper find the expected electricity price to be highest in week 4 compared to week 50 in this thesis. This shift of the annual prices of 6 weeks can be caused by climate changes resulting in earlier spring flood shifting the filling and depletion periods of the year. The mean reversion

---

[34] The Excel file is a further development of the one created and used in Krossøy and Torgersrud (2004).

speed (κ) of the short term price component is found to be higher than in the original paper, giving faster reversion to the deterministic part of the price model.

Both the models find a negative long term drift rate (μ_{ϵ}^{*}), mainly due to high price periods followed by relatively lower price periods prior to the end of the estimation period. High prices occurred during the winter of 1993-1994 and parts of 1996, followed by lower prices in 1997 and 1998. The electricity prices in 2006 were also higher compared to the ones in 2007 and 2008. Based on today's forward curve seen in the market and presented in appendix A.4, it is possible to argue that our model do not capture a long term positive drift. This may be caused by lack of sufficient data, resulting in inaccurate parameter estimates, or the arguments above. Further the use of market prices on power contracts results in a model that predicts prices in nominal terms. Since net present value calculations are done in real terms in this thesis, the model has to be adjusted for this. Based on the arguments presented above it is argued that it is reasonable to expect a positive drift of 2-3% per year in the long-term equilibrium component. For simplicity it is therefore chosen a long term drift of 2.5%, this being equal to the expected inflation rate. The model can therefore be used directly in the net present value calculations, as it gives prices in real terms.

Simulation

Simulations are used to see how the price model performs. Figure 17 displays realized prices over three year periods from 1996 to 2007. Further figure 18 shows the results after 100 simulations for the price model over a three year period. The chart displays the average, maximum and minimum values. None of the maximum values seem to reach the magnitude of the high realized electricity prices in 2002 and 2006. Letting the model simulate for longer periods then 3 years, will give samples that reach prices in the 2002 and 2006 range. The jump characteristics seen in historical prices will however not occur, since this property is not included in the model. The average simulated price seems to be in a sensible range compared to the realized prices.

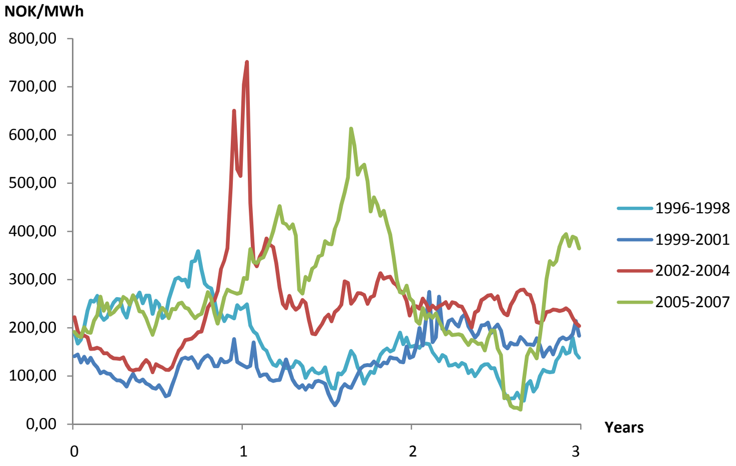


Figure 17: Realized prices over three year periods from 1996 to 2007

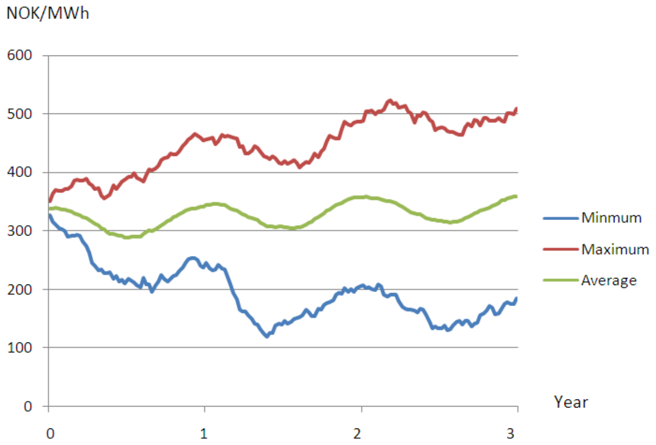


Figure 18: Maximum, minimum and average prices after 100 simulations

6.3.2 Heat price

This section gives a description of how heat delivered from the combined heat and power station fueled with biomass or biowaste is priced in this thesis. It is the alternative price that decides the price of heat delivered to households in Norway. Since electric power is the dominating source of heating, the equivalent prices of electric heating are usually the relevant basis of comparison when heat is to be priced. According to the Energy Act (1990), section 5-5, "the charge for district heating shall not exceed the charge for electrical heating in the same supply area". The alternative price for households in this case is therefore the electricity spot price, fees for transmission and distribution (exclusive VAT) and electrical tax (exclusive VAT).[35] Situations can however occur, when the electricity price to households exceeds other alternative costs of heating such as oil or gas, and in these cases the price of oil or gas will represent the alternative cost. The price of electric heating to households is however used as the alternative cost for heat in this thesis, and a suitable premium to the power price is found. The power price will be calculated from the power price model described earlier and the Norwegian electrical tax is equal to 0.105 NOK/kWh. The fees for transmission vary between different grid owners, and an overall average for Norway is used. It is the variable term of the transmission fee exclusive VAT that is relevant. This average is approximately 0.165 NOK/kWh (NVE (2008)). It is further relevant to add a markup on the electricity spot price to cover administrative costs etc. NVE found it reasonable to use a markup of 0.022 NOK/kWh (inclusive VAT) in 2005 (Dalen, Moen and Riis (2007)). In this paper it is used markup of 0.03 NOK/kWh (exclusive VAT). This results in a total premium of 0.30 NOK/kWh.[36]

6.3.3 Support schemes

There are several aspects of the support schemes that contribute with great uncertainty for investors in renewable energy projects. The need for stability of support over longer periods is necessary to attract investors and Norway is now in a transitory stage with much uncertainty which have practically stopped all investments in wind energy (Musum

---

[35] Electrical tax is equivalent to "elavgift" in Norwegian.

[36] This corresponds to an overall discount of approximately 12% on energy delivered as heat compared to electricity.

(2008)). There are basically two different types of support schemes for power that are being considered for introduction, as described in section 2.1.4. Another source of uncertainty that needs to be addressed is when these new systems will be introduced.

Timing and form of support scheme

The timing of when the new system will be introduced can not be set for certain. Last time the government was in dialog with the Swedish government about a common certificate market, the negotiations broke down and the transition period extended. If this happens again the alternative system with a fixed premium that was designed will probably be introduced. The possible inclusion in a common European certificate market is also present, but this will probably not happen in the nearest future and will be disregarded in this thesis. To model the timing of when the system is introduced, probability weights for the different years close to the planned year of implementation are used. The weights sum to 1 and are set based on interviews with representatives from Enova SF and other relevant sources (Christophersen (2008); Jenssen (2008); Musum (2008)).

The form of the support scheme will also be important for potential investors and another source of uncertainty. As mentioned before, two possible support schemes are assumed realistic for implementation in Norway. These are a fixed premium feed-in system and a system for tradable green certificates together with Sweden which are described below. To model the type of support schemes, probability weights are given to the different schemes considered. These weights are also based on interviews with representatives from Enova SF and other relevant sources in the industry(Christophersen (2008); Jenssen (2008); Musum (2008)).

Fixed premium feed in system

A fixed premium system for the Nordic market will probably be based on an updated version of the system developed after the last break in negotiations (St.meld nr.11 (2006-2007)). This support system is not technology neutral and different production technologies will receive different amounts of support per kWh electricity delivered. The old version suggested a support of 0.08 NOK/kWh for wind projects and 0.10 NOK/kWh for bio projects. Due to increased investment costs for wind projects in recent years, the support for wind projects will probably be increased to 0.15 NOK/kWh in the new version while the support for bio projects will remain the same (Musum (2008)). These last estimates for the support per kWh renewable energy delivered will be used in this thesis and for simplicity assumed to be denominated in real terms. No uncertainty about the actual level of the fixed premium is therefore included.

Green certificate system

A tradable green certificate system will include power generated from both wind turbines and bio plants, but the heat produced from the bio plant will most likely not be included in the market.

A support scheme for the heat produced is less likely to occur in the nearest future but could easily be included in the model. According to Econ Pöyry (2006), the creation of a common certificate system should attempt to include both electricity and heat. If this cannot be accomplished, a production support that follows the certificate price will be the best support scheme to secure equal competition. This thesis ignores any potential support systems for heat, but the model can easily adapted to include this if desirable for further use.

A common market for Norway and Sweden will probably result in a slightly lower certificate price than the one seen in the Swedish market today. The reason for this being a higher potential for renewable energy in Norway that can be commercialized at a lower cost per kWh. On the other hand, the Swedish government will probably be interested in setting a total ambition level so high that the price will be held relatively constant, in order to prevent large changes in the economic conditions for investors in renewable energy.

Based on this, historical prices of the certificates in the Swedish market are used to find a stochastic model for the price movements in a future common market. A graph of the historic Swedish certificate price for the period the system has been in operation is given in figure 19.

Figure 19: Time series of closing prices of the Swedish green certificate market 2004-2007

The certificate price movement will be modelled as a geometric Brownian motion (GBM), as was also applied in Fleten and Ringen (2006). This thesis uses however an updated data set. This is a simple model to estimate and prevents negative certificate prices during simulations. The certificate price movement, C_t, can therefore be described by equation 29.

$$\frac{dC_t}{C_t} = \alpha dt + \sigma dz \tag{29}$$

The drift parameter α is set to be -0.000475, found as the average drift rate of the high and low ambition scenario given in Fleten and Ringen (2006). The annual volatility σ is estimated to 0.0738.[37] For further details in regards to the estimation of the parameters see Fleten and Ringen (2006). The level of a potential future certificate market is also an important parameter subject to discussion. In this thesis the starting level of such a certificate price is set equal to the average certificate price in the Swedish market for the period 01.01.2007-01.01.2008, in lack of better estimates.[38] This gives a starting value of 0.18 NOK/kWh, which is also used irrespective of when the new support system is introduced. For simplicity the certificate price model is assumed to be in real terms. In 2008 the TGC price in Sweden has increased significantly, suggesting scarcity of certificates in 2009/2010. This can in term lead to underprediction from the model used in the thesis.

---

[37] Found from the standard deviation of $\log\left(\frac{C_t}{C_{t-1}}\right)$ where C_t is the certificate price at the Swedish market, using data from the period 03.03.2004-01.01 2008

[38] Using an annual exchange rate for 2007 of 86,67 between NOK/SEK given by Norges Bank (2008)

European certificate market

A common certificate market for European countries is a future scenario that may seem distant today, but nevertheless possible and also lucrative for an investor in Norway. The certificate price in such a market would most likely be significantly higher than the one observed in the Swedish certificate market today and a possible future certificate price for a common Norwegian/Swedish market. The reason for this being a much higher total ambition level and many relatively cheap renewable energy projects in Norway compared to other European countries. An example of this is wind projects with good wind conditions in Norway, as can be seen from figure 2 in section 2.2.

The future price level of such a market is however very difficult to estimate due to uncertainties about: how many countries that are to be included; the total ambition level; the congestions in relation to transmission capacity between Norway and central Europe. Estimates for the volatility and drift in such markets would also be difficult to estimate if a GBM model for the price movements (or any other model for that matter) were to be used, as done above.

If a successful common certificate market for Norway and Sweden is created it is also likely that more countries will be included in time.[39] As more European countries are included, the total ambition level would increase and the certificate price would also probably increase. This type of scenario could be modelled by using the same model as for the certificate price above, only that the drift parameters are manipulated to include this increase in prices. The drift parameter in such a case would also be difficult to estimate, but a scenario such as this is presented in section 7.5.3.

Investment support

This thesis assumes that a new support system will be introduced to replace the old transitory system with investment support until a desicion is made between the fixed premium system and the TGC system. A future system of investment support is however another possible scenario but not included in this thesis. The model can also easily be adapted to include this scenario.

6.3.4 Wind power generation

The wind velocity at a wind park can be modelled with a Weibull-distribution given by equation 30 (DWIA (2008)).

$$f(\nu_1) = \left(\frac{\varphi}{S}\right)\left(\frac{\nu_1}{S}\right)^{\varphi-1} e^{-\left(\frac{\nu_i}{S}\right)^{\varphi}} \tag{30}$$

Here φ is the form factor describing the peak shape of the distribution, S the scale factor describing the skewness, and ν_i the assumed constant velocity in front of the turbine. This gives different distributions each month due to different average wind velocities. This thesis uses the estimated monthly parameters for a wind project with an average annual wind velocity of 8.4 m/s as done by Krossøy and Torgersrud (2004), given in appendix A.5. The utilization time of the wind park is set to 2650 h, giving an expected total net generation of 102 GWh/year.

New parameters can be estimated based on wind observations on the site of the wind park being analyzed, but this is not the purpose of this thesis and so this simplification

---

[39] A possible scenario could be the inclusion of Finland and Denmark after a few years, then Germany after a few more years etc

will be used to model the stochasticity of the wind resource. This gives the following probability density functions for the wind velocity in the respective months, as illustrated in figure 20.

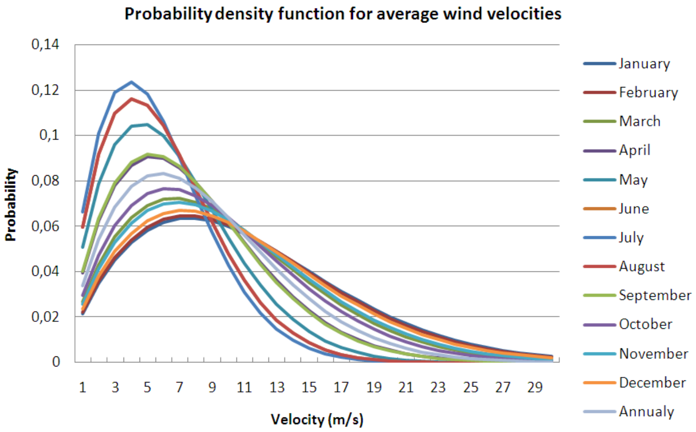


Figure 20: Probability density function for wind velocities in different months of the year

These are the instant probabilities for wind velocity at the specific site in a given month. The simulated average wind velocity in a month can then be found by sampling many observations from this distribution and averaging it. This results in a normal distribution centered round the average wind velocities for each month as given in appendix A.6. These normal distributions are then used to simulate the wind production in each month. Running simulations from the model show an annual standard deviation of 10-12% compared to the expected generation. It also gives annual deviation of +/- 20% for the maximum and minimum values. This is in accordance with numbers presented by Løvseth (2008).

6.3.5 Availability of plants

The different power generation units will not be operational all the time due to breakdowns, maintenance of equipment or other reasons. This varies between different projects and technologies and increases probably with the life of the project. In this project the availability is assumed to be constant over the life of the projects, but the costs of operation and maintenance increase at the end of the project lives. The availability of wind power generation units are set equal to 97% based on Nelson (2008), and the annual availability of the wind turbines is assumed to be normally distributed with an annual standard deviation of 0.5%. These numbers are in accordance with production statistics for wind published by NVE (NVE (2006)). The availability of biomass and biowaste power generation units are set equal to 95% based on Cogeneration Technologies (2008). The annual availability of our plant is also assumed to be normally distributed with an annual standard deviation of 0.5%.

6.4 Managerial flexibility

Valuing the managerial flexibility of investment projects is the main difference between using a real options analysis versus a standard NPV procedure. Identifying such flexibility and modeling them as options can be a difficult task, compared to financial options on common stocks for instance. The volatility of the underlying and the correct strike of the option can change over the projects life and may also be difficult to estimate in the first place. In this section the three options that are included in this thesis are described, representing the managerial flexibility that may exist in renewable energy projects.

6.4.1 Wait-and-see option

The first and often the most valuable option investors in a renewable energy project have is the option to postpone the investment awaiting more information from the market. This information can be whether or not a new support scheme will be introduced, if price movements turn out favorably or other factors affecting the profitability of the project. This wait-and-see option can be modelled as a call option with the projects present value as the underlying and the investment cost as the strike price. The investor will therefore only exercises the option and pay the investment cost if the present value of the project's cash flows are larger than this initial investment cost. The length of such an option will typically be given by how long the investor can postpone the investment before the concession expires and a new one needs to be applied for. There is also a risk that after such a period the permit will be given to someone else since the government is interested in implementing such projects.

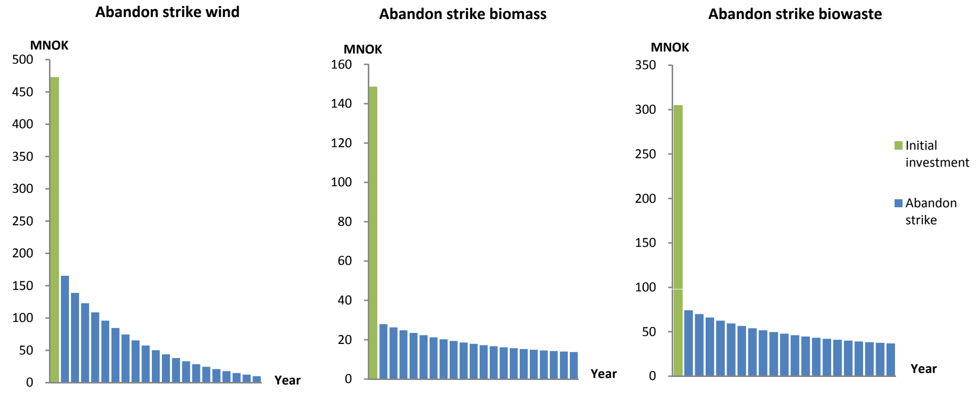
The wait-and-see option for a typical wind project will be given a strike price equal to the total investment cost for the wind park. The investment support is deducted from this amount since it is not paid by the investor in order to receive the future cash flows of the project. The length of such an option is set to 5 years since this is the length of the concession period given by NVE before the investor either has to build the windpark or apply for a new concession. For investments in biomass and biowaste projects the concession periods are different. The concession to build lasts for 5 years, but other players can also be given the same permit at the same time. It is therefore a risk associated by postponing the investment. This risk is however not modelled in this thesis. All the investment projects are given a 5 year time to maturity of the wait-and-see option and a strike price equal to the calculated investment cost in the base case calculations.

If the investor decides to exercise the wait-and-see option he/she automatically receives two other options described below, i.e. an abandon and expand option. These are contingent on the first option and must be included in the underlying project value used to price the wait-and-see options. Further details on how this is performed in the model is given in the readme file in appendix A.12.

6.4.2 Abandon option

The abandon option in an investment project can be the opportunity of abandoning the project and salvaging all the possible values, by for instance selling or scraping the equipment and buildings. By doing so the investor gives up all the future cash flows of the project in exchange for this one-time payment. The abandon option is modelled as a put option with the salvage value of the project as the strike price. The option will therefore only be exercised if the present value of the future cash flows is less than this salvage value. The salvage value of a project will typically diminish over time and is modelled with a constant negative growth rate in this thesis.

The abandon value for the wind project consists of several parts. First of all the possibility of selling the windpark to another operator is disregarded, as we assume that if it is not profitable to operate for the investor, it is also non-profitable for other operators. The salvage value of the windpark at a given time is therefore the income from either selling the turbines or scraping them. Based on price information for used 10-15 year old wind mills obtained by Finden (2008), a decreasing sales value for the wind turbines was estimated, as calculated in appendix A.12. If a windpark is to be abandoned, the investor would also incur the costs of restoring the site back to former conditions before the construction took place, assumed to be 20% of the initial site preparation costs. The strike price for the put option, as illustrated in figure 21, would therefore be the revenues obtained from selling or scraping the equipment minus the costs of restoring the site. The length of this option is set equal to the life of the project as the option to abandon will be available at all times after the wind park has been constructed.



Abandon strike wind

Abandon strike biomass

Abandon strike biowaste

Figure 21: Abandon strike prices for investment projects

The abandon option for an investment in a biomass or biowaste project will be the option to abandon the project by selling off the buildings and equipment or scraping the material. The value of the equipment will typically depend on what type of fuel the burners are dimensioned for, and the calculations are given in appendix A.12. The bio cases do not have a site restoration cost, but the buildings and site are assumed to give a constant sales price over the projects life. Abandon strike prices for the bio cases are illustrated in figure 21.

6.4.3 Expand option

Expand options in an investment projects are the possibility of expanding the project if conditions turn out to be more profitable than first expected. This can be triggered by e.g. higher power prices than expected, more production from wind turbines due to better wind conditions etc. The expand option can be modelled as a call option where the investor pays the investment cost of the expansion in exchange for the present value of the increased future cash flows. The option will not be exercised unless the present value of these future cash flows is higher than the strike price.

For an investment in a wind park this expansion can be considered as the construction of more windmills or replacement of old turbines with new and larger ones. The inclusion of new windmills will typically demand less investment costs in terms of infrastructure, but loses some of the benefits of assembling several turbines at the same time. The best wind spots will probably also be taken by the first windmills, but market conditions can make sites previously considered non-profitable into profitable. Several sets of different expand options could of course be considered, but in this thesis uses only one. We argue that there is a lower limit of how small this expansion can be due to high investment costs per kW installed. We also argue that there is an upper limit constrained by the amount of wind sites that are profitable in the close vicinity of the already built wind park. Due to this we have considered an investment that expands the windpark's generation capacity by 25% and assumed that this in turn will increase the present value of all future cash flows by 20%. The inclusion of new windmills will be placed on less fortunate wind sites and thus not give the same production per windmill as the ones built in the first place. The cost of this follow up investment is the strike price of the expand option. The length of this option is set equal to the life of the project as the option to expand will be available at all times after the windpark has been constructed. It is then assumed that the investor can either get a new concession for the additional 25% capacity considered built or that he/she has chosen not to utilize the whole concession given at the time of investment. The calculations of the strike price is given in appendix A.12.

The expand option for the bio cases is the possibility of investing in new burners or upgrading old ones to capitalize on e.g. higher demand and prices. The thesis considers an investment that expands the heat and power production by 25% and assumes that this in turn will increase the present value of all future cash flows by the same percentage. This expansion of capacity will typically demand less investment costs per kW installed due to already existing buildings and infrastructure, and assumed to be only 70% of the initial investment costs per kW installed. The expansion will however call for an expansion of the district heating system in order to increase the demand for heat. These expansion investment costs, including any type of support received, will represent the strike price of the expand option. The option will thus only be exercised if the present value of the additional future cash flows is higher than the cost of installing this new capacity and expanding the district heating system. Several sets of different expand options could also be considered in this case. We argue that there is a lower limit of how small this expansion can be due to high investment costs per kW installed and expansion of district heating systems for only a few new consumers would also be very costly. We also argue that there might be an upper limit constrained by the amount of households that is located in the close vicinity of the already existing district heating system. The length of the expand option is set equal to the project life, as the option is assumed to be available to the management during the whole project life. It is then assumed that the investor either can get a new concession for the additional area considered supplied to, or that he/she has not invested in infrastructure to supply the whole concession area given at the time of the initial investment. Cost of investments in pipelines for district heating systems are based on data presented by Enova (Grønli (2008)), and the calculations of the expand strike price is given in appendix A.12.

7 Results and analysis

This section uses the model described in section 6 to make assessments on the value of investments in renewable energy projects and the managerial flexibility contained in them. Sensitivity analysis are also presented for certain important input parameters. Scenarios are further generated to illustrate the significance of uncertainty in renewable energy investments. The section separates between two investor types. The ROA investor applies the real option methodology for valuing projects and timing of the investment, while the NPV investor invests when the net present value of the project is greater than zero.

The projects are first analyzed using the standard valuation framework with no flexibility included. These results are then compared to the values found using the ROA model developed in this thesis, and the cost of energy is found for the two investor types. The results and the model are further analyzed to see how the assumptions made impact the final solution. Different scenarios are also created and analyzed with the model to illustrate the effect of uncertainties that investors in renewable energy projects face. The use of real option methodology can also serve as decision support for investors, and this is analyzed by comparing the decisions made by a NPV investor and a ROA investor. The section ends with an analysis of different support systems and how uncertainties related to them may affect investment behavior. The results are discussed and commented as they are presented, while the paramount implications are handled in the discussion section.

7.1 Standard valuation

The standard valuation framework in this thesis is described in section 3 and is characterized by valuing the different cases without any managerial flexibility included. Table 10 presents the results obtained from the valuation of the three different investment cases. The absolute NPV is presented as a share of the total investment cost to give a reference point for the resulting NPVs found.

Table 10: Statistics of base case valuation. a) the absolute value of NPV i used.

	Wind	**Biomass**	**Biowaste**
NPV (MNOK)	-5.59	4.28	34.53
NPV (share of investment cost^a)	1.2%	2.9%	11.3%
Internal rate of return	4.60%	4.63%	4.99%

As can be seen in the table, the standard valuation framework evaluates both bio cases to be economically sound projects already with no flexibility included. These projects will therefore be effectuated based on this valuation technique. The wind project however has a negative net present value and would not be undertaken based on the traditional NPV method, although the value of the option to invest is valuable, as will be seen in the next section when real option methodology is considered.

7.2 Valuation including flexibility

This section values the base case projects including the managerial flexibility arising from the uncertainty of the underlying project value, and compares the results to the traditional approach presented in the previous section.

7.2.1 Base case valuation

The managerial flexibility increases the total project value and figure 22 presents the investment cost for each base case project together with the NPV and ROA values.[40]

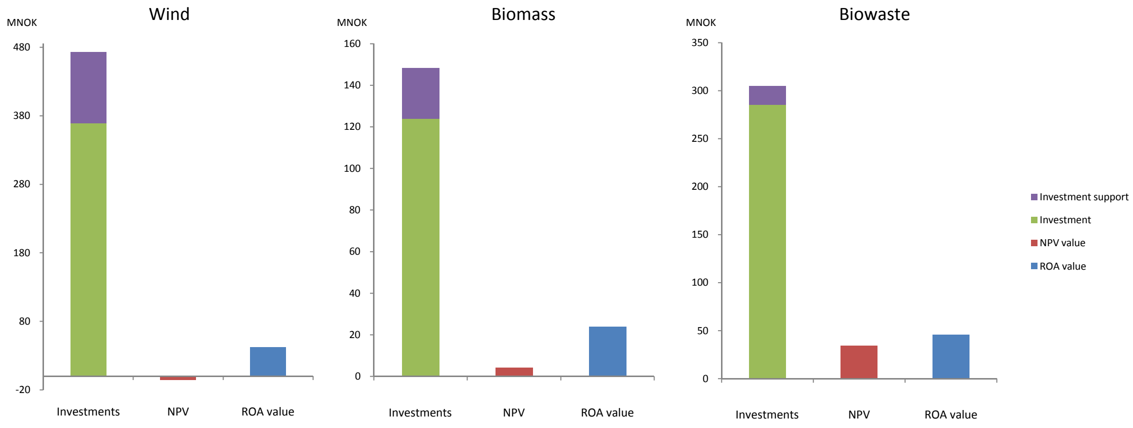


Figure 22: Valuation of base case projects including flexibility

The ROA value for the wind and biomass projects contribute with a larger increase in project value, due to higher volatility of the underlying and thus higher wait-and-see options values, as will be illustrated later in this section.[41] The biowaste project, considered the most profitable, is estimated to receive the least investment support relative to the initial investment cost. The option to invest given a concession period of 5 years is considered valuable in all the three base cases.

The ROA investor would require a higher present value of the underlying project before committing to an investment due to a higher trigger level, as will be discussed in section 7.6. The investment at such a higher trigger level will thus give a higher internal rate of return, and these implied IRRs are compared to the rates of return found using the NPV approach, presented in table 11.

Table 11: Internal rates of return for NPV and ROA investor using a wait-and-see option with 5 years to maturity (real after tax)

Cases	**NPV**	**ROA**
Wind	4.60%	8.80%
Biomass	4.63%	8.66%
Biowaste	4.99%	5.48%

The implied internal rates of return would be lower for options with shorter maturities, as this reduces the trigger levels and so also the implied rates of return. This will as mentioned before be discussed more thorough later in this section. From table 11 it can be seen that the ROA investor will demand a rate of return of approximately 8.5-9% before investing in the wind and biomass projects, while only a 5.5% rate of return for

---

[40] The ROA value is calculated using a 5 year wait-and-see option.

[41] The volatility is presented in table 13.

the biowaste case. The wind and biomass base cases are also the projects found to have the largest volatility of the underlying project values.

7.3 Cost of energy

The cost of energy can be used to compare investment projects based on different technologies. The cost of electricity and heat for the different base cases are computed using the ROA method and the traditional net present value and given in table 12. The numbers are found calculating equivalent annual costs for the different base cases and dividing these among the expected annual production. These costs are also found with and without the calculated investment support from Enova.

Table 12: Cost of energy for the base cases using NPV and ROA techniques with a wait-and-see option with 5 years to maturity.

	NPV [NOK/kWh]		**ROA [NOK/kWh]**	
	Support	No Support	Support	No Support
Wind				
Electricity	0.3617	0.4417	0.4642	0.5441
Biomass				
Electricity	0.3695	0.4008	0.4410	0.4723
Heat	0.6766	0.7339	0.8075	0.8648
Biowaste				
Electricity	0.2850	0.3007	0.3251	0.3408
Heat	0.6866	0.7244	0.7832	0.8210

Cost of electricity and heat must be seen together for the biowaste and biomass cases, as it depends on how the total costs are allocated between the heat and power generation. The cost of heat includes the cost of generation and the transportation cost of delivering the heat to the customers. The cost of electricity on the other hand only represent the cost of generation, and so not the cost of delivering electricity to end customers, hence the difference of approximately 0.3 NOK also discussed in section 6.3.2.

Based on the numbers presented in table 12, the biowaste technology is the most efficient way of generating electricity, given the three alternative investment projects. The cost of producing electricity from the biomass and wind project is slightly higher. All the cases give a cost of electricity in the range of 0.29-0.44 NOK/kWh if no support is given and the traditional NPV method applied. Based on a ROA investor the cost of electricity would be in the range of 0.33-0.54 NOK/kWh. The cost of heat from the two bio cases are in the same range with an increasing cost of 0.1 NOK/kWh if using the ROA method compared to the NPV technique. The costs can be compared to the actual prices obtained for the electricity and heat by the given producer. For the wind case using the net present value method and electricity prices below 0,44 NOK/kWh, it can be seen that support systems are necessary in order to make the projects profitable. An investor using the ROA method would require a higher price of the energy generated as he/she demands higher cash flows before investing. This can also be seen from table 12. As the time to maturity of the option to invest decreases, the ROA trigger level of investment decreases and so will the cost of energy demanded by the ROA investor.

7.4 Model validation

This section analyzes the model developed in this thesis and the assumptions made when modeling the managerial flexibility as options. The model accuracy is tested and sensitive input parameters are identified and their consequences on the model results analyzed.

7.4.1 Number of simulations

In order to decide on the number of simulations needed in the model to get accurate values for the volatility of rates of return, an analysis of the results from the Monte Carlo simulation is performed. Sets with different numbers of simulations are run for both the wind and biomass cases and the results are found in appendix A.7. The result from the simulation on the biomass case is assumed to apply for the biowaste case as well. The simulation is run once for 75 000 simulations for the wind and biomass case to get an accurate base case value for volatility of rates of return, equal to 21.68% and 24.84% respectively. The deviation is measured relative to these values for each set, and the percentage deviation is used to measure the accuracy of the model.

Based on the results, it is decided to use 10 000 simulations per run, giving an adequate accuracy and acceptable computational times. This gives a percentage deviation of less than 1% relative to the base case volatility for both the cases and a computational time of around 4-5 hours per volatility estimation. When performing analysis using the volatility of rates of return as constant in the base cases, the value obtained from running the 75 000 simulations is used.

The distribution of rates of return needs to be normally distributed in order to use the binomial method described in Copeland and Antikarov (2003). A histogram of the different rates of return obtained from running 10 000 simulations with the wind model, is presented in figure 23.

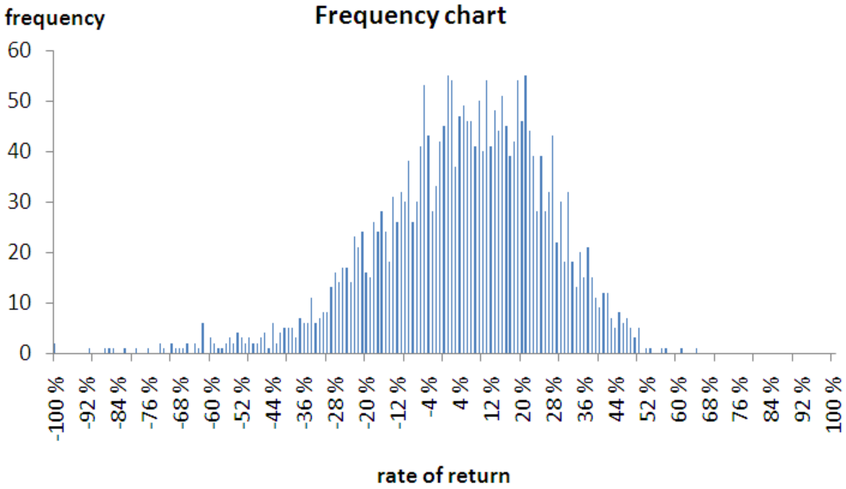


Figure 23: Distribution of rates of return for the wind project

The rates of return seems approximately normally distributed and centered round the weighted average cost of capital for the wind case, equal to 4.78%. Copeland and Antikarov (2003) do not check for normality using test statistics, and base their decisions on examination of frequency charts. Using the Jarque Bera statistics on the data above leads to rejection of normality due to both skewness and excess kurtosis in the data, and the same seems to be the case if the same test is run for the examples in Copeland and Antikarov (2003).[42] The volatility of rates of return in our model is however assumed to be approximately normally distributed, but the reader is made aware of this simplification.

7.4.2 Volatility of rates of return

This section focuses on the estimation of volatility of rates of return and the underlying factors affecting its value.

Underlying factors affecting the volatility of rates of return
The underlying stochastic factors described in section 6.3 affect the value of the project volatility in different ways. In order to make an assessment of which factors that contributes with the most uncertainty, their individual impact on the resulting volatility of rates of return is analyzed. Some of the uncertainty factors may be intertwined with others, but these correlations are ignored in the stochastic models used in this thesis. The different uncertainties are therefore modelled independently of each other, and their individual effects can be found by holding the other factors deterministic.[43] This is done for the wind, biomass and biowaste base cases. An alternative procedure is to remove the different uncertainties in term, and measuring the reduction in volatility of rates of return this results in. The factors giving the largest reduction in volatility of rates of return will thus be the factors contributing with the most uncertainty in the investment project. This will in turn be the most dominating factors driving the value of the managerial flexibility, as will be illustrated later in this section. Table 13 displays the total volatility of rates of return in the base cases by including all uncertain factors (here total volatility of rates of return) and using 75 000 simulations.

Table 13: Volatility of rates of return for the base cases

Cases	**Volatility of rates of return**
Wind	21.7%
Biomass	24.8%
Biowaste	13.4%

The wind and biomass projects experience the highest volatility in the rates of return, above 20%, while the biowaste project is considered less volatile. Using the procedure described above, the individual contributions of the underlying factors on the total volatility of rates of return are found, illustrated in figure 24.

---

[42] The Jarque Bera statistic is defined as: $JB = \frac{6}{n}\left(S^2 + \frac{(K-3)^2}{4}\right)$, where n is the number of observation, S the skewness and K the kurtosis.

[43] Deterministic power price is found by using the expected power price; deterministic support scheme is set to be the fixed price system and introduced in year 2010; deterministic availability is found by setting the volatility equal to zero; deterministic production (only for wind) is found by setting the volatility equal to zero.

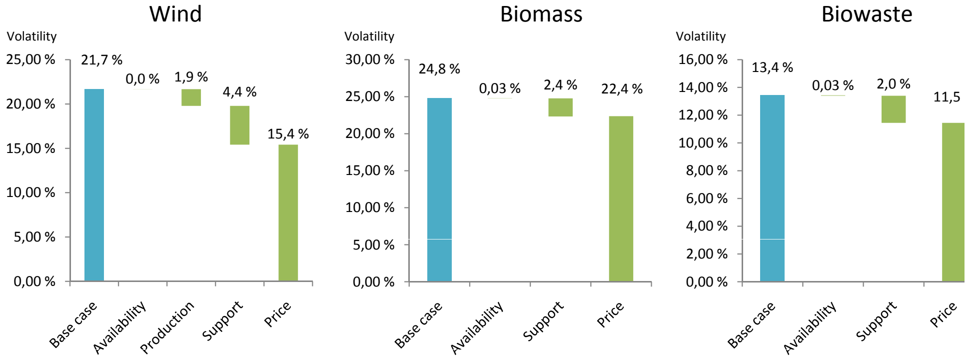


Figure 24: Uncertainty factors' contribution to the total volatility of rates of return

The price is the main driver of uncertainty in all three cases, but is most significant in the two bio cases. This may be due to the inclusion of an additional uncertainty factor in the wind case, representing the production uncertainty, lowering the relative importance of the price volatility. For the bio cases the demand is considered fixed and so are the fuel prices. The fuel prices may vary substantially, but can also be fixed through long term contacts with local suppliers or communities, as assumed in this thesis.

The total annual wind production vary with +/- 12% (standard deviation) from year to year, but the uncertainty seem to average out over the 20 years of operation. There is however a level uncertainty of the total wind-resources at a given site, given by errors in the wind measurements previous to the investment. This uncertainty is neglected in the thesis and the historic wind measurements performed at the given site assumed to correctly predict the level of wind resources.

The support uncertainty is more dominating in the wind case compared to the biomass and biowaste cases. The effect of different support systems are less prominent for the bio cases, since only a portion of the energy production in the combined heat and power plants are subject to support from the potential future systems. Most of the initial investment support will therefore be kept when the new system is included (if the investor decides to take part in it) and so the level of support is kept more stable over the different simulations. The availability of the different plants have a negligible effect on the estimation of volatility of rates of return as it averages out over the 20 years, and could be excluded from the model.

Effects on option values

This section performs an analysis of how the option values are affected by changes in the volatility of rates of return. The consequences of falsely over or under estimating the volatility in our model is thus illustrated.

By changing the volatility of rates of return around the value found in the base case, the value of the different options is found relative to the respective base case, as illustrated in figures 25, 26 and 27.[44]

---

[44] The wait-and-see option is valued using 5 years to maturity

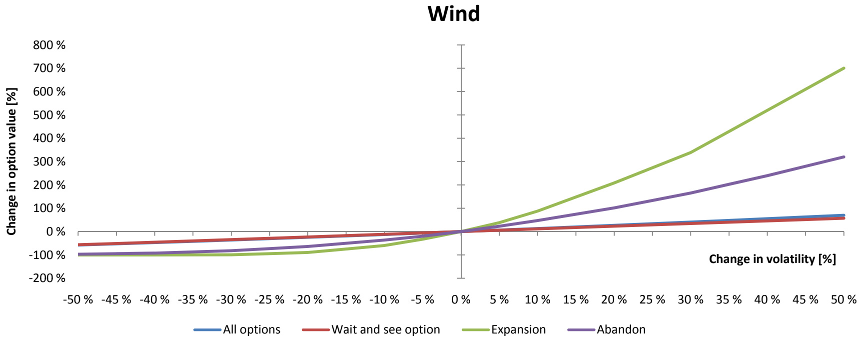


Figure 25: Changes in option values due to changes in volatility for the wind case

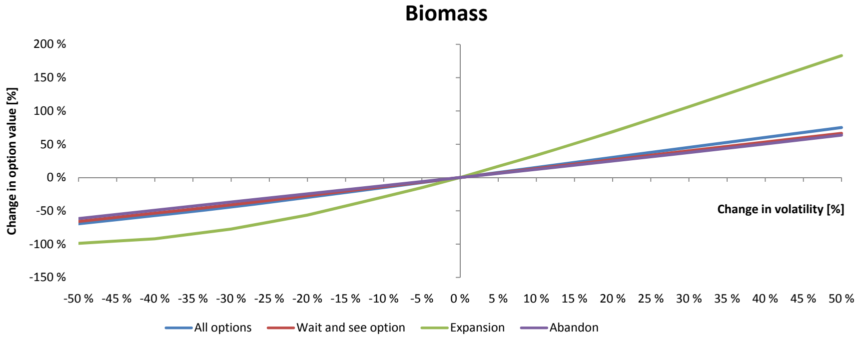


Figure 26: Changes in option values due to changes in volatility for the biomass case

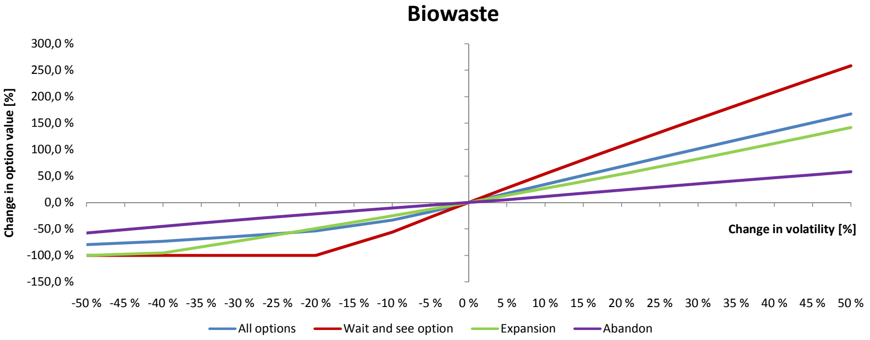


Figure 27: Changes in option values due to changes in volatility for the biowaste case

The figures clearly show that the volatility of the project rate of return has a strong effect on the value of each individual managerial option. These values are presented relative to the respective base cases and the actual option values are given in appendix A.8. Figure 28 displays how the individual options contribute to the total option value, for a range of changes in the base case volatilities.

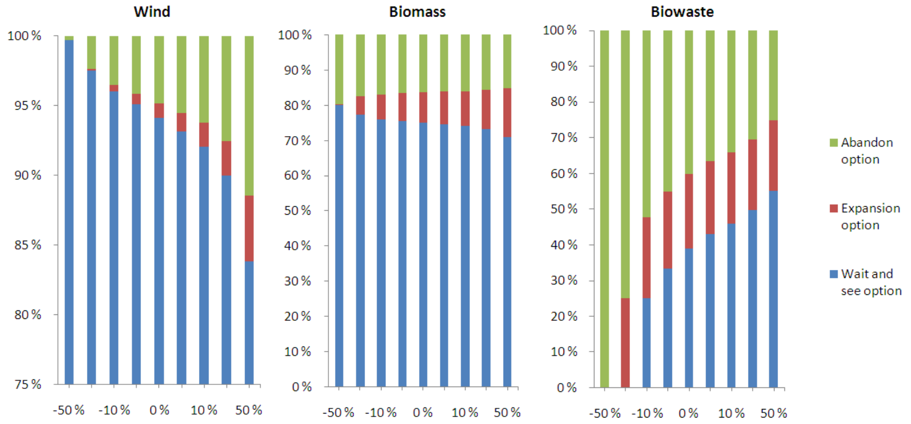


Figure 28: Each options relative contribution to the total option value due to changes in the volatility

The wait-and-see option is dominating in the wind project where the NPV is negative and the option to wait for more information is of high value. As higher volatility increases the likelihood of extreme outcomes, the value of the abandon and expand options increases as well. The individual options share of total value is relatively stable for the biomass case, but the biowaste case on the other hand shows a slightly different picture. As the volatility decreases the wait-and-see option becomes worthless, as the project will not be postponed. This is because the biowaste project already is considered very profitable with a positive NPV that is higher than the ROA trigger value of investment. The calculation of trigger values and changes in investor behavior compared to the NPV rule will be further elaborated in section 7.6. As the volatility decreases in the biowaste project, the expand option also becomes worthless, as the possibility of positive extreme events diminish.

7.4.3 Analysis of WACC

The WACC formula presented in equation 7 in section 3.1 is used as the correct discount rate for the investment projects considered in this thesis. Equation 7 requires input parameters that must be estimated either based on historical numbers or expected future values. The assumptions made and values used in this thesis are given in section 3. These parameters are of course subject to changes and subjective assessments, which in term alters the resulting value of the WACC for different investors and projects. In this section a sensitivity analysis of the different input factors of the WACC formula is performed and a range of reasonable WACCs for the different investment cases is calculated. A tornado plot resulting from the sensitivity analysis for the WACC formula based on the wind project is given in figure 29. It shows the absolute change in the WACC subject to a +/- 50% change in the factors given in the figure, ceteris paribus.

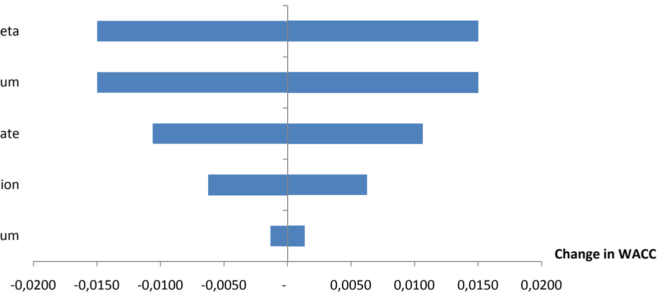


Figure 29: Tornado plot of parameters' effect on the WACC formula

The WACC formula is most sensitive to changes in the asset beta and market premium selected. The risk-free rate and inflation changes have moderate effect on the value, while the debt premium demanded by lenders has very little impact. These relationships apply for both the bio cases as well and can be verified by inspection of the WACC formula mentioned above.

The WACC parameter is a crucial value that needs to be estimated accurately in order to prevent making wrong decisions. It is however not an exact science and even professionals do not always agree on what the correct value is. A range of possible WACCs constrained by a high and low scenario for each of the investment cases are therefore given in table 14.

Table 14: Range of WACCs for investments in wind and bio projects

Case	**Low**	**Base**	**High**
Wind	4,04 %	4,78 %	5,57 %
Biomass	3,14 %	3,78 %	4,47 %
Biowaste	3,59 %	4,28 %	5,02 %

The assumptions made for the different input factors are given in appendix A.9, together with the base case values. This range of WACC values will be considered in the next section where we analyze the effects different WACCs have on the valuation.

Analysis of effects of different WACCs

The WACC treats the systematic risk that projects and companies face, while the company specific risks and managerial flexibility can be modelled through the volatility of rates of return in a ROA analysis. In order to see if the selection of WACC affects the volatility of rates of return, the range of possible WACCs obtained above is used to estimate the volatility of rates of return, as given in table 15.

Table 15: Volatility of rates of return for different WACCs

Case	**Low**	**Base**	**High**
Wind	21.51%	21.68%	21.57%
Biomass	13.50%	13.43%	13.32%
Biowaste	25.16%	24.84%	25.16%

The selection of WACCs will affect the level of rates of return, but does not seem to affect the volatility of rates of return for the different projects valued. Using different WACCs will thus not affect the option values much, but the net present value of the projects will change, as the present value of cash flows are reduced. This will in term affect the total ROA value. Figure 30 shows the NPV and ROA value (all options included) for the wind, biomass and biowaste investments respectively.

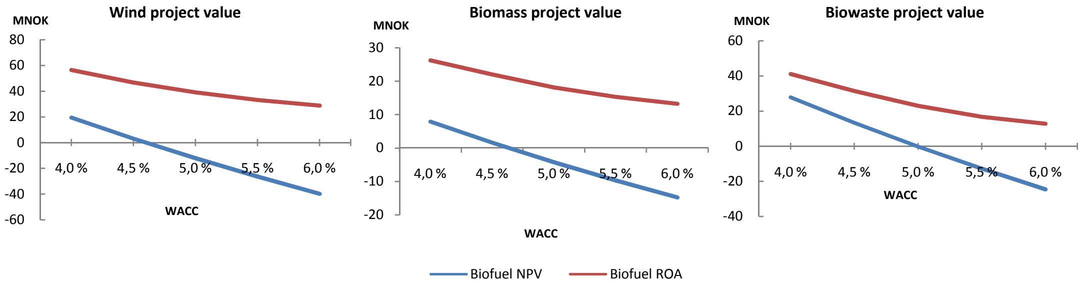


Figure 30: NPV and ROA value for different WACCs

Figure 30 illustrates how the additional value of the managerial options shift the value of the project upwards. It also shows the additional value of being able to postpone the investment awaiting possibly better conditions, and the ability to further expand or abandon the project given investment. The figures show that the option value increases slightly with an increasing WACC. As table 15 shows, the volatility of rates of return is not changed as the WACC changes. The present value of all future cash flows, which is the option's underlying, do however change significantly with changing WACC. Since the volatility of the underlying is not affected by changing the WACC and the ROA value can never be less than zero, the option value has to increase as the WACC increases and the NPV decreases. As will be described in section 7.6, the wait-and-see option does not increase the actual value obtained from the project given investment, it only shifts the investment trigger level. Once the investment is committed, the expected project value equals the ROA value with the abandon and expand options included.

Figure 30 shows that the NPV valuation procedure understates a projects value compared to a ROA analysis that also includes the managerial flexibility contained in projects. A natural analysis is therefore to find which WACC that would be necessary to use in order to make the NPV equal to the ROA value. It is however not advised to include a reduction in the WACC to incorporate the value of managerial flexibility, and so this is only performed for illustrative purposes.[45] The necessary changes are given in table 16 for the different cases.

Table 16: Necessary changes in WACC to make NPV equal to the ROA value with a 5 year concession period

Case	**WACC**	**New WACC**	**% reduction**
Wind	0.0478	0.034	-30%
Biomass	0.0428	0.029	-33%
Biowaste	0.0378	0.034	-9%

---

[45] A discussion of why such "fudge factors" should not be included in the WACC can be found in Brealey and Myers (2006).

The wind and biomass case demand an approximately 30% reduction in the WACC to make the NPV equal to the ROA value. These cases had the largest volatility and the large reduction in WACC is therefore necessary due to the high option value embedded in these projects. These are all changes in the real WACC and the percentage change will be lower if nominal and/or pre tax terms are used.

7.4.4 Effects of modelling managerial flexibility

The inclusion of managerial flexibility is done by modeling them as options, and the value of the individual options reflect the value of this flexibility. The valuation of the different options the investor faces is analyzed in this section, using the different base cases and a constant volatility of rates of return.

Analysis of wait-and-see option
Section 7.4.2 finds that the wait-and-see option contributes most to the total options value for the wind and biomass projects. Figure 31 presents the development in this value over the possible range of lifetimes of the wait-and-see option, where time to maturity is the only thing changing in the calculations.

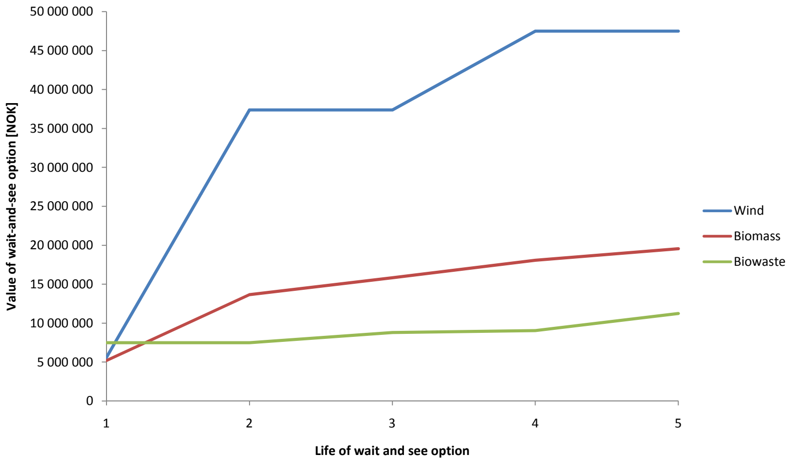


Figure 31: Development in wait-and-see option values of the range of lifetimes

The wait-and-see option for the biowaste case is relatively stable as time to maturity increases, while for the wind and biomass cases it increases to a stable level as the lifetime of the option is increased. The wind case experiences the highest increase in value as the time to maturity increases, stabilizing at a level of approximately 45 MNOK. The biomass and biowaste options stabilize at approximately 20 MNOK and 12 MNOK respectively. This can be explained by the high net present value without flexibility in these projects, shifting the underlying project value closer to the investment trigger level.

Analysis of the abandon option
Determining the strike price of the abandon option is highly dependent on the assumptions round the possible selling or scraping price of the equipment. It is therefore useful to perform a sensitivity analysis of how the value of the abandon option changes over a reasonable range of strike prices. Figure 32 presents the development of the abandon

option's absolute value over a range of strike prices, ranging from +/- 20% compared to the abandon strike values estimated for the base cases.

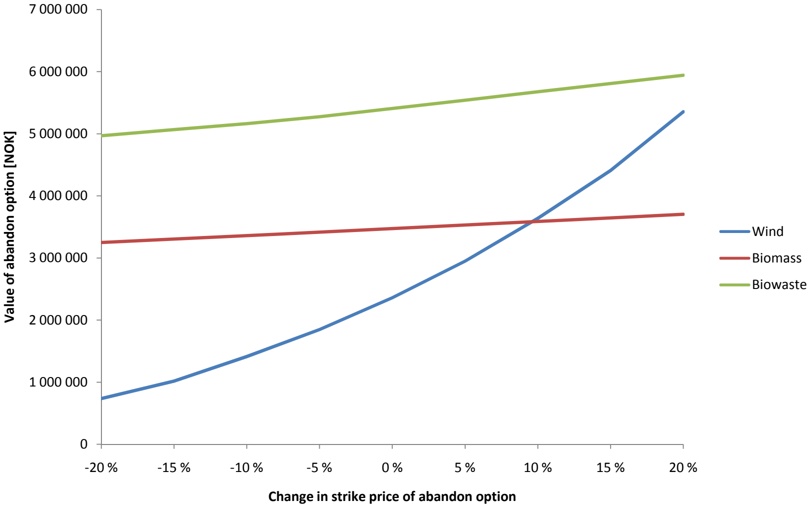


Figure 32: Development in value of abandon options for changing strike prices

From figure 32 it can be seen that the biomass and biowaste cases are only marginally affected by changes in the abandon strike price. The value of the wind project's abandon option is however more sensitive to changes in the strike price. It is therefore crucial to accurately estimate this value when using the model, although little data is available for performing such an analysis.

Analysis of the expand option

The value of the expand option is also highly dependent on the assumptions made, and a sensitivity analysis on this option can be performed by either changing the size of the expansion or the expansion strike price. As the installed power is known when considering an expansion, the investment cost is considered as the part most plausible for false estimates, and so the analysis is performed on this parameter. Figure 33 presents the development of the expand option's value over a range of strike prices, ranging from +/- 20% compared to the abandon strike values estimated for the base cases.

The change in the strike price impacts the value of the expand option opposite to the abandon option, as the expansion strike price is the cost the investor must pay in exchange for the present value of the increase in future cash flows. The biowaste case is the most sensitive to changes in expansion strike price, which must be considered when estimating the parameters of the expand option.

When estimating the parameters of the different managerial options, several assumptions were made as little or no information is available on these subjects. This section illustrated some of the consequences of making these assumptions and what effects they have on the option values.

7.5 Scenario analysis

This section uses the model developed to analyze several potential future scenarios, with and without the managerial flexibility included. The cases are used to illustrate possible

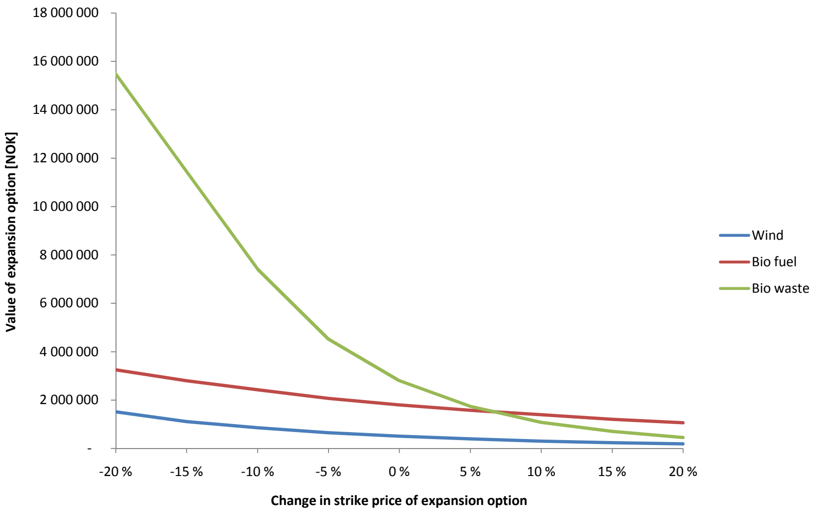


Figure 33: Development in value of the expand options for changing strike prices

outcomes and the significance of the many uncertainties present in investments in renewable energy. The scenarios are also a way to re-examine some of the assumptions drawn earlier, and to see how they may affect results. The following cases are examined:

- Scenario 1: Windpark built in a surplus area resulting in on average lower prices.
- Scenario 2: Windpark investment with increasing investment costs.
- Scenario 3: Windpark investment with deterministic support system
- Scenario 4: Biowaste investment delivering heat to industry customer.
- Scenario 5: Biomass investment analyzing changing fuel prices.

7.5.1 Scenario 1: Wind – low price area

Scenario 1 analyzes a situation where the electricity system price drops by 5% and the investor builds a wind park in a surplus area. The electricity price model used in this thesis models the system price and not area prices, and so does not necessary reflect the price power-producers face. The power price will therefore be seasonally adjusted compared to average relative differences between the system price at Nord Pool and the relevant price area, for the last 10 years. This price difference may occur due to external events, transmission constraints, or the construction of additional wind or other power producing units in the same area.

The following manipulations of the wind base case are performed:

- The level in the price model is reduced by 5%
- The simulated and expected power prices are seasonally adjusted to represent the area prices that a producer receives for its power.

The seasonal adjustment is found by analyzing the price difference between the system price and a price in an area that experiences a power surplus in parts of the year.[46] This analysis resulted in a monthly discount compared to the system price as presented in table 17.

Table 17: Monthly discount in the system price

Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
0%	0%	0%	0%	2%	5%	5%	10%	5%	0%	0%	0%

Table 17 shows that during the summer months the producer in a surplus area is experiencing a price lower than the system price. This can be due to the fact that Norway is dominated by hydro power and forced production is large in these months.[47] The adjustment in the price scenario leads to a reduction in the expected present value of income from power sales by 26.7 MNOK, corresponding to a 5.75% reduction. Figure 34 compares the original wind case with the low price area case.

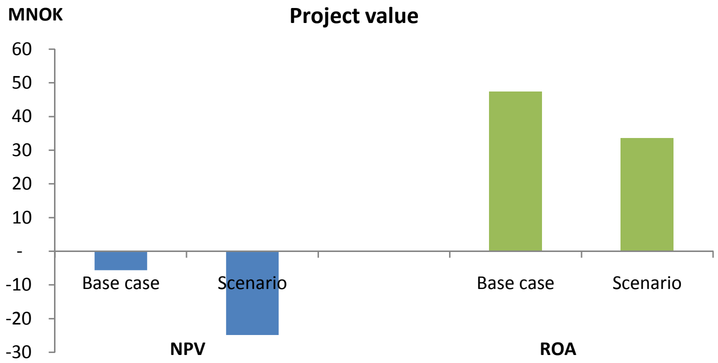


Figure 34: Comparison of NPV and ROA value between base case and scenario 1

The low price area leads to a reduction in net present value of 19.7 MNOK, and the total ROA value of the project is reduced by 10 MNOK. The value of the abandon option will in this scenario increase compared to the original case since abandoning the project becomes more likely, and the option to abandon more lucrative. The opposite is the case for the expand option. A concession to build the wind farm will have a ROA value of 37 MNOK even if this scenario should occur, mainly driven by the value of waiting for better conditions.

7.5.2 Scenario 2: Wind – increasing investment costs

Scenario 2 analyzes a case where the investment costs for wind energy projects increases in real terms, i.e. the cost of wind turbines grow faster than the expected inflation of 2.5%.

---

[46] Due to transmission constraints, Norway is separated into different price areas. Areas with high electricity generation are often referred to as surplus areas. These areas are characterized by periods with lower price due to energy surplus. NO1 (Southern parts of Norway) is such an area and used as an example in scenario 1.

[47] Forced production due to run-of-river power stations or stations with small reservoir capacity. This has been the situation at several occasions in the recent years, among others in 2007 and 2008. The spring flood can give significant price differences in early parts of the year, although the timing may vary.

This can be due to national renewable energy obligations such as the RES-directive, inducing support systems for renewable energy projects. These support systems will again stimulate construction of wind power plants, resulting in increased demand and prices. As the demand increases, the scenario assumes that wind turbine construction capacity will increase as well and that the investment cost will level out in real terms to a constant level. The investment cost per MW installed effect in NOK is assumed to increase with a constant annual growth rate from the current level of 11.8 MNOK to 14 MNOK in the next 5 years. The level of investment costs per MW is then assumed to stay constant for the remaining period. The expansion costs are also affected by these increasing prices, while the effect is ignored for the salvage value that can be obtained from old turbines represented by the abandon option. The investment support received by Enova is increased to make the project's NPV marginally positive. This way the investor is faced with the decision of investing today or postponing the project.

The following manipulations of the wind base case are performed:

- Investment costs are increased by 4.33% (in real terms) each year until 2013.
- The investment costs are set constant at 14 MNOK per MW installed capacity from 2014.
- Expansion strike price will be affected by the same increase.
- Investment support increases to approximately 23% of the total investment costs, giving the project a marginally positive NPV based on the investor's assessment, if investment takes place today. This percentage share is for simplicity assumed to be constant, despite the increasing investment costs.

The inclusion of increasing investment costs reduces the ROA project value, caused by a lower value of the expand option and the wait-and-see option in particular. As investment costs increase it becomes less profitable to postpone the investment, due to higher investment costs relative to the value of waiting for more information.

This can also be noticed as the decisions made at the nodes in the event tree change, illustrated in figure 35. Due to the increasing investment costs it may become optimal to exercise the wait-and-see call option already in period 2. The increasing investment costs also changes the decision to invest in certain nodes previously considered profitable.

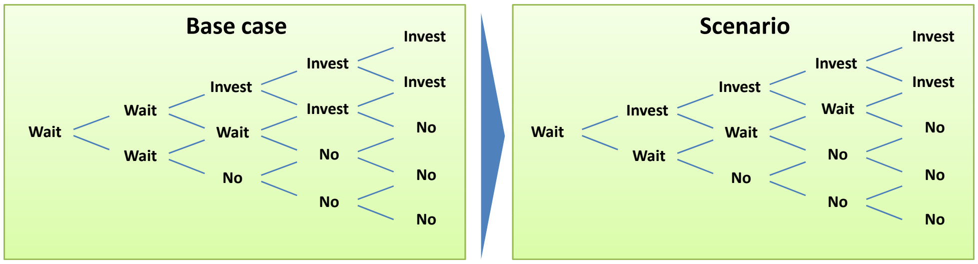


Figure 35: Decision tree changes caused by increasing investment costs

Increasing the growth of the investment costs shifts the decision to invest up and leftwards in the tree, as it becomes profitable to capitalize on lower investment costs early in the tree compared to the value of holding the option.

An intuitive explanation of the early exercise of the wait-and-see option seen in figure 35 can also be given by using examples from holding an American option on a stock. It will never be optimal to exercise an American call on a non-dividend paying stock before maturity (McDonald (2006)). Dividend however is equivalent to a lease rate that changes the risk neutral probabilities, and potentially makes the investor exercise the call option early. This is because only holders of the stock are entitled to dividends, not holders of a call option on the same stock. This argument is transferable to the scenario treated in this section. The increase in investment costs (strike price of the real option) can be seen as a capital gain and hence an increasing lease rate, and the underlying value is reduced analogous to a dividend payment from a stock. Cf. section 4.3 for further description on early exercise of options.

7.5.3 Scenario 3: Wind – deterministic support scheme

Scenario 3 analyzes a situation where the future support system is decided during the first year of operation, and so the investor is shielded from this uncertainty. This scenario assumes that Norway will then be included in a green certificate system together with Sweden from 2010. It is also assumed that more countries are included in the system in time e.g. Finland, Denmark and Germany. As these countries are incorporated the total ambition level is assumed to increase, resulting in higher certificate prices. This will all happen in a stepwise fashion, and so it is modelled by manipulating the drift rate of the certificate price model. A drift rate of 2.5% is used, giving an expected certificate price of approximately 0.3 NOK after 20 years.

The following manipulations of the wind base case are performed:

- New support system decided and implemented in 2010.
- Support system is set equal to a TGC system.
- The drift rate of the certificate price model is set equal to 2.5%.

The determination of support system removes some of the underlying uncertainty and the new volatility of rates of return is estimated to 17.31%, reduced from 21.7%. This scenario represents some of the upside potential in a wind project, and the project value found using NPV and ROA methods is presented in figure 36.

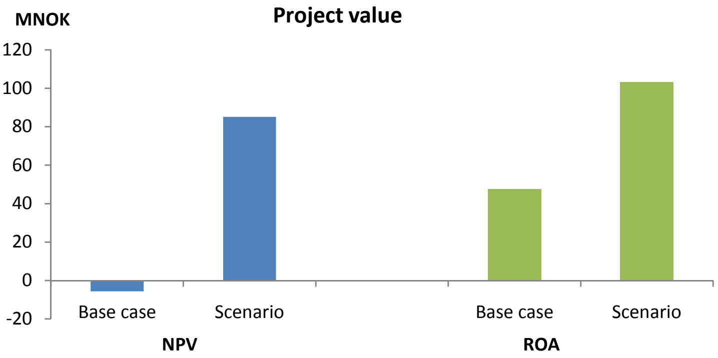


Figure 36: Comparison between NPV and ROA value

Figure 36 shows that the type of support system and the price behavior of such are important for the profitability of projects. The NPV of the project increases by 95 MNOK, and a substantial increase in the ROA value is also noticed. The value of managerial options does however decrease. The reason for this is that the net present value in the scenario is much closer to the ROA investment trigger value, which reduces the option value significantly, as will be discussed in further detail later in this section. The reduction in volatility does also contribute to a reduced option value, as the insurance value lost by early exercising is greater when volatility is greater (McDonald (2006)).

7.5.4 Scenario 4: Biowaste – industry customer

Scenario 4 analyzes an investment in a waste-fueled combined heat and power plant that delivers heat to an industry customer. The plant is assumed to have long term price contracts for the heat delivered to the industry, and the utilization time for the heat delivered is increased. The abandon option is removed as the plant have committed to long term contracts of guaranteed delivery of heat. The expand option is also excluded, since the plant is custom designed for the industry customer and no other suitable industry is situated nearby. The length of the wait-and-see option is also not solely determined by the length of the concession period, as the industry customer would demand heat delivered immediately. The industry customer will not allow the investor to wait for better condistions before investing, as the heat demand must be covered in a relatively short time. The value of the project is therefore calculated for different lengths of the wait-and-see option, but only the short times to maturities are assumed likely. Power plants having only industry customers are assumed to be more vulnerable to business cycles in the economy, and so a slightly higher beta value is used for this scenario.[48] The new discount rate is calculated as described in section 3.1.

The following manipulations of the bio waste case are performed:

- Utilization time for heat delivered is set equal to 8000h per year, the same as for the power production.
- The fixed price received for the heat is set equal to 0.3 NOK/kWh.
- The discount rate is set equal to 4.03% (real after tax).
- The investment support received from Enova is recalculated using the changes above.

The resulting volatility of rates of return for this scenario was found to be 6%, about half the volatility as in the household customer case, due to less heat price uncertainty.

---

[48] The asset beta is increased with 0.05 compared to the biowaste case (household customers), giving it a value of 0.45.

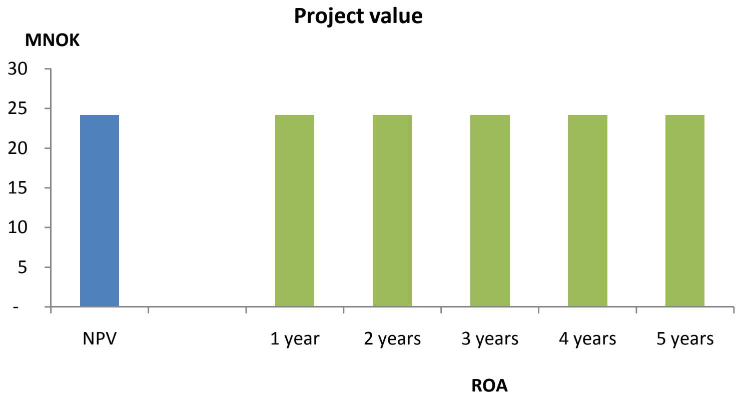


Figure 37: NPV and ROA value for different lifetimes of the wait-and-see option

Figure 37 shows that the project gets a positive NPV of approximately 24 MNOK. The ROA values for the different life times of the wait-and-see option do all equal the net present value, and hence the wait-and-see option does not have any value in this scenario. The project will therefore be undertaken straight away, since the value of waiting is worthless. The reason for the wait-and-see option being worthless is that the present value of future cash flows in the scenario is equal to or greater than the corresponding ROA investment trigger value.

7.5.5 Scenario 5: Biomass – fuel price sensitivity

In the base case the biomass prices where assumed to be constant, set by long term contracts with local suppliers. At present biomass is regarded a local resource available for producers located nearby industry producing biomass or felling waste. If biomass becomes an important energy source in Norway, it is possible that it will become a traded asset and hence it can be reasonable to discuss a situation with market determined prices. If so happen, price models can be developed and the biomass price can be included as an underlying uncertainty in a Monte Carlo simulation. As this was not done in the base case, an analysis is performed to illustrate how sensitive the biomass case is on changing fuel prices. Scenario 5 analyzes a case with fluctuating biomass prices due to the same arguments as presented above. A sensitivity analysis is performed to see how dependent the biomass case is on changing fuel prices. This sensitivity analysis is not a way of handeling uncertainty in fuel prices, but merely a way of illustrating how the fixed price assumtion affects the results.

The following manipulations of the biomass case are performed:

- The fuel price is changed around the base case value in order to perform a sensitivity analysis.

The fuel cost is the dominating part of the biomass projects' operating cost structure and thus very decisive for the total free cash flows. The distribution of revenues for the base case biomass project over the 20 years of operation is presented in figure 38.

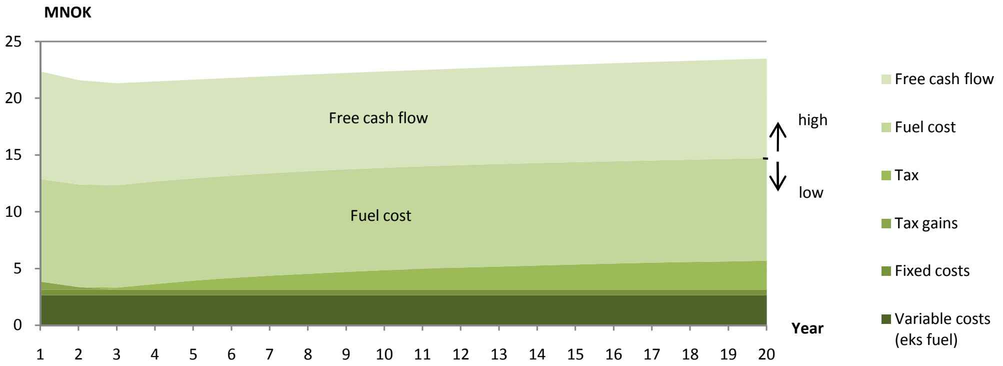


Figure 38: Operating cost structure over the lifetime of the biomass project

By changing the fuel cost +/- 20% around the current level of 0.237 NOK/kWh (NVE (2007)), the following project values were obtained, illustrated in figure 39.

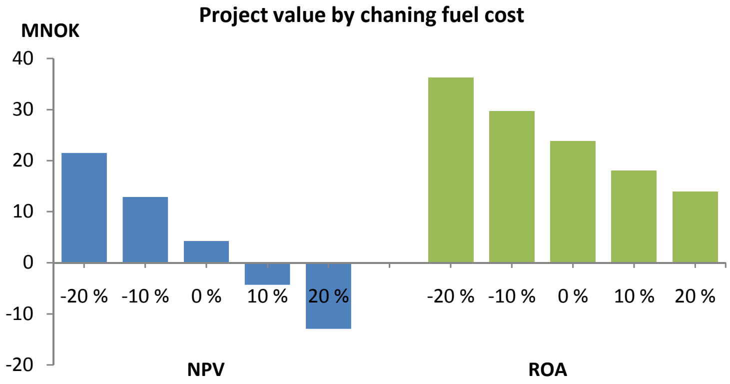


Figure 39: NPV and ROA value for changing fuel prices

The project can incur a fuel cost of 0.249 NOK/kWh before the project becomes unprofitable according to the NPV method.[49] It is clear that the increase in fuel prices leads to a steeper reduction in net present value than in ROA value. This is again due to the fact that the ROA value can not become zero, while the net present value does not have this downside restriction.

7.6 Decision support for investors

The application of the ROA method for valuation of investment projects gives better decisions for timing of investments under uncertain conditions (Fleten et al. (2007)). Figure 40 shows the different trigger values for the wind project used by an investor applying the NPV and ROA techniques respectively. The traditional NPV method's trigger value is when the net present value of the project is equal to zero. The ROA investor however does not invest unless the option value is equal to the project's present value. For an investment in a project with only a wait-and-see option, the PV of the

---

[49] Corresponding to a 5.1% increase.

project is the underlying. This thesis do however also include an expand and abandon option that is contingent on the wait-and-see option. When the investor decides to invest he/she automatically receives the two options in addition to the traditional present value and so the sum of these represent the underlying of the wait-and see option. The ROA value of the project in figure 40 applies for an investor holding a 5 year wait-and-see option, and the lines are plotted based on values obtained from the model.

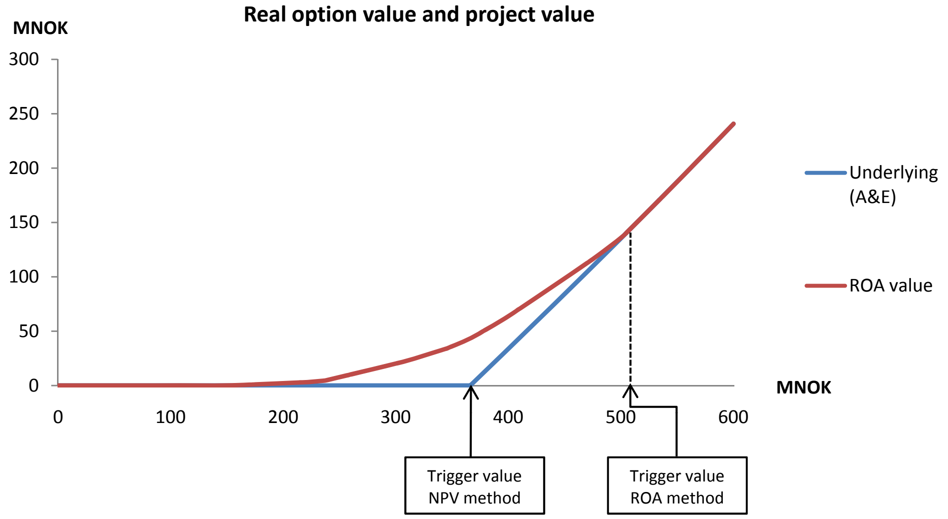


Figure 40: Real option value and underlying project value including abandon and expand options for the wind case. A&E denotes that the abandon and expand options are included.

As the time to maturity decreases the ROA investment trigger value will also decrease. Other things being equal, the early-exercise criteria becomes less stringent closer to expiration, since the value of the insurance diminish as the option approaches expiration (McDonald (2006)). Figure 41 illustrates this, where the ROA investment trigger levels are found for decreasing time-to-maturities for the wait-and-see option.

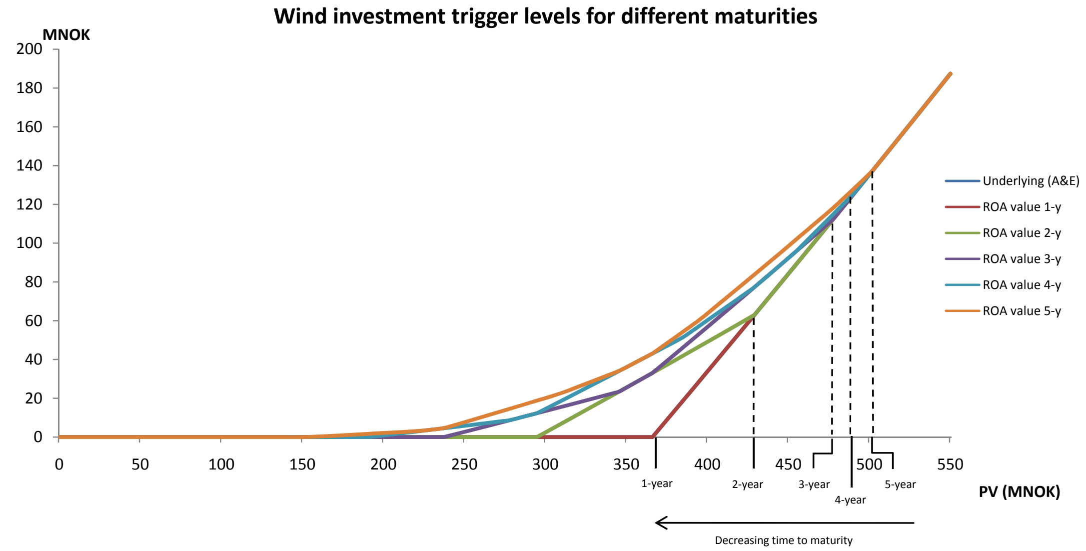


Figure 41: ROA trigger values for decreasing time to maturity for the wait-and-see option in the wind case

Figure 41 shows that the graph becomes smoother as time to maturity increases. This is due to the rouge time step division used in the model.[50] This may also result in inaccurate estimates of the trigger values for lower maturities. The resulting trigger values for the different maturities of the wait-and-see option can then be used to construct an early exercise boundary as illustrated in figure 42. These trigger values form the basis for the decisions made by the investor in the different nodes in the decision tree for 5 years lifetime of the wait-and-see option, also illustrated in figure 42.

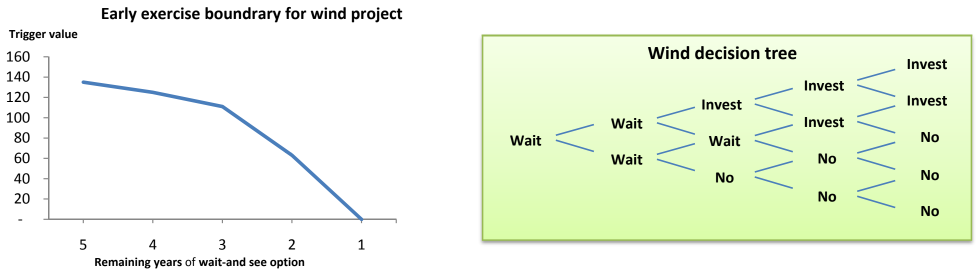


Figure 42: a) Exercise boundary for the wind project's excess present value compared to the underlying trigger value of investment (in MNOK). b) Wind project decision tree for an investor using the ROA method holding a wait-and-see option with 5 years to maturity.

The ROA investment trigger values for the biomass and biowaste projects are illustrated in figure 43 and 44, together with the decision trees for the respective cases. The ROA investor will not invest unless the underlying value of the project, including the abandon and expand option, is equal to 180 MNOK for the biomass case and 334 MNOK for the biowaste case, given a wait-and-see option with 5 years to maturity.

---

[50] Steps of 1 year is used.

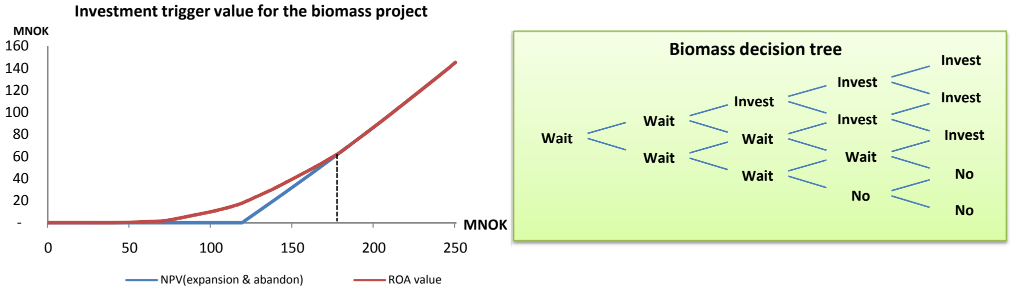


Figure 43: a) ROA investment trigger level for the biomass project with a 5 year wait-and-see option. b) The decision tree for an investor using the ROA method to value the biomass project

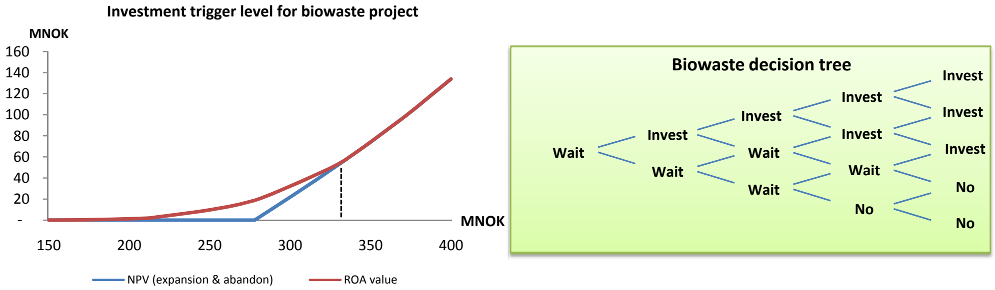


Figure 44: a) ROA investment trigger level for the biowaste project with a 5 year wait-and-see option. b) The decision tree for an investor using the ROA method to value the biowaste project

Both the bio projects have positive net present values but the ROA investor would not invest immediately as the underlying value is less than the trigger level. The biowaste project however, being considered the most profitable of the three base cases, is the project closest to the ROA investment trigger level, and investment may be conducted already in year 2 as seen from figure 44 above.

This section illustrates how the time to maturity can affect investment trigger levels, and how the current present value of the project shifts the ROA and NPV investor closer to the decision of actually committing to an investment. Section 7.7 shows how the volatility of the underlying also affect these trigger values as the uncertainty of support schemes are analyzed.

7.7 Analysis of support uncertainty

This section takes a more thorough look on how the support regimes affect an investor's decision. Uncertainty about support system is the uncertainty that easiest can be altered or removed, and therefore an interesting factor to analyze more in-depth. First the expected amount of support an investor will receive from the different support schemes are calculated, and then an analysis of the necessary level of the fixed premium support system is conducted. The fixed premium system is analyzed since its level is directly controlled through political decisions, while the TGC price level is set by the market conditions and political ambition levels and is thus not altered that easily.

7.7.1 Expected support

For an investor it is the expected net present value of the different support systems that decide which system that is preferable. The expected support received from different support systems are presented in figure 45 for a 20 year wind investment project and a 20 year biomass investment project.[51] The support will depend on the amount of support per kWh generated and the actual production of renewable energy from the project. In the calculation the expected values for support and production is used, and so the results are sensitive to the assumptions made about the level of support. The NPV of the support is calculated for a high and low production scenario, and a high and low certificate price levels for the TGC system.[52]

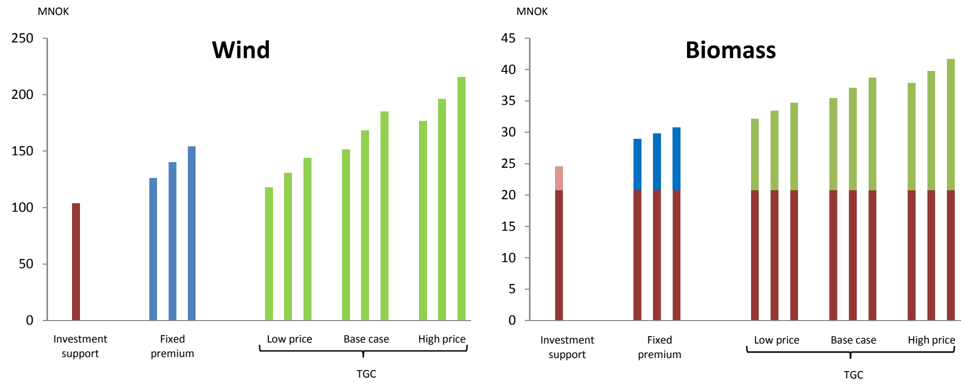


Figure 45: Expected total support from the different support schemes for the wind and biomass case

In the biomass project the investor only needs to repay the investment support received for the electricity generation part of the investment if he/she chooses to take part in one of the other support systems, since heat is not subject to fixed premium or TGC support. It can however be realistic to include such a system in the future, but this is disregarded in this thesis. Based on figure 45 the investor would prefer a TGC system for both investment cases given the expected level of 0.18 NOK/kWh used in this thesis. The fixed premium system with 0.15 NOK/kWh for wind and 0.10 NOK/kWh for biomass gives a slightly lower NPV of support, while the current investment support system gives the least amount of support. Figure 45 can give some explanation to the present situation in Norway, where investments in wind has slowed down. The reason for this can be that the expected amount of support in the existing support regime is not sufficient and less than the expected support from the possible future support schemes, and so they are awaiting the situation.

Investment support systems analyze projects individually, tailoring the amount of support needed to stimulate an investment. Generation based support systems do however

---

[51] The WACC calculated in section 3.1 is used.

[52] Expected TGC price levels of 14, 18 and 21 NOK/kWh generated for the low, base and high certificate prices respectively.

not discriminate between projects, which normally gives some investors a windfall. This will not occur given an approximately flat supply curve. It is further worth mentioning that some investors do take other factors than just expected support into account when deciding on which support system they would prefer. Financially strong investors tend to dislike investment support since it lowers the threshold to investors and they may then have to compete with more players.[53]

7.7.2 Trigger value

There is an ongoing debate in Norway about what level of support that is necessary to stimulate more investments in renewable energy than seen today. This section analyzes how much production support that is necessary for the investor to undertake a wind project and how the support uncertainty is affecting the valuation and the investor's decision. The analysis is conducted by fixing the support to the fixed premium support scheme. Then the necessary level of support is analyzed for both a NPV investor and a ROA investor. The analysis is only conducted for wind since electricity generation is largest in this project.

The wind base case had a net present value of -5.6 MNOK, and the investor is assumed to receive investment support. The fixed premium support suggested in St.meld nr.11 (2006-2007) had a level of 0.08 NOK/kWh. The Norwegian Wind Energy Association (Norwea) is advocating a level of minimum 0.20 NOK/kWh to make onshore wind profitable in Norway (NORWEA (2008)). Based on the standard net present value model used in this thesis, a fixed premium level of 0.11 NOK/kWh is needed to give the investor a net present value of – 5.6 MNOK and hence make the fixed premium system as attractive as the current investment support system. A level of 0.12 NOK/kWh is further necessary to make the NPV equal to zero.[54] An investor relying only on the NPV approach in the decision making will therefore require this level of support before investing if this system is introduced. To see how the ROA investor is affected if the fixed premium support system is introduced, it is necessary to reduce the volatility of rates of return since one of the uncertainty factors is removed. The new volatility is 17.31% according to the results in section 7.4.2. Table 18 presents the investment trigger values when the lifetime of the wait-and-see option varies from 1 to 5 years, while figure 46 shows the NPV exercise boundary.

Table 18: Present value trigger for different lifetimes of the wait-and-see option in the wind case. The NPV trigger value is equal to 367 MNOK.

Lifetime (years)	**Present value trigger (NOK)**
5	459 000 000
4	448 000 000
3	445 000 000
2	414 000 000
1	369 000 000

---

[53] A lower threshold will make more investors able to undertake similar investment projects.

[54] Investor will not receive investment support in this situation.

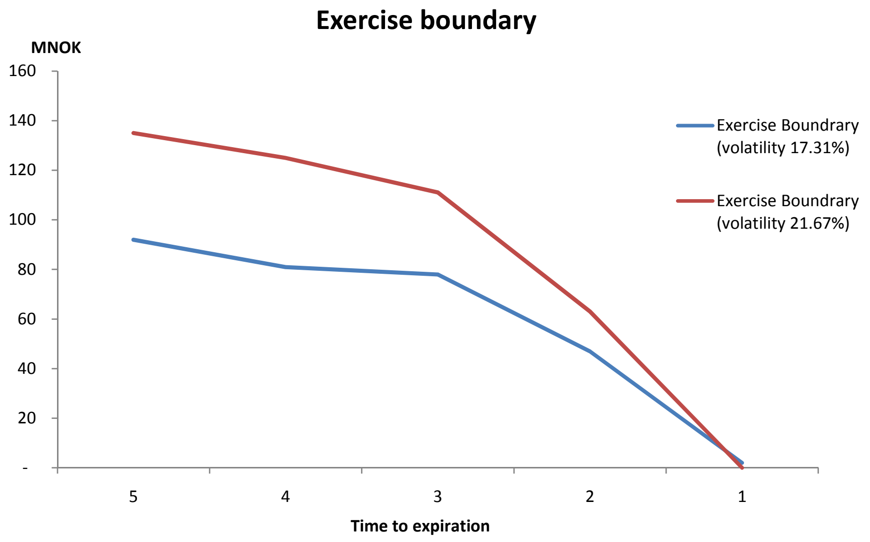


Figure 46: NPV exercise boundary for the wind case

It is clear that the investment trigger value is reduced as the lifetime of the wait-and-see option decreases. Even more important in this example is that the trigger value also reduces as the volatility decreases due to the fact that support uncertainty is removed. This will again affect the fixed premium level required by the ROA investor to initiate the investment and increase the probability of early exercise of the option. Table 19 presents the fixed premium levels corresponding to the investment trigger values for the wait-and-see options considered in this thesis.

Table 19: Fixed premium levels corresponding to investment trigger values for the wind case

Lifetime (years)	**Fixed premium trigger level (NOK/kWh)**
5	0.21
4	0.20
3	0.20
2	0.17
1	0.12

For an investor with a remaining lifetime of the wait-and-see option presented in table 19, the corresponding fixed premium trigger level is necessary to make the ROA value equal to the underlying project value. The ROA investor will then not have incentives to postpone the investment any further.

Previous in this thesis an expected fixed premium level of 0.15 NOK/kWh was assumed if the fixed premium system is introduced. This level is sufficient for an investor basing the decision on the standard NPV criteria, while a ROA investor will not build unless the wait-and-see option has only one year left. On the other hand, the support uncertainty is as previously stated the underlying uncertainty that easiest can be eliminated. Even though a fixed premium system with a level of 0.15 NOK/kWh will not make the ROA investor invest today, it will however change the probability that he/she will invest in the near future. Figure 47 shows the changes in the decision tree for the investor as a result of deciding on the fixed premium system with a level of 0.15 NOK/kWh.

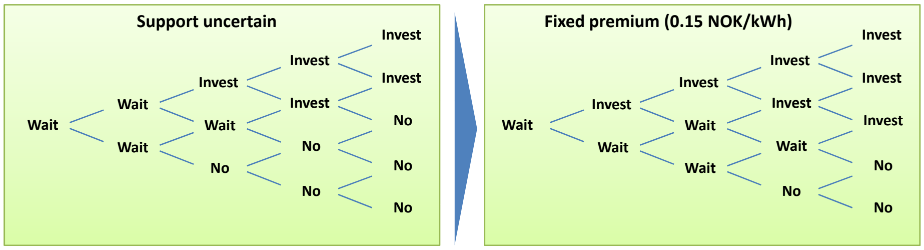


Figure 47: Changes in decision tree when going from the base case to a scenario with fixed premium support (0.15 NOK/kWh)

Figure 47 shows that with the support uncertainty removed there is a possibility that the ROA investor will initiate the investment in year 2, compared to earliest in year 3 with the support uncertainty still present.

The Norwegian Wind Energy Association's required fixed premium level of 0.20 NOK/kWh seems to be in a somewhat reasonable range if the target is to reduce the time from concession is given to the investor decides to build. This level can make it attractive for a ROA investor to invest already after 1 year (remaining option lifetime of 4 years). Based on the standard NPV criteria projects are already profitable with a fixed premium level of 0.12 NOK/kWh, and a level of 0.20 NOK/kWh may thus over-subsidize investors in renewable energy projects. NORWEA do however base their arguments on increasing real prices of equipment, a factor not considered in the base case in this thesis, only examined trough a scenario in section 7.5.2.

8 Discussion

Most investments are characterized by a degree of uncertainty, and this uncertainty can be ascribed different economic, operational and technological factors. Investments in renewable energy are exposed to all these classes of uncertainty, as can be viewed as the volatility in the value of the project evaluated. This volatility of projects will in turn give the management an opportunity to react to the changes that occur, an opportunity not treated in standard valuating frameworks such as the net present value. As long as management is able to change the cash flows of an asset, this flexibility adds a value to the project. The real options framework explicitly incorporates and values this flexibility. This is necessary in order to understand the value uncertainty provides a project through flexibility, and discussed among others by Dixit and Pindyck (1994), Myers (1984) and Trigeorgis and Mason (1987). Options can be found in almost any project, and they have considerable value not included by the net present value approach.

Real options have yet to gain the strong impact and influence that many predicted it would have, and a survey conducted by Bain & Company (Bain and Co (1999)) among 451 senior executives in more than 30 industries, showed that only 9% used real options as a management tool. Some critics to real options have pointed at its complexity ("black box"), e.g. due to the sophisticated mathematics. It is however little doubt that the real option approach adds value to the valuation of projects. An important contribution is therefore to transform the framework from a theoretical and technical finance exercise to a practical and implementable approach to avoid undervaluation of assets and misallocation of capital. Copeland and Antikarov (2003) is a contribution to lower the threshold of implementing real options in every corporation's capital budgeting decisions, something already highlighted in the subheading: A Practitioner's Guide. Even though practical approaches are important when it comes to valuing uncertainty through real options, it is nevertheless important to be aware of the possible pitfalls and shortcomings when going from a theoretical point of view to a practical one. It is important not to lose theoretical foothold, and important drawbacks caused precisely by the transformation of the real options framework from a theoretical to a practical world, as conducted in this thesis, is presented later. This section further discusses important assumptions in the thesis, our main results and potential drawbacks.

Assumptions
In order to quantify how uncertainty is driving the value of the cases examined in this thesis, it is necessary to make assumptions about several input parameters. These assumptions where then analyzed to measure their effect on the final results in order to test the validity of the model, presented in section 7.4.

A key parameter to value real options is the volatility of the underlying asset, which in this thesis is not a tradable asset, and so historical market data is not available. This problem is handled by identifying assumptions affecting the bottom line of the project, and further the risks associated. Through the MAD assumption and Monte Carlo simulation it is then possible to quantify a volatility of the option's underlying. The underlying risk factors that are modelled in this thesis include the power price, the support system and availability for all three cases. In addition the production is assumed stochastic for the wind case. These factors are chosen, as they are considered the most prevailing. In addition, stochastic heat demand could have been included as this is a factor that may affect the bottom line in the bio cases due to the fact that heat is a local energy resource. Also variable fuel prices in the bio cases could be a sensible uncertainty factor as seen from scenario 5 analyzing the change in fuel prices for the biomass case. It is however assumed that this is regulated through long term contracts with local suppliers. To model the power price, availability and wind production, high quality historic data are available. This is not the case for the support uncertainty. The assessment of this uncertainty is as previously described done through interviews with relevant people within the authorities and industry, and thus highly dependent on subjective judgments. We do however consider it to be a sufficient way since this uncertainty originates from political negotiations and decisions which can not be modelled in mathematical rational way. The results in section 7.4.2 show that the uncertainty is highest for the wind and biomass cases and lowest for the biowaste case. The biowaste case have a steady generation of electricity through the whole year, while the wind case is dependent on available wind resources and the biomass case only generates electricity when heat is generated. This will reduce the uncertainty in the biowaste case compared to the wind and biomass cases. The wind case is also influenced by an uncertain wind resource, fluctuating with an annual standard deviation of 10-15% around the expected generation. No serial-correlation is however modelled and the actual wind velocities at a site is assumed to be measured correctly previous to the construction. It is also clear that the power price is the dominating uncertainty in all three cases. This is as expected considering the high volatility of historic power prices in Norway compared to the other uncertainty factors.

The volatility of renewable energy projects can not be observed in the market, but estimated by modeling underlying uncertainty factors. The total project volatility must therefore be considered an approximation. It is impossible to include all underlying uncertainties and modeling them in a correct way, cf. the discussion above. The option values' sensitivity to changes in the volatility where therefore examined in section 7.4.2. As expected will the option values change significantly over a range of changes in the volatility, which underlines the importance of correct volatility estimates in all options pricing. The wind case has the largest option values in total since this case has the lowest NPV and hence the project where it is most sensible to wait for more information. Since the probability of possible changes in the volatility is not known, anything more specific about the probable error in the volatility estimation can not be specified, but the reader is made aware of the importance of possible estimation errors. It is also worth mentioning that no correlations between the uncertainty factors are assumed, which is further discussed later in this section.

Calculation of WACC is crucial in standard valuation approaches like the net present value. Its importance is also present in valuation of real options, though not that dominant as in the net present value approach. The calculation of WACC in this thesis relies on the Capital Asset Pricing Model by Treynor, Sharpe, Lintner and Mossin (see e.g. Sharpe (1964)). Even though the model's assumptions and usefulness has been faced with critics (e.g. Jagannathan (2002); Roll (1977)) and the model has been challenged by other models like the Arbitrage Pricing Model (Ross (1976)) and Fama and French Three-Factor Model (Fama and French (1993)), it is still presented in most textbooks on the subject. We will not treat the pros and cons of the CAPM model in this thesis since this is not our main focus, and assume that it is sufficient to calculate the cost of capital for our purposes. The reader should nevertheless be aware of the discussions around the validity of the model.

The WACC is further depending on correct input values for its parameters. Figure 29 in section 7.4.3 presents an analysis of the sensitivity of the WACC by changing its input parameters. As presented earlier it is the asset beta and market premium that has the strongest absolute impact on the WACC value. Previously the difficulties caused by the lack of listed companies with similar risk profile, as the cases presented in this thesis, were discussed. This complicated the calculation of the asset beta. For the wind case a listed peer group is used together with previous relevant work to calculate the asset beta.[55] The wind case benefit from the fact that there are a number of listed companies in different parts of the wind energy value chain with a somewhat similar risk profile. It is however more difficult to find listed copies of companies with similar characteristics as the two bio cases presented. This is treated by relying on findings by Econ Pöyry (2008), and the asset beta in the bio cases are therefore decided based on a more qualitative approach, as described earlier. The systematic risk in the bio sector used in this thesis is also in accordance with the results from Gjølberg and Johnsen (2007). The difficulties in calculating the correct asset beta in addition to the WACC's sensitivity of its value is important to notice. When it comes to the market premium, this thesis uses a forward-looking world equity premium based on the work by Dimson, Marsh and Staunton (2006) and Campbell (2008). Both the calculation of the asset beta and the market risk premium requires an assumption about what the "market" is. Theoretically the market should contain all possible assets, including intangible. This is however not possible and this thesis uses the MSCI World Index as a benchmark for the market. This can off course give rise to discussions around estimation of the correct market premium. Since this is not the core problem in this thesis and the market premium relies on work by Dimson, Marsh and Staunton (2006) and Campbell (2008), we confine ourselves to just mentioning the difficulties and the reader is encouraged to consult the sources for further discussion on this issue. Finally the debt ratio is treated separately, as this also affects the WACC calculation in a significant degree. As presented in section 3.1.8, Mjøs (2007) finds an average debt ratio of listed companies on Oslo Stock Exchange of about 60%. Energy companies in Norway have traditionally had a lower than average debt ratio, and hence our assumption of 50% debt ratio. It can however be discussed if this is the correct value to use since our investor is internationally focused (Skjølsvik (2008)). Based on the discussion of the different input parameters in the WACC calculation above, it is reasonable to calculate a range of reasonable WACCs for the different projects. This is presented in table 3.1. The analysis showed that the different WACCs did not affect the volatility of rates of return in the project, but both the NPV and ROA value changed.

The resulting values for the WACCs obtained in this thesis is considered slightly lower than the ones seen in among other Gjølberg and Johnsen (2007) and Haas (2002). Biomass projects are especially considered as relatively uncertain (Skjølsvik (2008)), although this may be due to inclusion of more unsystematic risk factors than suggested by theory. As a concluding remark about the WACC calculation, we would like to point out the fact that traditionally too much effort is put in the calculation of the WACC compared to the cash flows (Johnsen (1996)).

In order to calculate the strike price of the abandon and expand option many assumptions have been made. This was necessary, as little market information about prices on used equipment for renewable energy generation exists. Further prices and increased output from exercising the expand option are highly dependent on the individual project and therefore difficult to estimate. Section 7.4.4 presented how the value of the abandon and expand option changes as the strike price changes. The value of the abandon option is highly dependent on the strike price in the wind case, while it is relatively stable for the biomass and biowaste cases. The expansion option is relatively stable for the wind and biomass cases, while the biowaste case changes significantly over the range of expansion strike prices. The lack of good data for estimating strike prices and the expansion options' dependency on these, makes the resulting expand option values very uncertain.

---

[55] Previous work includes: Gjølberg and Johnsen (2007); Johnsen (1996); Lehman Brothers (2006)

This thesis has used cost data from the Norwegian Water Resource and Energy Directorate (NVE (2007)). These cost data are from 2006 and it is to be expected that prices on equipment, particularly for wind projects, have increased beyond the expected inflation rate since then (Undeland (2008)). This will of course affect the total value of the project, both with and without flexibility included, since the total cost level is too low. Further the cost data from NVE (2007) ascribes from projects that were all economically sound projects and undertaken, and hence can be an upward bias in the valuation. The validity of our projects serving as representative examples of considered projects can therefore be challenged, but we argue that the numbers presented by NVE (2007) represents the best data available on the subject.

The assumption that the construction of the different plants can be done within a year do also bias the project values upwards. Further it is assumed that the power generated from the biowaste plants are 100% renewable, which in practice might not always be the case. This will lower the amount of support this case is eligible for, and further reduce the NPV and ROA value for the bio projects.

Evaluation of results

The results obtained from the standard valuation gave resulting net present values in the vicinity of zero for the wind and biomass projects, as would be expected given the purpose of the calculated investment support received by Enova. The biowaste project is found to have a substantial positive NPV. The discrepancies stem from different assumptions used by the defined investor in this thesis and the ones used by Enova. Both the wind and biomass projects would be uprofitable without investment support, illustrating the necessity of support schemes to induce renewable energy investments. The biowaste project is in this thesis considered the least risky seen from a CAPM perspective, with the lowest asset beta, due to a fixed customer base relatively independent of economic business cycles and a socially desirable function beyond producing energy, i.e. the removal of waste. The lower considered WACC makes this the economically most viable project based on the traditional net present value approach.

The results from the real options analysis incorporating the additional value of managerial flexibility shows an increasing value of the option to invest mainly due to a high value of being able to postpone the investment awaiting more information. The results showed the highest option value compared to the initial investment for the wind and biomass projects, the same projects having the largest volatility of the underlying project value. These results indicate that biomass and wind projects might be considered as more volatile and sensitive to changing economic conditions or other uncertainty factors affecting the projects cash flows. The implied internal rates of return demanded by ROA investors also reflect this statement, as they were higher in the case of the wind and biomass cases compared to the biowaste case. Given these assumptions and the fact that Enova does not differentiate between the WACCs used in their support calculations for these technologies, the biowaste project turns out very profitable for our investor.

The cost of energy shows the cost an investor would demand from the power or heat generated by the project. The additional implied cost a ROA investor would demand for the energy generated was found by simply allocating the additional net present value the investor would demand before investing, over the projects 20 year costs. The allotment of costs between the heat and power generated from the bio projects is also dependent on how the separation of investment costs are handled between the two technologies. The results show that both wind and biomass projects require investment support based on electricity prices below 0.44 and 0.4 NOK/kWh respectively, while the biowaste project is considered profitable for electricity prices above 0.3 NOK/kWh. If the objective is to generate renewable energy at the lowest cost, this would suggest that investing in combined heat and power plants based on biowaste is the optimal choice, given the three cases presented in this thesis. The ROA values found in this analysis is slightly higher since the investor would demand a higher price for the energy generated before investing. The implied cost of energy for the ROA investor will however decrease towards the cost of energy for the NPV investor as the investment trigger level decreases along with the time to maturity of the wait-and-see option. The results are thus dependent on the trigger levels found and subject to the inaccuracy of the time step resolution.

The model developed in this thesis is used to analyze as set of possible scenarios described in section 7.5. These scenarios are used to illustrate the significance uncertainty can have on the outcomes of renewable energy projects, and they are created to illustrate what we consider to be representative and potential outcomes. The likelihood of the different scenarios is however difficult to predict and so they may give an overly optimistic or dismal picture of the real world depending on how much weight the reader puts on the probability of the respective outcome. The same apply for any sensitivity analysis conducted in the scenarios to illustrate the projects sensitivity to changes in certain input factors. Project value may change significantly by alternating such factors, but the probability of such a change's occurrence must always be kept in mind when reading such an analysis.

The thesis describes three scenarios for the wind project, one with a low price area giving a negative outcome, one covering increasing investment costs, and the third a scenario with a fixed support system giving a positive outcome. The assumptions made in these scenarios are presented in the text and serve as illustrations of the many possible outcomes from an investment in renewable energy projects. They also illustrate the application of using the model to run what-if analysis to see the paramount effects of changes in different input parameters. The result from the low price area scenario, which resulted in a significant drop in the base case NPV and ROA value, may be analogous to the situation a possible wind investor will face in certain parts of Norway today. In scenario 2 the effect of increasing investment costs is analyzed to see how it affects project value and the investor's decisions. The inclusion of such an effect induced earlier exercise of the wait-and-see option in order to capitalize on the lower investment costs early in the concession period. This increase have occurred since the numbers used in this thesis was presented by NVE (2007) and so the investment cost data is most likely underestimating the actual investment cost today. The point illustrated in the scenario however is still valid, although the shape and size of the growth in investment costs is subject to discussion, and another source of uncertainty not covered in the scenario. The increasing investment costs observed in the market today should also induce higher levels of potential new support systems in order to make wind projects economically viable. If this is a temporary effect and the level will further stabilize and perhaps drop due to technological progress or increased wind turbine production capacity, the opposite case of a decreasing investment cost might be just as interesting to analyze. Again the likelihood of the different scenarios must be considered when interpreting the results.

In the biowaste scenario delivering heat to the industry it was illustrated that the addition of managerial flexibility does not always contribute with a significant change in the projects value using a real option approach rather than the traditional NPV method. This case was characterized by less uncertainty compared to the base case and little flexibility due to long term contacts and limited options both for expanding or abanding the projects and in terms of postponing the investment. The individual suppositions for contracts entered into with industry customers are very dependent on the individual case and so this scenario mainly serves as an example to illustrate that the inclusion of managerial flexibility is not always necessary. The last scenario explores the effect of changing biomass prices on the overall project value. In the base case the fuel prices were assumed fixed due to long-term contracts with local suppliers. Based on the results obtained in this scenario and discussions with Enova (Skjølsvik (2008)), fuel prices for the biomass project could be included as an uncerlying uncertainty factor. The scenario illustrates the outcome of different fuel prices, but makes no attampt of quantifying the probability of the different prices used.

The inclusion of the ROA framework does, in addition to valuing the opportunity to invest in a project, provide the user with decision support whereas to when he/she should invest. The investment trigger values for the different projects are found using the model and by altering the time to maturity of the wait-and-see option. The rough separation of the project periods into years when constructing the binomial trees result in a stepwise figure when drawing the early-exercise boundary for the investment, and not a continuous line as would be seen if infinitesimal time steps were used. This would however increase the computational time of the model and further complicate the calculation of cash flows and was not conducted in this thesis. The analysis will thus present annual trigger values which must be considered as rough estimate of the changing trigger levels for the investor as the concession period decreases. The analysis does however show the difference between the investment decisions made by a traditional NPV investor and a ROA investor, illustrated through decision trees. The use of the model for decision support would probably require the need for a binomial tree with a more detailed resolution as the resulting trigger values is sensitive to changes in the different nodes in the decision trees, resulting from stepwise changes.

Many of the underlying uncertainties that drive the volatility of the underlying project value are difficult for an investor to remove, e.g. the wind resource, being a natural phenomenon that cannot be controlled, or the fluctuating power prices set by market conditions. The support uncertainty however is due to regulatory decisions and the signals they send to the investors. Parts of this uncertainty can be removed if the system is decided and implemented, like the inclusion of a fixed premium system analyzed in this thesis. The reduction of uncertainty and the following increase in amount of support will result in a double effect, giving a higher value of the underlying project value and lower trigger values for the ROA investor, thus stimulating earlier investment in the energy projects. The analysis also evaluates different levels of the fixed premium, and the fixed premium level of 0.15NOK/kWh signalized by Enova (Musum (2008)) would lead to a positive net present value, thus stimulating investment by a NPV investor. The ROA investor would however still postpone the investment given these levels. These calculations are based on the numbers presented in NVE (2007) and so any increase in investment costs would require higher levels for the fixed premium in order to make wind power investments economically sound. The fixed premium level of 0.2 NOK/kWh suggested by NORWEA (2008) is however, based on the assumptions made in this thesis, considered to be too high based on the traditional NPV method. The results from this analysis illustrate that the uncertainty about future support systems created by political instability, result in less investments in renewable energy projects.

Drawbacks

The four step process presented in Copeland and Antikarov (2003) that is used in this thesis has been criticized for overestimating the volatility of the underlying asset that the real option is contingent on. Godinho (2006) concludes that the Monte Carlo simulation procedures lead to an upward bias in the volatility estimate, thus overstating the option value of the managerial flexibility. The model also assumes constant project volatility over time that does not change with project value. The critics argue that the procedure aggregates the entire projects uncertainty into the first year's rate of return, instead of simulating the first year and then using expected values for the remaining years of operation. This way the investor would only use information that is available up to and including the current moment. The use of these ex post values includes more sources of uncertainty than exist in the first year of operation, and contributes with a larger range of possible outcomes and a higher volatility of the underlying project value. A more thorough description of the model critics is given in appendix A.10. Different methods for using Monte Carlo simulations on projects' cash flows to estimate project volatility is discussed in Haahtela (2007). The paper also presents a volatility estimation procedure that separates the ambiguity in underlying asset value in the beginning from the uncertainty caused by volatility.

The overstatement of the volatility of the underlying would lead to an overstatement of the option values and thus also the ROA value of the project, as seen in section 7.4. A reduction in volatility would reduced the investment trigger values and thus also alter the decisions made by a ROA investor. An over-prediction of volatility would thus sometimes lead a ROA investor to postpone investments even if it would be preferable to invest. The neglecting of underlying uncertainty factors when estimating the volatility of rates of return would in most cases lower the volatility, giving the opposite effect of what is mentioned above.

The use of real options methodology is still a relatively young science and although many scientific papers have been written on the subject, it has yet to become a customary and applied technique such as the NPV method. The complexity of the technique creates a threshold for users and so the results from the model describing the behavior of a ROA investor might not be a representative way of describing today's investors.

When modeling the underlying factors driving the uncertainty of the investment project's value, the stochastic processes are modelled independently of each other and thus assumed to be uncorrelated. This assumption might not hold for all the factors, especially if more factors are considered for inclusion. The correlation of the certificate price in a future TGC system with the electricity price was examined, and presented in appendix A.11. One could expect to observe a long term negative correlation between the electricity and certificate price, as increasing power prices would demand a lower certificate price for the most profitable and mature renewable technologies, and vice versa for decreasing power prices. This correlation analysis was conducted using data from the current Swedish system, but no stable correlation was found. The TGC system has however not been in operation for a long time and so only data reaching back to 2004 was obtained, making it difficult to identify long term trends in the time series. Negative correlation between certificate and electricity price is also discussed in Bye, Olsen and Skytte (2002).

9 Conclusion

Investments in renewable energy projects are subject to many sources of uncertainty, but the management of such projects also has the flexibility to alter the cash flows from the projects through different options. These can include the ability to expand the project given more favorable conditions, abandon the project if the opposite occur, or the ability to postpone the investment awaiting more information. The traditional NPV understates the project value and the option to invest by neglecting this flexibility. For the projects considered in this thesis the option to postpone the investment is found to be the most valuable.

There are hardly any wind projects initiated in Norway in the recent time. The reason for this can be explained by the negative NPV found for the wind base case project evaluated in this thesis. This may also be explained by the high value of the wait-and-see option, as investors are postponing their investment awaiting more information. This is of course founded on the assumption that investors apply the real options methodology.

Support uncertainty contributes with a significant share of the underlying project's volatility for all the cases evaluated. This is especially true for the wind project which only generates electricity and where all the generated energy is subject to support from a future potential support system. The instability of potential future support systems signalized by political authorities is found to increase the volatility of the underlying project value. This will in term increase the investment trigger levels for a ROA investor thus increasing the probability of the investor postponing the investment awaiting more information. The inclusion of a new support system with the expected levels considered in this thesis would also increase the net present value of the support received by the investors, and so this may also be a reason for why investors are awaiting investments until the introduction of a new system.

Combined heat and power plants based on biowaste is considered the most profitable based on the three projects considered in this thesis. The standard case considered in this thesis gave an IRR of 4.99% in real terms, compared to the estimated WACC of 3.78%. This gave a NPV of 32 MNOK for the 20 year project with investment costs of 304 MNOK. The resulting cost of energy for the biowaste project also confirms these results. If the objective is to generate renewable energy at the lowest cost, we recomend investing in a combined heat and power plant based on biowaste, given the three projects considered in this thesis.

This thesis focuses on the comparison between the standard framework, represented by the net present value, and the real options technique including the value of flexibility. It is however important to stress that real options methods are not a replacement of the net present value but rather a supplement to include the additional value of managerial flexibility. Real options methods also serve as a decision tool for investors giving optimal trigger values for timing of the investment. Real options methodology is therefore of great value to investors operating under uncertain conditions, and through applied methods such as the one discussed in this thesis, it may become more applicable at a corporate level.

10 Further work

Based on assumptions made and findings in this thesis, there are aspects that can be further developed.

- More uncertainty drivers can be included, particularly uncertain fuel prices in the biomass and biowaste cases. This is more relevant if and when these become traded commodities. Further an uncertain heat demand can be included, together with a possible support system where heat is included. It is also possible that support systems may change after they are introduced.
- Improved volatility estimation described in Godinho (2006), cf. section 8 and appendix A.10.
- Allow for possible discrete jumps in power prices due to e.g. further restrictions in CO2 emissions.
- Extend model to perform a social cost-benefit analysis.
- The model can be expanded to include other technologies or options, e.g. possibility to switch between share of electricity versus heat generated in order to increase utilization time of biomass plant.

References

Awerbuch, S. (2000), “Getting It Right: The Real Cost Impacts of a Renewables Portfolio Standard”, Public Utilities Fortnightly.

Awerbuch S., Berger, M. (2003), “Energy Security and Diversity in the EU: A Mean-Variance Portfolio Approach”, IEA Report Number EET/2003/03, Paris.

Agence France Trèsor, homepage visited 30.04.2008 (www.aft.gouv.fr).

Bain & Company (1999), “Management Tools and Techniques”, annual survey of senior executives by Darrell K. Rigby.

Berger, P.G., Ofek, E. (1994), “Diversification’s effect on firm value”, Journal of Financial Economy, 37, 1995, pp 39-65.

Black, F., Scholes, M. (1973), “The Pricing of Options and Corporate Liabilities”, Journal of Political Economy, 81, pp. 637-59.

Bloomberg, homepage visited 30.04.2008 (www.bloomberg.com).

Bodie, Z., Kane, A., Marcus, A.,J. (2005), “Investments”, 7th edition, Irwin/McGraw Hill.

Brealey, R.,A., Myers, S.,C., Allen, F. (2006), “Corporate Finance”, 8th edition, McGraw Hill.

Brundtland, G.H., et al. (1987), “Our Common Future: The World Commission on Environment and Development”, Report from the United Nations World Commission on Environment and Development (WCED).

Bye, T., Olsen, O.J., Skytte, K. (2002), “Grønne sertifikater - design og funksjon (Green certificates - design and function)”, rapport 2002/11, Statistics Norway (SSB).

Copeland, T., Antikarov, A. (2003), “Real Options: A Practitioner’s Guide”, Thomson Texere.

Campbell, J.Y. (2008), “Estimating the Equity Premium”, Canadian Journal of Economics, 41: pp. 1-21.

Campbell, J.Y., Lo, A.W., MacKinlay, A.C. (1997), “The Econometrics of Financial Markets”, Princeton University Press.

Cogeneration Technologies (2008), webpage visited 09.04.2008, http://www.cogeneration.net/condensing_steam_turbines.htm.

Cortazar, G., Schwartz, E.S. (2002), “Implementing a Stochastic Model for Oil Futures Prices”, 25, pp. 215-238.

Cox, J.C., Ross, S.A., Rubinstein, M. (1979), “Option pricing: A Simplified Approach”, Journal of Financial Economics.

Christophersen, E.B. (2008), advicor at Enova SF, mail 04.04.2008.

Dalen, D.M., Moen, E.R., Riis, C. (2007), “Regulering av fjernvarme” (Regulation of district heating), study made for the Norwegian Ministry of Petroleum and Energy, Center for Research in Economics and Management, BI, Norway.

DWIA (2008), Danish Wind Industry Association, webpage visited 02.02.2008, http://www.windpower.org/en/tour/wres/weibull.htm.

Dimson, E., Marsh, P., Staunton, M. (2006), "The Worldwide Equity Premium: A Smaller Puzzle", EFA 2006 Zurich Meetings Paper.

Dixit, A.,K., Pindyck, R.,S. (1994), “Investments under Uncertainty”, Princeton University Press.

Econ Pöyry (2006), “Likebehandling av fornybar varme og kraft”, Report 2006-014, Econ Pöyry report, Oslo.

Econ Pöyry (2008), “Datagrunnlag for økonomisk regulering av varmesektoren (Information requirements for financial regulation of the heating sector”, Econ Pöyry report (forthcoming), Oslo.

“Act relating to the energy and water resources sector in Norway (unofficial translation), Ministry of Petroleum and Energy. Found at: http://www.lovdata.no/all/nl-19900629-050.html.

Enova SF (2008), web-page visited 03.02.2008, www.enova.no.

European Wind Energy Association (2002), “Support Schemes for Renewable Energy - A Comparative Analysis of Payment Mechanisms in the EU”.

Fama, E., French, K. (1993), "Common Risk Factors in the Returns on Stocks and Bonds." Journal of Financial Economics. Volume 33, Issue 1, pp 3-56.

Finden, Per (2008), Research Manager at Institute for Energy Technology, mail 05.05.2008.

Fleten, S.-E., Grinden, B., Maribu, K.,M., Morch, A.,Z. (2007), “Case studies of investments strategies in distributed generation”, CIRED, 19th International Conference on Electricity Distribution, Vienna, 21.-24. May 2007.

Fleten, S.-E., Ringen, G. (2006), “New renewable electricity capacity under uncertainty: The potential in Norway”, Proceedings of the 9th International Conference on Probabilistic Methods Applied to Power Systems, Stockholm, June 11-15, 2006.

Gjølberg, O., Johnsen, T. (2007), “Investeringer i produksjon av fornybar energi: Hvilket avkastningskrav bør Enova SF legge til grunn?”, paper prepared on commission from Enova SF.

Godinho, P.M.C. (2006), "Monte Carlo Estimation of Project Volatility for Real Options Analysis", Journal of Applied Finance, Vol. 16, No. 1, Spring/Summer 2006.

Grønli, H. (2008), Senior adviser Enova SF, meeting 02.05.2008.

Haas, R. (co-ordinator) (2004), “The Green-X project”, Research project within the 5th framework programme of the European Commission, DG Research.

Haahtela, T.J. (2007), "Separating Ambiguity and Volatility in Cash Flow Simulation Based Volatility Estimation".

Hohle, E.E., et al. (2001), “Bioenergi - miljø, teknikk og marked”, Energigården.

Holbergfondene (2008), Månedens HolbergGraf, mai 2008, slide 16. Reproduced with permission from Holbergfondene.

Huang, J., Huang, M. (2003), "How Much of Corporate-Treasury Yield Spread Is Due to Credit Risk?: A New Calibration Approach", 14th Annual Conference on Financial Economics and Accounting (FEA), Texas Finance Festival.

Hull, J.C. (2006), “Options, Futures and other Derivatives”, 6th edition, Pearson Prentice Hall.

Intergovernmental Panel on Climate Change (2007), “Climate Change 2007 - Synthesis Report”.

IEA (2006), “World Energy Outlook 2006”, International Energy Agency.

Jagannathan, R., Meier, I. (2002), “Do we need CAPM for capital budgeting?”, NBER working paper no. 8719.

Jensen, M. (1986), “Agency Costs of Fee Cash Flow, Corporate Finance, and Takeovers.” American Economic Review 76, 323-329.

Jenssen, Å. (2008), Senior Economist at Econ Pöyry, meeting 09.04.2008.

Johnsen, T. (1996), “Avkastningskrav ved vurdering av lønnsomheten i statlig eiet forretningsvirksomhet”, SNF-prosjekt nr 7460: Staten som eier og investor.

Kaye, C., Yuwono, J. (2003), “Conglomerate Discount or Premium? Why some diversified companies create exceptional value, Marakon Associates Research.

Koller, T., Goedhart, M., Wessels, D. (2005), Valuation: Measuring and Managing the Value of Companies”, McKinsey & Company, John Wiley & Sons.

Krossøy, K., Torgersrud, P.-C.T. (2004), “Analyse av vindkraftutbygging”, Master thesis at NTNU.

Lehman Brothers (2006), “Valuation Report of Statkraft”.

Lucia, J.J., Schwartz, E.S. (2002), “Electricity Prices and Power Derivatives: Evidence from the Nordic Power Exchange”, Review of Derivatives Research, 5, pp. 5-50.

Løvseth, J. (2008), associate professor emeritus at Department for Physics, NTNU, e-mail correspondence 21.05.2008.

Markowitz, H. (1952), “Portfolio Selection”, Journal of Finance, 7, pp. 77-91.

Martinot, E. (2007), “Renewables 2007 Global Status Report”, World Renewable Energy Assembly, Bonn, Germany.

McDonald, R. (2006), “Derivatives Markets”, Addison-Wesley, Boston.

Merton, R.C. (1973), “Theory of Rational Option Pricing”, Bell Journal of Economics and Management Science, 4, pp. 141-83.

Mjøs, A. (2007), “Corporate Finance: Capital Structure and Hybrid Capita”, doctoral thesis, Norwegian School of Economics and Business Administration.

Morgan Stanley Capital International (2008), web page visited 28.05.2008, http://www.mscibarra.com/products/indices/equity/definitions.jsp#WORLD.

Muhlbradt, T. (2007), Consul and Trade Commissioner in Innovation Norway Toronto, “Bør Norge satse på industriutvikling basert på vind?”, presentation on Wind Power Seminar in Stavanger, 30.01.2007.

Musum, J. (2008), Senior adviser Enova SF, meeting 27.02.2008.

Myers, S.C. (1984), “Finance Theory and Financial Strategy”.

Norges Bank, home page visited 30.04.2008 (www.norges-bank.no).

The Norwegian Ministry of Finance/Finansdepartementet (2008), webpage visited 08.03.2008, http://www.regjeringen.no/nb/dep/fin.html?id=216.

Nelson, V. (2008), "Wind Energy and Wind Turbines for Windy Land Owners", Alternative Energy Institute, West Texas A&M University.

NORWEA (2008), Norwegian Wind Energy Association, news bulletin, 14.01.2008, http://www.norwea.no/module_info/index.php?level=2&xid=257

NVE (2006), "Vindkraft - Produksjonsstatistikk for 2006", Norwegian Water Resources and Energy Directorate.

NVE (2007), "Kostnader ved produksjon av kraft og varme", Manual published by The Norwegian Water Resources and Energy Directorate.

NVE (2008), Transmission tariff statistics, http://www.nve.no/modules/module_109/publisher_view_product.asp?iEntityId=9732

NVE et al. (2007), "Fornybar Energi 2007", booklet from NVE, Enova SF, Innovation Norway, The Research Council of Norway.

Roll, R. (1977), "A critique of the asset pricing theory's tests Part I: On past and potential testability of the theory", Journal of Financial Economics.

Ross, S. (1976), "The arbitrage theory of capital asset pricing", Journal of Economic Theory.

Samuelson, P.A. (1965), "Proof That Properly Anticipated Prices Fluctuate Randomly", Industrial Mangement Review, 6:2, pp. 41-49.

Schall, L.,D., Sundem, G.L., Geijsbeek, W.R. (1978), "Survey and Analysis of Capital Budgeting Methods", The Journal of Finance, Vol. 33, No. 1, pp 281-287.

Sharpe, W.F. (1964), "Capital asset prices: A theory of market equilibrium under conditions of risk", Journal of Finance, 19 (3), 425-442.

Sharpe, W.F. (1978), "Investments", Prentice-Hall, Englewood Cliffs, NJ.

Schwartz, E.S. (1998), "Valuing Long-Term Commodity Assets", Financial Management, Spring 1998, 27, 1, pp 57.

Skjølsvik, K.O. (2008), Enova SF, presentation held at Econ Pöyry, 20.05.2008.

Stortingsmelding nr. 29 (1998-1999), "Om Energipolitikken", The Norwegian Ministry of Petroleum and Energy.

Stortingsmelding nr. 18 (2003/2004), "Om forsyningssikkerhet for strøm mv.", The Norwegian Ministry of Petroleum and Energy.

Stortingsmelding nr. 11 (2006-2007), "Om støtteordningen for elektrisitetsproduksjon fra fornybare energikilder (fornybar elektrisitet)", The Norwegian Ministry of Petroleum and Energy.

Trigeorgis, L., Mason, S.P. (1987), "Valuing Managerial Flexibility", Midland Corporate Finance Journal, 5 (1), 14-21.

Undeland, T.M. (2008), professor at Department of Electrical Power Engineering, NTNU, Trondheim, meeting 19.02.2008.

List of Figures

List of Tables

A Appendix

A.1 Description of investor

This appendix gives a short description and a summary of the investor used in this thesis. Short facts about the investor:

- Located in Norway and subject to the Norwegian tax system.
- Internationally well-diversified (considers only systematic risk).
- Invests in developed markets.
- The renewable energy projects considered are localized in Norway.
- Uses the MSCI World Index as a benchmark for the market.

About MSCI World Index:
This is a free-float market capitalization weighted index measuring equity market performance of developed markets. It is maintained by Morgan Stanley Capital International and has been calculated since 1969. Pt. the index consists of 23 countries: Australia, Austria, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Hong Kong, Ireland, Italy, Japan, Netherlands, New Zealand, Norway, Portugal, Singapore, Spain, Sweden, Switzerland, UK and US (MSCI Barra (2008)).

A.2 One year historic yield for government bonds with 10 years to maturity in Norway, EU and US

The figure is taken from Holbergfondene (2008), and reproduced with permission.

Figure 48: One year development for government bonds with 10 years to maturity in Norway, EU and US.

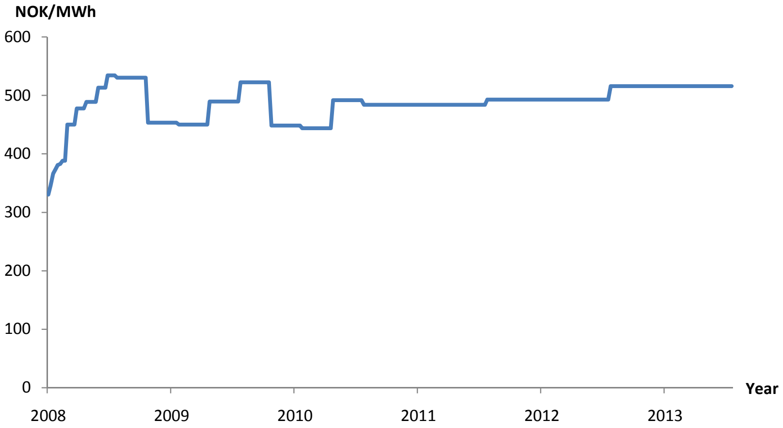
A.3 Parameters obtained in Lucia and Schwarts (2002) for the two-factor price model

Table 20: Parameters obtained in Lucia and Schwartz (2002).

α^*	κ	μ_ε^*	α	γ	τ
-53.74	0.0077	-0.029	151.08	30.27	3.96

A.4 Nord Pool forward curve

Figure 49: Forward curve in the Nordic power market, 04.06.2008.



A.5 Monthly parameters for a wind project taken from Krossøy and Torgersrud (2004)

Table 21: Monthly parameters for a wind project taken from Krossøy and Torgersrud (2004)

Form factor	1.74

Month	**Avg. wind velocity [m/s]**	**Scale factor**
January	11.1	12.4
February	10.9	12.2
March	9.7	10.9
April	7.7	8.7
May	6.7	7.5
June	6.1	6.8
July	5.7	6.4
August	6.1	6.8
September	7.7	8.6
October	9.2	10.3
November	10	11.2
December	10.5	11.8
Annual	8.4	9.5

A.6 Parameters of normally distributed monthly wind velocities

Table 22: Parameters of normally distributed monthly wind velocities

Month	**Mean**	**St.dev**
January	11.048	1.197
February	10.855	1.187
March	9.711	1.038
April	7.740	0.851
May	6.683	0.713
June	6.049	0.658
July	5.705	0.626
August	6.063	0.650
September	7.673	0.825
October	9.167	0.993
November	9.975	1.069
December	10.524	1.123
Annual	8.432	0.269

A.7 Summary statistics from model accuracy analysis

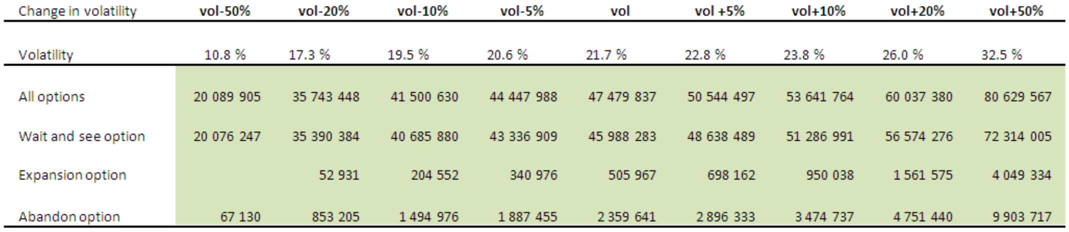
The table reports the results from the analysis of number of simulations needed to get accurate results from the Monte Carlo Simulation described in section 6.2. The simulations are run on a computer with 2.0 GHz Intel Core 2 Duo and 512 MB RAM.

Table 23: Summary statistics from model accuracy analysis. a) 100 sets are performed for each number of simulations, except for the 5000 and 10 000 simulations per set where 30 sets are performed, due to long computational times. b) Standard deviation of the volatility of rates of return, calculated for the different runs. c) The average deviation divided by the volatility of rates of return obtained when running 75 000 simulations.

	Simulations per set	**Standard deviation**[a]	**Average abs deviation**[b]	**Percentage deviation**[c]	**Average computational time**
Wind	**100**	**0.02723**	**0.01470**	**6.78%**	**00:02:42**
	500	**0.01113**	**0.00624**	**2.88%**	**00:13:23**
	1000	**0.00857**	**0.00506**	**2.33%**	**00:27:22**
	2500	**0.00511**	**0.00251**	**1.16%**	**01:09:11**
	5000	**0.00300**	**0.00187**	**0.86%**	**02:14:49**
	10000	**0.0014**	**0.00101**	**0.47%**	**04:32:34**
Biomass	**100**	**0.01869**	**0.01844**	**7.40%**	**00:02:52**
	500	**0.00826**	**0.00805**	**3.23%**	**00:14:32**
	1000	**0.00595**	**0.00540**	**2.17%**	**00:28:12**
	2500	**0.00423**	**0.00368**	**1.48%**	**01:12:11**
	5000	**0.00364**	**0.00303**	**1.22%**	**02:23:43**
	10000	**0.00275**	**0.00230**	**0.92%**	**04:48:23**

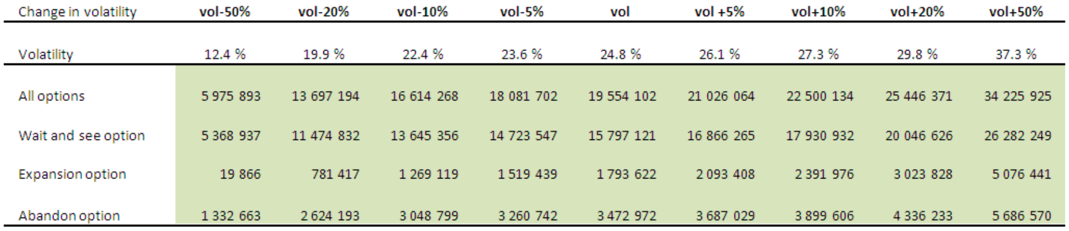
A.8 Option values

Table 24: Option values in the wind case for changing volatilites.



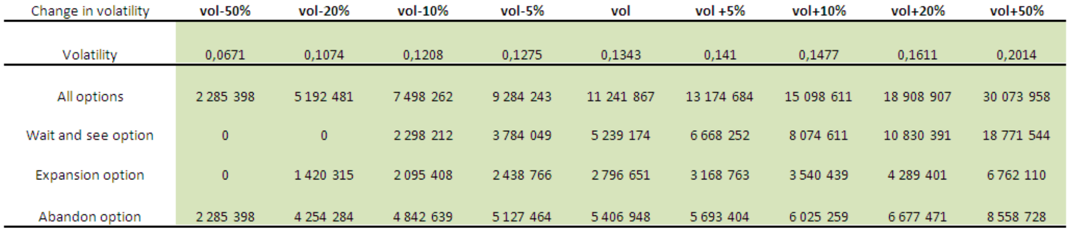
Change in volatility	vol-50%	vol-20%	vol-10%	vol-5%	vol	vol +5%	vol+10%	vol+20%	vol+50%
Volatility	10.8 %	17.3 %	19.5 %	20.6 %	21.7 %	22.8 %	23.8 %	26.0 %	32.5 %
All options	20 089 905	35 743 448	41 500 630	44 447 988	47 479 837	50 544 497	53 641 764	60 037 380	80 629 567
Wait and see option	20 076 247	35 390 384	40 685 880	43 336 909	45 988 283	48 638 489	51 286 991	56 574 276	72 314 005
Expansion option		52 931	204 552	340 976	505 967	698 162	950 038	1 561 575	4 049 334
Abandon option	67 130	853 205	1 494 976	1 887 455	2 359 641	2 896 333	3 474 737	4 751 440	9 903 717

Table 25: Option values in the biomass vase for changing volatilites.



Change in volatility	vol-50%	vol-20%	vol-10%	vol-5%	vol	vol +5%	vol+10%	vol+20%	vol+50%
Volatility	12.4 %	19.9 %	22.4 %	23.6 %	24.8 %	26.1 %	27.3 %	29.8 %	37.3 %
All options	5 975 893	13 697 194	16 614 268	18 081 702	19 554 102	21 026 064	22 500 134	25 446 371	34 225 925
Wait and see option	5 368 937	11 474 832	13 645 356	14 723 547	15 797 121	16 866 265	17 930 932	20 046 626	26 282 249
Expansion option	19 866	781 417	1 269 119	1 519 439	1 793 622	2 093 408	2 391 976	3 023 828	5 076 441
Abandon option	1 332 663	2 624 193	3 048 799	3 260 742	3 472 972	3 687 029	3 899 606	4 336 233	5 686 570

Table 26: Option values in the biowaste vase for changing volatilites.



Change in volatility	vol-50%	vol-20%	vol-10%	vol-5%	vol	vol +5%	vol+10%	vol+20%	vol+50%
Volatility	0,0671	0,1074	0,1208	0,1275	0,1343	0,141	0,1477	0,1611	0,2014
All options	2 285 398	5 192 481	7 498 262	9 284 243	11 241 867	13 174 684	15 098 611	18 908 907	30 073 958
Wait and see option	0	0	2 298 212	3 784 049	5 239 174	6 668 252	8 074 611	10 830 391	18 771 544
Expansion option	0	1 420 315	2 095 408	2 438 766	2 796 651	3 168 763	3 540 439	4 289 401	6 762 110
Abandon option	2 285 398	4 254 284	4 842 639	5 127 464	5 406 948	5 693 404	6 025 259	6 677 471	8 558 728

A.9 Calculations of high and low beta values for the three renewable energy projects

Table 27: Calculations of high and low beta values for the three renewable energy projects

	Wind		
	Low	**Base**	**High**
Risk-free rate (real)	0.0400	0.0425	0.0450
Market premium	0.045	0.050	0.055
Asset beta	0.55	0.60	0.65
Debt ratio, D/(D+E)	0.5	0.5	0.5
Tax rate	0.28	0.28	0.28
Inflation	0.025	0.025	0.025
Debt premium	0.0075	0.0075	0.0075
WACC	**4.04%**	**4.78%**	**5.57%**

	Biomass		
	Low	**Base**	**High**
Risk-free rate (real)	0.0400	0.0425	0.0450
Market premium	0.045	0.050	0.055
Asset beta	0.45	0.50	0.55
Debt ratio, D/(D+E)	0.5	0.5	0.5
Tax rate	0.28	0.28	0.28
Inflation	0.025	0.025	0.025
Debt premium	0.0075	0.0075	0.0075
WACC	**3.59%**	**4.28%**	**5.02%**

	Biowaste		
Risk-free rate (real)	**Low**	**Base**	**High**
Market premium	0.0400	0.0425	0.0450
Asset beta	0.045	0.050	0.055
Debt ratio, D/(D+E)	0.35	0.40	0.45
Tax rate	0.5	0.5	0.5
Inflation	0.28	0.28	0.28
Debt premium	0.025	0.025	0.025
WACC	0.0075	0.0075	0.0075
	3.14%	**3.78%**	**4.47%**

A.10 Drawbacks using the method for estimating project volatility presented in Copeland and Antikarov (2003)

Godinho (2006)concludes that the Monte Carlo simulation procedure presented in Copeland and Antikarov (2003) lead to an upward bias in the volatility estimate, thus overstating the value of the managerial flexibility options. The Copeland and Antikarov model assumes constant project volatility over time that does not change with project value. The rate of return of the project (k_n) is calculated using equation 31.

$$k_n = ln\left(\frac{PW_n}{MV_{n-1}}\right) \tag{31}$$

Monte Carlo simulation can be used to find the distribution for k_1, and the standard deviation of this distribution can be used as the volatility of the underlying project value. In the equation above the term PW is the present worth of the project and MV the market value, given by the equations 32 and 33.

$$MV_n = \sum_{t=n+1}^{T} F_t e^{-r(t-n)} \tag{32}$$

$$PW_n = MV_n + F_n = \sum_{t=n}^{T} F_t e^{-r(t-n)} \tag{33}$$

F_n is the free cash flow in year n. Copeland and Antikarov (2003) suggest that MV_0 should be estimated with the estimated cash flows and subsequently held constant, and so only PW_1 would be iterated in the simulation of k_1. Godinho (2006) argues that any measure of project value in a given moment should only use information that is available at that moment. The expression for PW_n above uses values of future cash flows (unknown at year 1), instead of only using information that is available at year 1, which would be expected values for the subsequent years after year 1. Equation 33 thus calculates an ex post value for a given scenario. By using these ex post cash flows instead of their expected values, more sources of uncertainty than exist in the first year are included. This will in turn lead to artificially higher annualized project volatility. The correct expressions for MV and PW should, according to Godinho (2006) be defined as in equations 34 and 35.

$$MV_n = \sum_{t=n+1}^{T} E_n(F_t) e^{-r(t-n)} \tag{34}$$

$$PW_0 = \sum_{t=n}^{T} E_n(F_t) e^{-r(t-n)} \tag{35}$$

There is however one problem with this method. The estimation of $E_0(F_t)$ is based on information available at the beginning of the project which is known and does not change. The estimation of $E_1(F_t)$ however must be based on information available at the end of year 1, which changes for each iteration. In order to cope with this problem a two-level simulation procedure can be applied. The first level would simulate the behavior in the first year, and then the expected value in year 1 is found by averaging the second layer of simulations from this point on. Each iteration of the first level must then be followed by a complete simulation of the second level, resulting in a very large computational time. Due to these drawbacks we have concluded not to use this method, but are aware of the upward bias that might occur when estimating the project volatility. For more discussion on the Copeland and Antikarov (2003) procedure and other methods using Monte Carlo simulation on cash flow calculations to estimate volatility, consult Haahtela (2007).

A.11 Correlation between TGC price and spot price (Sweden)

This appendix shows the results from a rolling window correlation analysis between the TGC price and electricity spot price for Sweden (Stockholm).

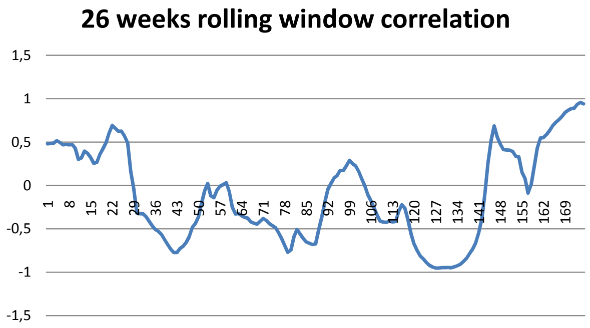


Figure 50: 26 weeks rolling window correlation between TGC price and electricity spot price.

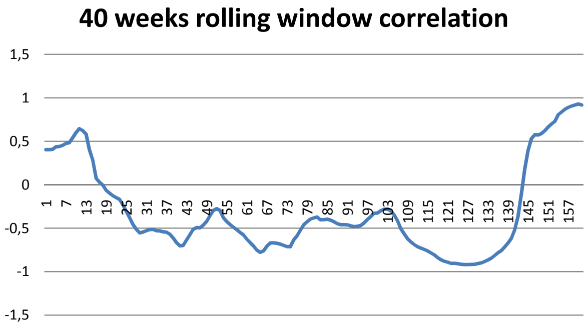


Figure 51: 40 weeks rolling window correlation between TGC price and electricity spot price.

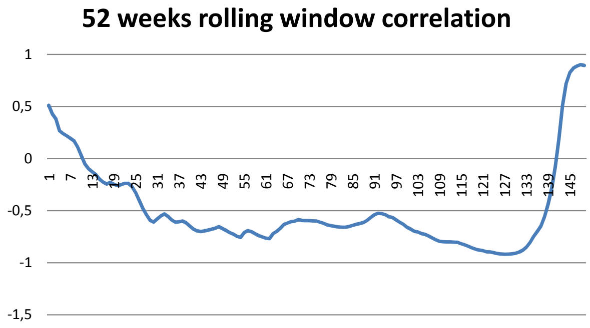


Figure 52: 52 weeks rolling window correlation between TGC price and electricity spot price.

A.12 CD