Investment in Mutually Exclusive Transmission Projects under Policy Uncertainty

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Abstract

In this paper we evaluate mutually exclusive transmission projects under policy and economic uncertainty. The alternatives being considered are transmission investment projects between Norway and Germany, and Norway and the UK. We apply a real option valuation framework allowing the investor to choose the optimal time and location of the investment, and also how different conditions affect the decision to invest in either of these two projects. The analysis shows that the value of the option does not necessarily increase with volatility.

Keywords: Real Options, Energy Markets, Decision Making, Case Study

1. Introduction

The European Union (EU) has committed to a binding goal for all member states of fifteen percent cross-border transmission capacity by the end of 2030. In this paper we aim to analyse the profitability and optimal investment timing of additional transmission capacity between countries when uncertainty is taken into account. This is done using real option valuation with the option to invest in one of two mutually exclusive projects; either building an interconnector from Norway to Germany or from Norway to the United Kingdom (UK).

The main contribution of this paper is twofold. First, we apply real option analysis to consider which country to connect to. In the real options literature there are several papers considering mutually exclusive investment projects [1, 2, 3], but they do not consider the option of choosing between different locations. Second, our paper is one of few to apply real option valuation to transmission assets. We draw inspiration from the paper of Fleten et al. [4], who analyse the option to invest in an interconnector, where the aim is to choose the optimal capacity of the cable. In this paper we focus on the application of real options when choosing between mutually exclusive projects under policy and economic uncertainty.

The two policy schemes we focus on are the EU emission trading system (ETS) and capacity markets. We find that capacity markets have no impact regarding project choice, but it does influence the option value. A reform to the EU ETS, necessarily increasing CO_2 emission prices, can increase the option value, leading to an increased spread between the Norwegian and German/UK electricity prices. The differences in production mix between the German and the UK market also makes a tightended EU ETS have a different effect on the two markets. The effects of the policy schemes are included in the model through the revenues from the two cables. We model the revenues as uncertain and fluctuating over time.

We further investigate the benefits of looking at the option to invest in one of two locations. Other papers have developed models for choosing the optimal entering strategy into a new market. Gilroy and Lukas [5] considered the option of choosing between two different market entry strategies. They emphasise the value of considering the option to invest as mutually exclusive choice between different locations. By doing so, the value of the option increases and it helps practitioners obtain an optimal investment strategy.

The valuation methodology builds on Rubinstein [6], and takes into account the yearly revenue streams for two potential projects, ramping restrictions and capacity markets. One important finding is the effect of uncertainty on the option value. The result shows that the option value does not necessarily increase when the volatility increases, unlike what we commonly find in real option valuations.

The rest of this paper is organised as follows: In Section 2 we present characteristics and trends in the electricity market, together with a brief description of the Norwegian, German and the UK electricity market. Section 3 discusses the main policy related uncertainties in the electricity market and how these uncertainties might affect the electricity price. Section 4 introduces and explains the two factor real option model. Section 5 presents the data set and describes the main findings. In Section 6 we perform a sensitivity analysis of the real option model and conclude in Section 7.

2. The Electricity Market

In the Norwegian production system hydropower produces over 98 % of the total generated electricity. Only a small fraction of the system is thermal generation emitting CO_2. Norway utilizes a market based support scheme established to promote new electricity production based on renewable energy sources, the Norwegian-Swedish electricity certificate market. The increased portion of new renewable generation is expected to increase the surplus in the Nordic system. The electricity price in Norway is low compared to other countries in Europe, as hydropower is the price setter in most hours.

In the United Kingdom, 36 % of the total generated electricity was generated from coal, 28 % from natural gas, 21 % from nuclear and 17 % from renewables in 2013 [7]. The government is also investing in a new nuclear power plant, Hinkley Point C, to secure supply as most of UKs existing nuclear stations are due to close before 2023. A capacity market will be introduced in December 2014 to create incentive to invest in new generation. The UK chose to introduce a price floor of 18 £/tCO_2 for all market participants to give an incentive to invest in low-carbon power generation[1].

[1] *Carbon price floor: reform and other technical amendments* published by the British government `https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/293849/TIIN_6002_7047_carbon_price_floor_and_other_technical_amendments.pdf`.

In Germany, 48 % of the total generation was generated from coal, 28 % from renewables, 17 % from nuclear and 6 % from natural gas in 2013. Germany actually has a target of consuming 80 % of its total electricity consumption from renewables by 2050. To this end, Germany has introduced a feed-in-tariff aimed to accelerate investments in renewable energy by providing a fee above the retail electricity price. This is a part of the Energiewende in Germany, the transition of the power sector from nuclear and coal to renewables.

The financial crisis has stalled investments in new generation capacity and reduced demand for electricity. This in combination with increased deployment of wind and solar generation, the evolution in the costs of gas and coal, and the low carbon price have resulted in reduced wholesale electricity prices in Germany [8].

3. Policy Uncertainty

The European Union introduced the EU2050 target to make the transition to a competitive low-carbon society by 2050. As a consequence of the framework, the energy markets have experienced extensive changes during the last decades, creating an uncertain environment for investors. This paper focuses on what we consider the two main sources of policy uncertainty in EU during the next 45 years; the future of the EU ETS and the possible introduction of capacity remuneration mechanisms. The EU ETS was implemented to reach the 2050 target of 80 % emission reduction compared to 1990 levels [9]. Today it is not incentivising much emission reductions due to the low carbon price. If it fails to increase the incentive to invest in green technology, it is expected that it will be reformed or replaced with another type of scheme. In addition, several countries have either implemented capacity markets or are considering it because they are concerned for their security of supply.

3.1. EU Emission Trading System

The EU ETS was started in 2005 and is the largest cap-and-trade scheme in the world. An absolute quantity limit (or cap) on CO_2 emissions is placed on 12000 emitting facilities located in the EU. This constitutes 45 % of the total carbon emissions in the EU. These facilities must measure and report their CO_2 emissions and subsequently surrender an allowance for every ton of CO_2 they emit during annual compliance periods.

The carbon price fell from almost 30 €/tCO_2 in mid-2008 to less than 5 €/tCO_2 in mid-2013 as there was a surplus of 2 billion allowances in 2013. The surplus has primarily been built up as a reaction to the financial crisis. It led to a reduction of industrial production, emissions, and thus the demand for allowances. The supply of allowances for 2008–2020, which is based on a much better outlook for the economy, is fixed. This has led to a low carbon price, which weakens the incentive for emission-saving investments[2].

The short-run effect of an increase in CO_2-prices in EU ETS is an increased electricity price. However, long term effects depend on investment reactions, which in turn is highly

[2]The web page of European Commission on EU ETS `http://ec.europa.eu/clima/policies/ets/reform/index_en.htm`

dependent on governmental policies. The future energy mix is uncertain, and thus the impact on spreads are uncertain.

For the valuation of an interconnector it is interesting how the EU ETS will influence the revenues through the electricity price spread between the two countries. The Norwegian system is dominated by hydropower, while both the UK and the German system are dominated by thermal generation. This implies that the carbon price will have a greater effect on the prices in the UK and Germany. There are hours where the Danish coal-plants are the price setters in the Norwegian market. However, hydropower is the price setter in most hours, due to existing bottlenecks in the grid. In these hours, the spread between the electricity prices will increase with a higher carbon price since there is no carbon emission from hydropower.

3.2. Capacity Remuneration Mechanisms

In energy-only markets the producers of electricity are paid based on the MWh delivered to the consumers. The question is whether some kind of capacity market should be implemented in addition to the energy-only market to contribute to the security of supply. It is designed to give incentives for investment in new generation, ensuring that existing generation does not get shut down and to increase the demand-side response, making demand more price elastic. Several EU-members have already implemented different types of capacity mechanisms, including Greece, Ireland, Italy, Portugal, Spain, Sweden and the UK.

The capacity market in the UK has committed to let interconnectors participate in it's auctions from 2015 on[3]. For the cable revenues this means that the new interconnectors can bid into the auctions and receive revenues from this market. Thus there is less policy uncertainty here.

A report published by the German Advisory Council on the Environment (SRU) highlights a strategic reserve as a better option than a capacity market to secure supply, due to a smaller intervention in the market[4]. However, the Council does not rule out capacity market as a necessity to ensure security of supply in the medium term. In October 2014, The Ministry of Economic Affairs and Energy in Germany published its Green Paper on the future development of the German electricity market. The paper considers two approaches for the long-term development of the electricity market: an optimised energy-only market or capacity market alongside the energy-only market[5].

It is uncertain how the electricity price will be affected by the capacity market. The general price level can decrease if the capacity market creates an incentive in the energy-only market to invest in capacity with lower marginal cost than the current price setter in

[3] *State aid: Commission authorises UK Capacity Market electricity generation scheme*, press release by European Commission July 2014 `http://europa.eu/rapid/press-release_IP-14-865_en.htm`

[4] *Shaping the Electricity Market of the Future - Key Recommendations* published by German Advisory Council on the Environment in November 2013 `http://www.umweltrat.de/SharedDocs/Downloads/EN/02_Special_Reports/2012_2016/2013_11_Special_Report_Electricity_Market_KfE.pdf?__blob=publicationFile`.

[5] *Ein Strommarkt für die Energiewende* published by Ministry of Economic Affairs and Energy in October 2013 `http://www.bmwi.de/BMWi/Redaktion/PDF/G/gruenbuch-gesamt,property=pdf,bereich=bmwi2012,sprache=de,rwb=true.pdf`.

off-peak hours. The resulting change in the wholesale price is dependent on the steepness of the merit order curve and how much new capacity is added in. More capacity in the market also reduces the market power of incumbents since the companies can to a smaller extent profit from price spikes by withholding capacity [10]. Capacity markets can also be designed to only pay a fixed capacity payment to peak plants. The incentives for investments in base load and mid merit capacity can be reduced, resulting in lower peak prices and higher mid-merit prices.

According to Cramton and Ockenfels [10], by getting costs recovered in two markets, the generation companies reduce their risk premium in the spot market. Therefore, a capacity market can lower the electricity price in the spot market by reducing the risk premium. The Department of Energy and Climate Change (DECC) has performed an assessment of the capacity market in the UK, which confirms that the general level of the wholesale price decreases. At the same time, it is difficult to predict the effect a capacity market has on the electricity price, due to the lack of empirical data.

The congestion rent (interconnector revenue) is equal to the hour-by-hour price difference between the two markets. We consider an asymmetric capacity market, i.e. a capacity market is only implemented in one market. We will refer to the market that introduces the capacity market, as market A, and the other market, as market B. In this paper Germany and the UK are market A since UK is implementing a capacity market and Germany is considering it due to the constrained capacity situation in the two markets.. Norway is market B because it is not considering implementing a capacity market. We will therefore assume that the capacity situation is more constrained in market A, implying higher peak load prices.

A capacity market can lead to lower peak prices in market A. If the peak prices are still higher in market A than in market B, A will continue to import from B in peak hours, so there will not be an immediate impact on traded volumes between the two markets. The effect on the congestion rent is dependent on how much the peak prices in market B decrease with peak prices in market A. We believe the peak prices will be reduced further in A than in B. This is dependent on the correlation between the two markets. It is not likely that the peak prices are reduced with the same amount, because this requires perfect correlation. This suggests reduced congestion rent. If the capacity market lowers the peak price in market A to the level where some peak prices in B are at the same level as in A, the capacity of the cable is not fully utilised and the trade volume is altered. As a consequence the congestion revenue will be reduced. At the same time, the interconnector will also get revenues in the capacity market, which compensates for the reduction in the congestion revenue.

Another result of introducing a capacity market in market A, could be that the overall market price decreases. If the market price is sufficiently lowered it will change the trade patterns so that market B imports more than before, shifting the overall market price downwards. An analysis published by the European Commission suggests that the congestion rent is reduced in peak hours and increased in low load hours[6]. Therefore it is difficult to

[6] *Capacity mechanisms in individual markets within the IEM* published by the European Commission in February 2013 `http://ec.europa.eu/energy/gas_electricity/consultations/doc/20130207_generation_adequacy_study.pdf`

determine in advance the total effect on the revenue.

4. Modelling the Investment Option

To model the investment decision a real options model has been developed. The characteristics of the investment decision will be explained in Subsection 4.1. The technical consideration is stated in Subsection 4.2 and the historical data used for the sensitivity analysis is introduced in Subsection 4.3. All these subsections are used to provide a better understanding of the modelling which follows in Subsection 4.4. Finally, the numerical implementation is explained in Subsection 4.5.

4.1. Characteristics of the Investment Decision

In the following paragraphs we will go through the main assumptions to provide a better understanding of the model in Subsection 4.4

Assumption 1: The market is perfectly competitive. This means that all market participants are price takers, that they do not have the market power to change the prices. This is a common assumption when considering investments in the electricity market [11, 12].

Assumption 2: The two investment projects are mutually exclusive; the decision to make one investment prevents making the other investment. We make this assumption based on technical limitations in the Norwegian electricity market. Statnett estimates that the maximum load in Norway could be as high as 25 000 MW and the production capacity is 28 000 MW[7]. In 2020, the total exchange capacity of the interconnectors in Norway will be equal to 5400 MW with the two already planned cables being built. These values indicates that there will be situations in the future when there will not be enough capacity to meet demand and at the same time export maximum capacity on the cables. These situations will decrease the profitability of the cables, by reducing the number of hours the cable can export maximum capacity. By introducing one more interconnector the situation will be even more strained and the number of hours with reduced capacity will increase. We therefore conclude that there is enough capacity in the Norwegian system to build one more cable, but that it will not be profitable to build two more cables.

Assumption 3: A new cable will at the earliest be built in 2020. Therefore, we set $t = 0$ equal to year 2020. One of the reasons for this is that to own and/or run an interconnector in Norway, Statnett must obtain a license from the Norwegian Ministry for Petroleum and Energy (OED). The process of applying for a license usually takes several years. This highlights the importance of looking ahead when considering investments in new interconnectors.

Assumption 4: The option has a lifespan of 10 years, following Schwartz [13, p.969]. After 10 years, the option is worthless. One justification is that competing projects that would destroy our option will take a long time to develop. A cable from a different country in the Nordpool-area, such as Sweden, would reduce the option value greatly, due to a decreased spread between prices in the Nordic area and continental Europe.

[7] *Estimated maximum production in Norway 2012* published by Statnett in 2011

4.2. Technical Considerations

Statnett is the only company in Norway which holds a license to own transmission assets which can be used for import and export of electrical energy (Energiloven 4-2). Reliable cost parameters for their projects have been made available to us. The costs used in this analysis are given in Table 1. All the values is quoted in million Norwegian NOK. Except for two parameters discussed in the following paragraph, these are identical to the numbers provided to us by Statnett, inflated to 2020 numbers assuming an annual discount rate of 4 %.

Table 1: Cost parameters for transmission capacity

Type of cost	**Germany**	**UK**
Annual costs:		
Congestion revenues from other interconnectors	-447	-477
Maintenance costs	-26	-33
Transit costs	-11	-39
System operating cost	-164	-164
Transmissions losses in the domestic grid	-132	-79
Investments costs:		
Investment cost in cable and station	-8422	-9146
Net cost of domestic grid reinforcements	-2369	-829

We have chosen to change the two parameters "congestion rate from other interconnectors" and "net cost of domestic grid reinforcement". The reason is rooted in two assumptions: 1) the investment is taking place in 2020 or later and 2) the investment is made after two new interconnectors are installed. In this investment decision, we are looking at the case where the two cables are assumed to be operating. With the two new cables installed, the total capacity on the interconnectors are doubled compared to the current situation. Therefore, we conclude that the the losses in congestion revenues are doubled from Statnett's estimate. The investment and total annual costs are presented in Table 2. Figures have been converted from NOK to EUR using an exchange rate (EUR / NOK) of 8.

Table 2: Technical parameters for transmission capacity

	Germany	**UK**
Investment cost	1 348 Mill. EUR	1 247 Mill. EUR
Total annual cost	1 930 Mill. EUR	1 953 Mill. EUR

The second change from Statnett's estimate is a decrease of the net cost of domestic grid reinforcements. Statnett is planning to invest 20 to 30 billion NOK in the transmission grid, independent of new interconnectors, the next decade[8]. Most of these reinforcements

[8] *Investment plan in Norwegian transmission grid* published by Statnett in 2014

are expected to be in place before 2020. Therefore, we assume that there is less need for domestic grid reinforcements for the next cable.

The technical parameters for the cable are assumed to be identical for both cables. We use a capacity of 1400 MW, an availability of 99 % and a lifetime of 40 years. We chose to use the same capacity, availability and lifetime of the cable as Statnett employed in the studies for the NordLink and NSN cable. We assume that capacity, lifetime and availability are constant.

Ramping is defined as the change in power flow from one time unit to the next. A continuous ramping project has been installed on the new interconnector to Denmark, Skagerak 4, to improve the frequency quality on the intra hour imbalance. With continuous ramping, the power flow can change with a rate of 1000 MW/hour. If this project is proven successful, Statnett will implement continuous ramping on all their new interconnectors including NSN and Nordlink [14]. We assume that continuous ramping will be introduced before 2020, and therefore the ramping is set to 1000 MW/hour.

4.3. Market Data

The market data is hourly historical spot prices from 2003 to 2013 from Norway (Nordpool spot), Germany (EPEX) and the UK (APX). The parameters; start revenues, correlation, drift rate and volatility are based on this data. For the Norwegian spot price the area price in the south Norway (NO2) region is chosen as the interconnectors which we consider will be connected to this region.

The spot prices of electricity change from hour to hour due to change in demand. Figure 1 shows the spot prices of electricity in the three countries in an average week in February 2013. The figure illustrates that the Norwegian spot price on average is the lowest, and does not have the same spikes in average price as the two other annual spot prices. One can see that the price spread between Norway and the two other countries are high during the day and small at night.

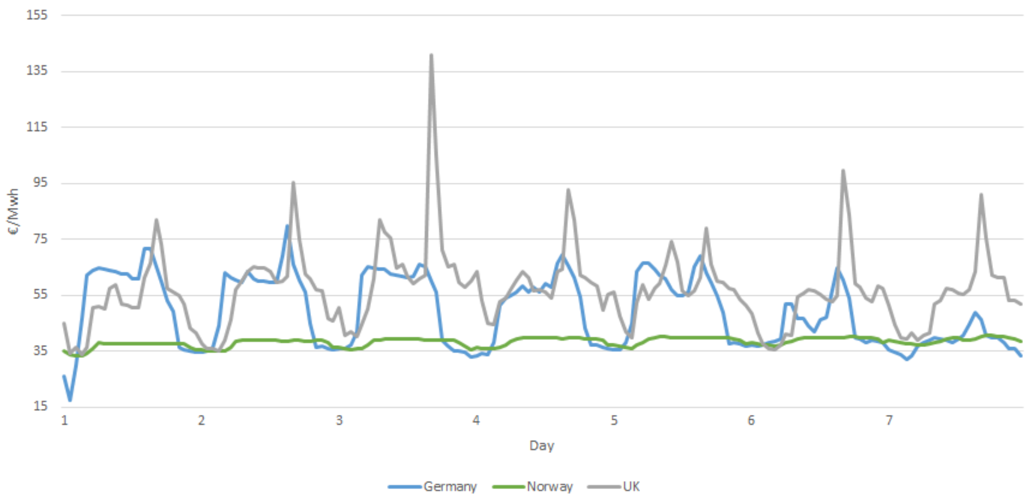


Figure 1: The historical spot price in the three countries in an average week in February 2013

Our findings from the historical data confirm that the Norwegian electricity prices tend to be less volatile then the two others prices. The Norwegian price also experiences less price spikes than the other two. One of the reasons for this is that the Norwegian generation assets can easily and without cost be regulated up and down to meet demand (see Subsection 2). The revenues from an interconnector are based on the price spread between two connected markets. Even though a country might have larger electricity prices than another market, it does not necessarily make it more profitable than the other market. The important parameters are how many hours the prices are different (i.e. the spread option is different from zero) and the absolute price difference between prices in these hours. The historical interconnector revenues are based on market data of the different spot prices, considering ramping and availability. Since 2010, the price spread between the UK and Norway has grown, making it more profitable to invest in the interconnector to UK. Before 2009, the German interconnector was equally profitable.

4.4. A Model for Valuing the Two Factor Investment Option

A transmission line gives the owner the right to transport electricity from one point to another. The value of such a line is the same as the value of the option on the spread between end point prices. Let P_a and P_b be the price of a unit of power at the endpoints, a and b, of the transmission line. Let K_i be the maximum capacity the line can transport at a given time and $K_{i_{RES}}$ denote the capacity allocation in the reserve market. The hourly revenue of the transmission line is therefore given by:

$$R_i = |P_b - P_a|(K_{i_t} - K_{i_{RES}}) + P_{reserve}(K_{i_{RES}}), \quad \text{where} \quad K_i \geq K_{i_{RES}}$$

The capacity, K_i, that can be transported on the line can change form hour to hour due to ramping restrictions. K_i is determined by the present state of the electricity price and the maximum capacity of the cable (K_{max}):

$$K_{i_t} = \begin{cases} Min(K_{max} \text{ or } K_{i_{t-1}} + 1000) & \text{for} \quad P_a > P_b \\ Max\Big(Min(0, K_{i_{t-1}} + 1000), Max(0, K_{i_{t-1}} - 1000)\Big) & \text{for} \quad P_a = P_b \ and \ K_{i_t - i} > 0 \\ Min\Big(Min(0, K_{i_{t-1}} + 1000), Max(0, K_{i_{t-1}} - 1000)\Big) & \text{for} \quad P_a = P_b \ and \ K_{i_t - i} < 0 \\ Max(-K_{max} \text{ or } K_{i_{t-1}} - 1000) & \text{for} \quad P_a < P_b \\ 0 & \text{for} \quad \text{elsewhere} \end{cases} \tag{1}$$

The transmission revenues, R_1 and R_2, are given in annual revenues. We calculate them by summing up the hourly revenues (R_i):

$$R_{annual} = \sum_{i=1}^{Hours\ in\ a\ year} R_i$$

The two potential cable investments have different expected payoffs. The reason for this can partly be explained by different endpoint prices and capacity market design/existence.

We will therefore get two different annual revenues, where R_1 is defined as the revenue of the first cable and R_2 the revenue of the second cable.

For computational tractability, the payoff between the price difference in the Norwegian and German (UK) market, i.e R_1 (R_2) is modelled as a geometric Brownian motion. Our argument for this is two-fold. First, revenues will be non-negative. Second, we are trying to capture the long-term dynamics of the present value of the revenues, so the relevant empirical basis is limited to, e.g. ten observations of annual revenues. In this case, a simple model is preferable. For this paper we assume that the two revenue streams follow two distinct GBM processes:

$$dR_1 = \alpha_1 R_1 dt + \sigma_1 R_1 dz_1, \tag{2}$$

$$dR_2 = \alpha_2 R_2 dt + \sigma_2 R_2 dz_2, \tag{3}$$

where α_1 and α_2 are the instantaneous drift rates, σ_1 and σ_2 are the volatility rates, and dz_1 and dz_2 are the increments of two correlated Wiener processes. All of the parameters are assumed to be known and constant. We impose the following relationship $\delta = \mu - \alpha$, where $\delta > 0$. Further we assume that uncertainty exists, so $\sigma > 0$ and that the investor are risk neutral $\mu = r$. The dependence between the two uncertain variables is described by the instantaneous covariance term, given by:

$$Cov(dR_1, dR_2) = \rho\sigma_1\sigma_2 R_1 R_2 dt, \quad \text{where} \quad \rho \leq 1.$$

We want to find an expression for the option value of the investment decision. Let $F(R_1, R_2)$ be the option value of the best of two mutually exclusive underlying assets. In this case this is two cables. We further assume that the transmission investment can be totally spanned and replicated by other traded assets in the market. Therefore, we obtain the following PDE using a contingent claim analysis:

$$\frac{\partial F}{\partial t} + \frac{1}{2}\sigma_1^2 R_1^2 \frac{\partial^2 F}{\partial^2 R_1} + \frac{1}{2}\sigma_2^2 R_2^2 \frac{\partial^2 F}{\partial^2 R_2} + \rho\sigma_1\sigma_2 R_1 R_2 \frac{\partial^2 F}{\partial R_1 \partial R_2} + \alpha_1 R_1 \frac{\partial F}{\partial R_1} + \alpha_2 R_2 \frac{\partial F}{\partial R_2} - rF = 0 \tag{4}$$

We set out to determine the boundary between investing in one of the two projects and waiting. The following conditions have to apply:

When both asset values are zero, the value of the option to invest is zero.

$$F(0, 0) = 0 \tag{5}$$

When one of the asset values are zero, the value of F is reduced to an American call option, C, on a single underlying asset.

$$F(R_1, 0) = F(R_1) \tag{6}$$

$$F(0, R_2) = F(R_2) \tag{7}$$

Due to the correlation, the variables R_1 and R_2 are not independent. When finding an optimal investment strategy we have to consider the two start revenues in relation to each other. We define $R_1^*(R_2)$ to be the exercise boundary of the first cable as a function of the second cable. Likewise, $R_2^*(R_1)$ is the exercise boundary of the second cable as a function of revenues of the first cable.

It is financially obvious that an option on two assets will always be more valuable than an option on just one of the assets [15]. Therefore $F(R_1, R_2) \geq F(R_1)$ and $F(R1, R_2) \geq F(R_2)$ have to hold. Let C_1 and C_2 be the sum of the initial investment cost of the cable plus the present value of operation and maintenance costs. The costs are assumed to be irreversible. In addition to the hourly spot price revenues, owning a transmission line can entail the owner to additional revenues from a capacity market. We let CM denote the annual revenue for participating in a capacity market given a capacity price (R_k). The following conditions have to apply:

$$F(R_1^*(R_2), R_2) = R_1^* + CM(R_K) - C_1, \quad \text{for } R_1 > R_2. \tag{8a}$$

$$F(R_1, R_2^*(R_1)) = R_2^* + CM(R_K) - C_2, \quad \text{for } R_1 < R_2. \tag{8b}$$

4.5. Numerical Implementation

Due to the complexity of the PDE in Subsection 4.4[9] we must solve the equations numerically. Several researchers have developed numerical techniques for pricing multi-assets options, including Landskroner and Raviv [16], Boyle et al. [17] and Broadie and Detemple [18]. Rubinstein [6] values options with two underlying assets by approximating continuous bivariate normal density functions as a discrete bivariate binomial density. This approach is called "binomial pyramids".

The pyramid is expanding each time step with 2^{i+1} distinct nodes and the total number of nodes in a tree is equal to $(1+N)^2$ at the last time step. Where N is the total number of time steps and i, is referring to a specific time step. The two underlying assets are assumed to have a risk-neutral joint lognormal distribution. The riskless interest rate is used as the discount rate and both underlying assets are expected to appreciate at the same riskless rate.

Rubinstein's (1994) multiplicative bivariate binomial model defines the possible states for the two assets. The first asset return is assumed to be either u or d, with equal probability. The second asset return is dependent on the first assets step and can be in one of for states; A, B, C or D. The time steps are based on the log transformed size of the underlying asset. In our model we are using log transformed revenues ($Y_i = \log(R_i)$) to calculate the time step. The risk neutral approach to option pricing gives us the return on the first asset, u and d, to be defined by:

$$u = e^{\mu_1 h + \sigma_1 \sqrt{h}} \text{ and } d = e^{\mu_1 h + \sigma_1 \sqrt{h}}, \text{ where } \; h \equiv t/n. \tag{9}$$

[9] The analytical approach of guessing a solution does not work in our case, since we lack an initial guess which can solve the PDE on general form.

Here $\mu_i = (r - \delta_i) - \frac{1}{2}\sigma_i^2$, where μ_i is the logarithmic mean of the underlying assets. The lifetime of the option $[0, T]$ is divided into n equal time intervals of length h. The risk free rate is r and δ_i continous dividend yield of the underlying asset.

When we invest in an asset we do not only get the revenues from that year, but all the revenues over the lifetime of the asset. We therefore need to calculate the expected present value of the revenue stream at each node. If $R_i(t)$ is the revenue at a specific time with start value R_i, the expected present value of the revenues, from time t to the lifetime of the cable, T_2, can be calculated knowing that the underlying asset follows a geometric Brownian motion:

$$E[R_i(t)] = R_i\left(\frac{1 - e^{-(r-\alpha)T_2}}{r - \alpha}\right), \text{for } t \in [0, T] \tag{10}$$

The n time intervals are denoted by i, where $i = 0, 1, ..., n$. The underlying revenue of asset 1 at each node is set equal to $R_1 u^j d^{i-j}$, where $j = 0, 1, ..., i$ is the number of up movements of underlying asset 1. For our cable, the revenues therefore are:

$$R_{1total}(i, j) = R_1 u^j d^{i-j}\left(\frac{1 - e^{-(r-\alpha_1)T}}{r - \alpha_1}\right) \tag{11}$$

If the return of the first asset is u, the return of the second asset is A or B with equal probability, depending on the correlation, ρ, between the two assets. Then if the return of the first asset is d, the return of the second asset is C or D. If the first move is (u, A) the second move can be (u, A), (u, B), (d, C) or (d, D). Multiplying these two moves together, the total return over the first two moves is either (u^2, A^2), (u^2, AB), (ud, AC), or (ud, AD), with equal probability $\frac{1}{4} \times \frac{1}{4} = \frac{1}{16}$. The mathematical formulation for the four possible steps are defined by:

$$\begin{aligned}
A &= e^{\mu_2 h + \sigma_2\sqrt{h}[\rho + \sqrt{1-\rho^2}]} \\
B &= e^{\mu_2 h + \sigma_2\sqrt{h}[\rho - \sqrt{1-\rho^2}]} \\
C &= e^{\mu_2 h - \sigma_2\sqrt{h}[\rho - \sqrt{1-\rho^2}]} \\
D &= e^{\mu_2 h - \sigma_2\sqrt{h}[\rho + \sqrt{1-\rho^2}]}
\end{aligned} \tag{12}$$

These definitions of (u, d) and (A, B, C, D) can be used to construct the appropriate size of the moves in a square binomial pyramid. To build the lattice for each state variable recombine the condition $AD = BC$ is imposed [16]. Starting at the end of the pyramid, the value of the option can be estimated at each node. Working backwards through the pyramid, 4 nodes are discounted into 1 at each move, using the same probability for each node.

For any node (i, j, k) the lattice evolves to four nodes, $(i+1, R_1u, R_2A)$, $(i+1, R_1u, R_2B)$, $(i + 1, R_1d, R_2C)$ and $(i + 1, R_1d, R_2D)$. Where R_2A, R_2B, R_2C and R_2D are the values of the underlying asset 2 in the different nodes. The value of asset 2 in each node, at any time period i and with j up moves of asset 1, is set equal to:

$$R_2(i,j,k) = R_2 e^{\mu_2 ih + \sigma_2\sqrt{h}\left[\rho(2j-i) + \sqrt{1-\rho^2}\times(2k-i)\right]}, \text{ where } k = 0,1,....,i \tag{13}$$

where R_2 is the start value of asset 2, μ_2 is the logarithmic means of the underlying assets 2 and ρ is the correlation between the two assets. The total value of the revenue stream for asset 2 with a lifespan of T_2 years is:

$$R_{2total}(i,j,k) = R_2 e^{\mu_2 ih + \sigma_2\sqrt{h}\left[\rho(2j-i) + \sqrt{1-\rho^2}\times(2k-i)\right]}\left(\frac{1-e^{-(r-\alpha_2)T_2}}{r-\alpha_2}\right) \tag{14}$$

The assets can potentially participate in capacity markets. Therefore, there is a possibility of receiving a revenue stream for participation in such a market. We define CM_i to be the total revenues received by participating in a capacity market. cm_i is the yearly revenues received from the government for participating in a capacity market. CM_i is defined by the sum of all capacity revenues received over the lifetime of the cable:

$$CM_i = \sum_{i=1}^{years} cm_i \tag{15}$$

The intrinsic value is the maximum value of the two assets minus the costs. For our call option, the intrinsic value of best of asset R_1 and R_2 is given by:

$$F(R_1, R_2) = Max(0, Max(R_{1_{total}} + CM_1 - C_1, R_{2_{total}} + CM_2 - C_2)) \tag{16}$$

where $R_{1_{total}}$ and $R_{2_{total}}$ total are the total revenue received by the cable investment over the lifetime of the investment. CM_1 and CM_2 is the revenues from participating in capacity markets, and C_1 and C_2 the total investment and maintenance cost of the investment. When the values of the two assets are given at any node, the value of the option at each node can be calculated by starting at maturity where the value is known with certainty and working backwards by discounting four nodes into one node at each move. The value of the investment at maturity, $i = T$, is:

$$F_{T,j,k} = Max\Big(0, Max(R_{1totalT,j,k} + CM_1 - C_1, R_{2totalT,j,k} + CM_2 - C_2)\Big) \tag{17}$$

At maturity there is no possibility of waiting, which means that the option value at maturity is equal to the maximum of zero and the intrinsic value. The value can never be lower than zero due to the fixed boundary conditions.

The value of the option is given by $F(0)$, which is the value of the option in year 0. It is found by working backwards through the pyramid and finding the option value at every node. This is done by taking the maximum of the intrinsic value and the value of waiting. If the option has a positive value in year 0, the project has a potential for making a profit. The option value at every node is :

$$\begin{aligned} F_{i,j,k} = Max\Big(&0.25e^{-rh}(F_{i+1,j,k} + F_{i+1,j,k+1} + F_{i+1,j+1,k} + F_{i+1,j+1,k+1}), Max(R_{1totali,j,k} \\ &+ CM_1 - C_1, R_{2totali,j,k} + CM_2 - C_2)\Big) \end{aligned} \tag{18}$$

The first argument in the outer bracket is the value of waiting while the second argument is the value of investing. By using this equation we find the value of the option.

5. Application

5.1. Estimation of Parameters

The parameters are estimated based on historical market data, technical reports published by Statnett and other public sources of information. The method and assumptions applied to estimate the parameters are given in the following paragraphs.

The annual revenues are a function of the difference in the electricity prices between the interconnected regions and the technical parameters of the cable. The intraday characteristics of the electricity price are captured by modelling the electricity price with a time resolution of one hour. The difference in the electricity prices between the interconnected regions were found by using the Phelix price from the European Power Exchange (EPEX) SPOT, the UKPX price on the Amsterdam Power Exchange (APX) and NO2 (south norway) price from Nordpool. We have used data from 2003 to 2013 to calculate the correlation between the two revenue streams, ρ, and discounted the 2013 revenues with the risk adjusted rate to get the revenues for the two cables in 2020 (year 0), R_1 and R_2, respectively. The risk adjusted rate is chosen based on NOU 2012:16 (Norway's public reports). NOU 2012:16 recommends to use a risk adjusted rate of 4 % for an economic analysis of a public investment with a lifetime of 40 years[10].

The participants in a capacity market are committed to deliver energy when needed or they will face penalties. This fear of not being able to meet their obligations affects the amount of capacity the interconnector owner bid in the auction. The price difference between the two regions that are interconnected determines the direction of the power flow. This means that Statnett cannot guarantee the capacity they bid in the auction, if the price in the UK is higher than the price in Norway at that time. We therefore assume Statnett will bid only 900 MW of the cables capacity in the auctions to reduce the risk of facing penalties. The total revenue from the capacity market in UK, CM_2, is calculated based on a capacity price of £30 kW/year.

The expected growth rate (α) for the cable revenues has a positive value. They were calculated based on the following inflation values: UK 2.56 percent, Germany 1.51 percent, Norway 2.13 percent[11]. The growth rate (α) is set to be half the inflation. Borovkova et al. [19] argued that the assumption that a commodity, in our case the cable revenues, will experience a positive growth forever is unrealistic. If the growth rate is set higher than inflation it means that the revenues will grow to an infinite size over infinite time. The Ragnar Frisch Centre for Economic Research found that the electricity price difference between Norway and Germany will increase to approximately 10 €/MWh in 2030, which

[10] *Samfunnskonomiske analyser* published by the Ministry of Finance in Norway in 2012 `http://www.regjeringen.no/nb/dep/fin/dok/nouer/2012/nou-2012-16/6/7.html?id=700896`

[11] Source: Inflation.eu

implies a positive growth rate of the cable revenues[12]. We therefore choose to set the expected growth rates between zero and the inflation rate in the two countries. This is consistent with Fleten et al. [4] which also chose a positive growth rate on the cable revenues between Germany and Norway.

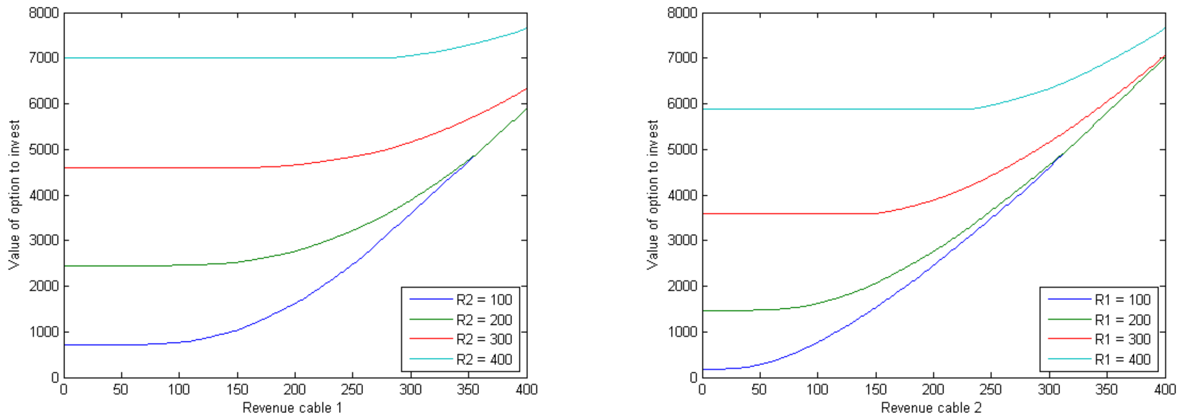
The volatility parameters of the revenue processes have been set based on i) analysis of the time series of hypothetical revenues 2003–2013, and ii) on a qualitative judgement of the relevant uncertainties that affect future price spreads. A GARCH analysis reveals that historical revenues have about the same level of variance. However, our discussions in Section 3 on the policy related issues concluded that revenues of the cable to Germany are exposed to higher policy related uncertainty than revenues of the cable to the UK, and therefore have higher volatility. The main reason is that the UK has implemented a capacity market and set a floor on the CO_2 price, while Germany is debating how to ensure security of supply and has not taken any measures to (unilaterally) increase the CO_2 emission price.

Based on these findings, the analysis uses the following parameters given in Table 3. The estimation of the investments costs, C_1 and C_2, are described in Subsection 4.2.

Table 3: Parameter for real option valuation of the investment project

Notation	Parameter	Value
R_1	Revenue from cable 1 in year 0	380 Mill. EUR
R_2	Revenue from cable 2 in year 0	176 Mill. EUR
CM_2	Revenue from capacity market project 1	0 Mill. EUR
CM_2	Revenue from capacity market project 2	914 Mill. EUR
C_1	Investment cost project 1	3280 Mill. EUR
C_2	Investment cost project 2	3200 Mill. EUR
r	Risk-free rate of return	4 %
α_{R_1}	Drift rate of revenue 1	0.9 %
α_{R_2}	Drift rate of revenue 2	1.2 %
σ_{R_1}	Volatility of revenue 1	17 %
σ_{R_2}	Volatility of revenue 2	14 %
ρ	Correlation between revenue 1 and 2	0.7
δ_{R_1}	Dividend of revenue 1	3.1 %
δ_{R_2}	Dividend of revenue 2	2.8 %
T	Lifetime of the option	10 years
T_2	Lifetime of cable	40 years
ex_1	Exchange rate (£/ €)	1.1
ex_2	Exchange rate (€/ NOK)	8

[12] *Simulations using the LIBEMOD model within the CELECT project* report published by Ragnar Frisch Centre for Economic Research in 2009



(a) R_1 = constant and R_2 changing. (b) R_2 = constant and R_1 changing.

Figure 2: The Value of the option to invest when one R is kept constant and the other is changing

5.2. Results

We have evaluated the real option of investing in one of two mutually exclusive transmission projects. The value of the option to invest is 6 531 million Euro. The value of the investment option with different start revenues is illustrated in Figure 2, keeping one starting revenue fixed, we change the value of the other across a relevant range. In both Figures 2 a and b, the value of the option increases with higher starting values. The reason for this is that the costs are held constant and revenues increases. This leads to a higher expected value and therefore a higher option value. Kay et al. [20] observed the same result when they valued Bermudan options on multiple assets.

The option has zero value when both start revenues are close to zero (see Figure 2b). In this case, the expected revenues from the cable investment are so small that none of the projects would ever break even. In other words, the initial investment cost would be higher than the potential gain from any of the two expected revenue streams. Before the start revenues reach the threshold value where the investment cost and the potential gain are equal, the option value is equal to zero.

Figure 2 also illustrates that the option has a positive value when one of the start revenues is equal to zero. In the mathematical model (see Equation (6) and (7)), we presented the boundary condition that the value of the option can be positive even though one of the start revenues is equal to zero. As the figure here shows, this boundary condition is satisfied for both cables. The option value is also increasing, when the start revenue of the cable that has an positive option value increases.

The value of our investment option is higher than both of the individual projects Statnett estimated [14]. In Statnett's analysis, they viewed the investment decision as a net present value of a single project. We analyse the investment decision as a real option analysis of two mutually exclusive projects. This increases the option value.

Table 4 shows that the value of the option increases with higher start revenues for project 1. It illustrates that the option to invest depends on both projects after the start revenue

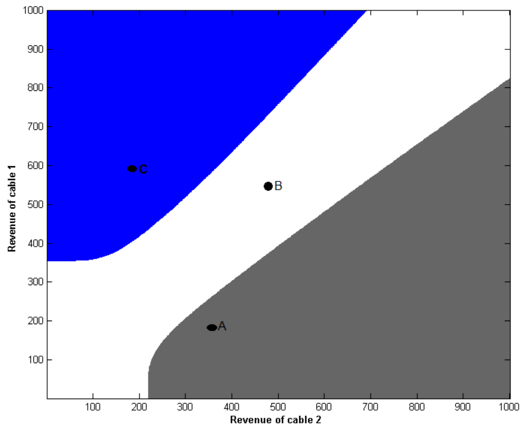
Table 4: Value of investment option for different values of R_1

Startprice	Option value
$R_1 = 0, \quad R_2 = 380$	6 531 Mill. EUR
$R_1 = 176, R_2 = 380$	6 531 Mill. EUR
$R_1 = 300, R_2 = 380$	6 586 Mill. EUR
$R_1 = 400, R_2 = 380$	7 389 Mill. EUR

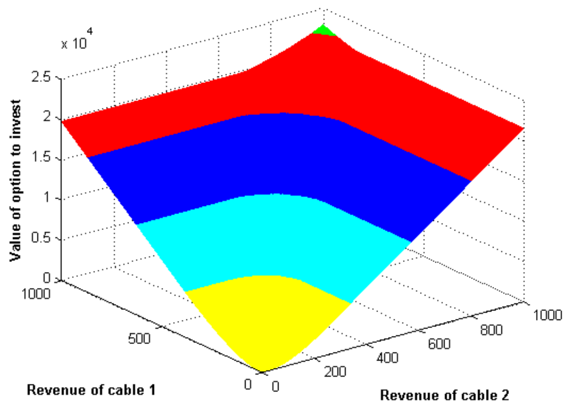
hits a threshold limit (Rt). Here, the threshold limit is the value of R_1 that makes it optimal to wait instead of immediately investing in project 2. From the table it is possible to see that it is between 176 and 300, because this is where the option value starts to change with R_1. This confirms Geltner et al. [21] results, that an option on mutually exclusive projects has a higher value compared to the situation of a net present value approach of two independent projects. The reason for this is that the investment option has flexibility of choosing which project to invest in at what time. This flexibility has a value when the start revenues has hit a threshold value (Rt).

5.2.1. The Effect of Time

Figure 3a shows a two dimensional early exercise boundary for non-negative values of R_1 and R_2. The figure consists of three different regions, which indicates the optimal investment strategy between waiting and exercising the option. The blue region illustrates where it is optimal to immediately invest in the cable to Germany and the grey region is where it is optimal to immediately invest in the cable to UK. The white region is where it is optimal to wait. If we are in the waiting region we will invest the first time the revenue hits either of the investment thresholds.



(a) Exercise boundary



(b) Two Assets call option Exercise boundary

Figure 3: The exercise boundary of the option on the two cable investment projects.

Point A in Figure 3a, which represent $R_1 = 176$ and $R_2 = 380$, is located in the grey region. The location of the point tells us that the optimal investment strategy is to invest in the cable to UK in 2020. To change this optimal investment strategy, the intersection point between the two revenues has to be in another region. Point C illustrates a situation where it would be optimal to build the cable to Germany. From the figure one can see that the starting values of the revenue R_1 has to be above 350 million euro to consider building the cable to Germany. In point B the optimal investment strategy would be to wait till the revenues hit one of the two threshold boundaries.

When both R_1 and R_2 get close to zero, it is optimal to wait. The intuition behind the shape of the curve at these values can be developed as follows. When R goes to zero, the value of the option decreases. When the total value of the revenues of the projects is smaller than the investment costs, it would never be optimal to exercise the option. This is why we observe the waiting region close to origin. The waiting region increases as both revenues goes to infinity. Geltner et al. [21] got the same shape for their exercise region. The reason behind an increased waiting region as R goes to infinity is that both projects are so in the money that both would be optimal. In such a situation it is optimal to wait, since the value of waiting is more valuable than the intrinsic value of either of the two projects. By applying financial theory, we would argue that in such a situation you can invest in either of the two projects because either way the intrinsic value is infinitely large.

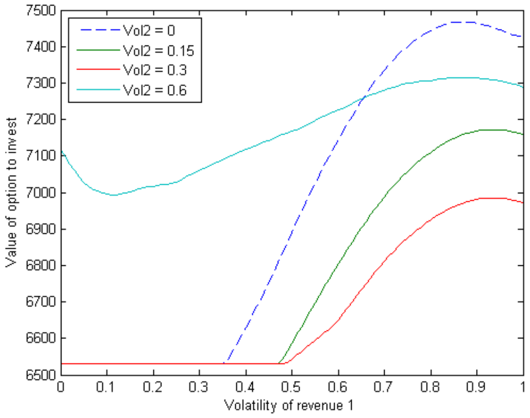
Figure 3b shows the three dimensional exercise boundary obtained for the investment option. The region above the surface is the waiting region and the area below the surface is the immediate exercise region. The shape is consistent with what we would expect, also for larger values of revenue stream. The surface continues linearly with no additional curvature other than located around the strike price. Kay et al. [20] obtained the same shape for their multi assets call option. For small values of yearly revenues (R), it is never be optimal to exercise the option. This is illustrated by the curved surface having a value equal to zero.

5.2.2. The Effect of Volatility

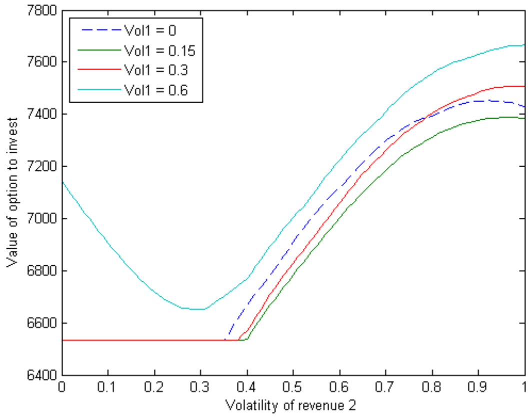
Dixit and Pindyck [15] observe that the option value and investment threshold increase with volatility for a case with one asset. Geltner et al. [21] observed the same effect when looking at a two-asset case, when increasing the volatility of one of the assets and keeping the other constant. In our case, this is true to a certain extent. This can be observed by looking at Figure 4a and 4b, where the value of the option increases with volatility for intermediate values of volatility (on the x-axis) for the dashed, green and red line. The exception is for the light blue line in both graphs, that first decreases and then increases with volatility.

In Figure 4a, the value of the red, green and blue lines are constant with respect to the change in σ_1 until they reach a threshold value of σ_1. The value of the option is constant because we exercise the option immediately. This means that the volatility does not affect the option value. When we reach the threshold value of σ_1, it is optimal to wait so the value of the option depends on σ_1. The light blue line is not constant as σ_1 changes, because it is optimal to wait for all values of σ_1.

Figure 4a illustrates that the entire curve shifts downward when the σ_2 is changed from 0 to 0.15 to 0.3. It then shifts upwards when σ_2 is increased to 0.6. The same is the case for Figure 4b, except that it starts to shift upwards sooner. This is not consistent with the



(a) σ_2 = constant and σ_1 changing.



(b) σ_1 = constant and σ_2 changing.

Figure 4: The Value of the option to invest when one σ is kept constant and the other is changing

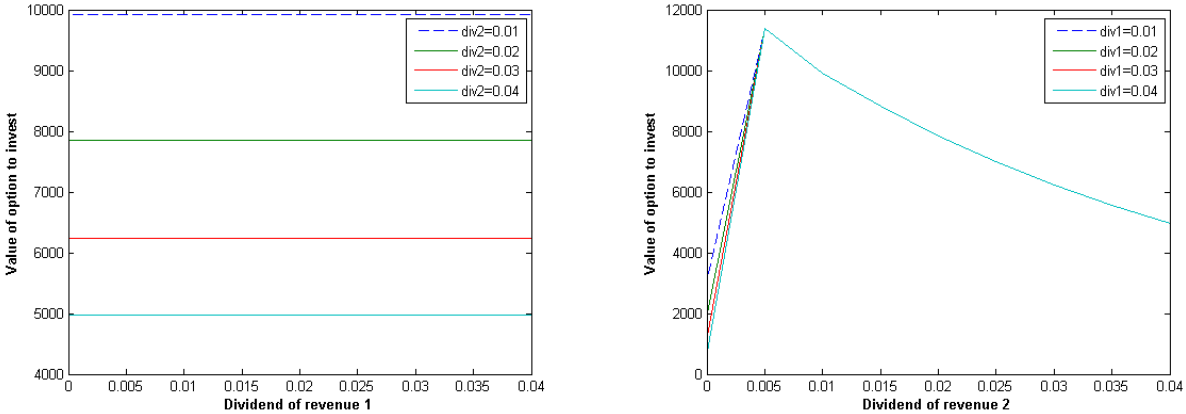
characteristic feature of the Black-Scholes theory, that the sensitivity of the option price with respect to the underlying assets volatility is always positive, i.e. the option value can only increase if the volatility increases. It is clear from the figures that the option value does not necessarily increase with volatility for basket options, both from the downward shift of the curves and from the light blue line that first decreases and then increases with the volatility. Permana et al. [22] argued that this does not contradict the Black-Scholes theory. They reasoned that by increasing one of the volatilities it can lead to a lower variability of the spread, which ultimately drives down the option value. This refers to a spread option, but our results show that it also applies for other basket options.

By increasing both volatilites, the waiting region is extended. Geltner et al. [21] observed the same effect, that when both volatilities increase both exercise regions are reduced. This makes sense, since a greater volatility implies a greater potential gain from waiting to see which of the projects that is most profitable.

If we keep the volatility of one of the cables constant and increase the other, the exercise regions for both cables shrink, though to a lesser extent for the cable with constant volatility. Geltner et al. [21] noticed the same. It makes sense that the change in volatility of one cable also affects the other cable. When we increase the volatility of cable 1, it implies a greater gain from waiting to see if cable 1 become sufficiently more valuable than cable 2. This reduces the exercise region of cable 2.

5.2.3. The Effect of Dividend Yield

In real option theory a high dividend rate increases the cost of waiting. The reason for this is that by choosing not to invest immediately the option holder foregoes potential revenue that it would have received by investing immediately. The size of the forgone revenue is determined by the dividend rate. The only time the investor is willing to forego revenues, is when the value of waiting is higher than the loss of revenues. The dividend therefore gives an incentive to invest earlier. It increases the cost of waiting for more information and



(a) δ_2 = constant and δ_1 changing. (b) δ_1 = constant and δ_2 changing.

Figure 5: The Value of the option to invest when one σ is kept constant and the other is changing

thereby reduces the start revenues of R_1 and R_2 which makes it optimal to invest. Dixit and Pindyck [15] also showed that a high dividend rate reduces the value of the option to invest. In Figure 5 we keep one of the dividend rates constant and change the other, and see how this affects the value of the option.

Figure 5b shows that the value of the option to invest decreases with the dividend rate. If the dividend rate (δ) would have been zero, a call option on an investment would always be held to maturity and never exercised prematurely [15]. The reason for this is that there is no cost of keeping the option alive. This is likely the reason for the odd shape in Figure 5b, because the dividend rate is so close to zero. This causes the option value to increase and at the same time the dividend increases in the interval ($0 < \delta_2 < 0.05$). We therefore impose a constraint that δ_1 and δ_2 has to be greater than 0.005 %.

In the case where $\delta \to \infty$, the value of the option will be very small because the opportunity cost of waiting is large. In these cases, the only option is to invest now or never, and the standard net present value rule applies. The fact that the value goes to zero as the dividend increases is the reason why the curve in Figure 5b decreased for larger values of δ_2.

Another important finding of the two asset case is illustrated in Figure 5a. When one option is highly in the money, project 2, the dividend rate of project 1 has no effect on the option value. The value of the option does only depend on the dividend rate for project 2. This is illustrated with lower option value as the divided rates increases. The reason for this is that the optimal investment strategy is to exercise immediately in project 2, and the intrinsic value of project 2 is independent of project 1's dividend rate.

6. Sensitivity Analyses

We performed a sensitivity analysis by estimating the effect the parameters have on the investment decision. In this section, the different scenarios will be explained in Subsection 6.1. In Subsection 6.2 we analyse the effect of the parameters changes on the option value and optimal investment strategy.

6.1. Scenarios - The Effect of Parameter Changes

The uncertainties in the electricity market are many and can change overnight. In this paper we have chosen to focus on long-term policy uncertainty that will affect the revenues from the cable in the long run (see Section 3). We have considered the uncertainties by taking them into account when deciding the parameters of the revenue streams (see Subsection 5.1). In this section we look directly at the two main policy uncertainties by creating four future scenarios, where we change the parameters. The scenarios have either low or high CO_2 price and in two of the scenarios a capacity market is implemented in Germany. We have chosen to use four scenarios: “Current Situation”, “Low Carbon Society”, “Green Growth” and “Stagnation”.

6.1.1. Scenario 1: Current Situation

The “Current Situation” scenario is based on the current market data and present policy schemes. In this scenario, we assume that Germany has not implemented a capacity market. The energy mix in Germany and the UK are different, with a large portion of gas in the UK electricity production. The gas plants are the price setter in UK, while coal determines the price in the Germany. The price of carbon emission is low and it has little effect on the settlement price in the electricity market (see Subsection 3.1).

In this scenario Germany has a growing portion of renewable energy in its energy mix and there are uncertainties regarding how the authorities will address the issue of security of supply. The policy uncertainties in the German market are therefore assumed to be higher than the UK market (see Subsection 5.1).

6.1.2. Scenario 2: Low Carbon Society

In the scenario “Low Carbon Society” a tightening of the EU ETS is causing a green shift in consumption and generation, without impacting other policy schemes. The price of carbon is increasing, resulting in increasing electricity prices, as the cost of pollution is put on consumers (see Subsection 3.1). As mentioned in Subsection 3.1, an increase in the CO_2 price will most likely result in increased spread between the revenue streams of the cables, because the price will increase more in Germany and the UK than in Norway. When the CO_2 price continues to rise this will result in a higher drift rate for both cables. We believe the increase in the drift rate will be higher for the cable to Germany based on coal being the price setter in the German market, and gas being the price setter in the UK market.

The policy uncertainties are reduced compared to scenario “Current Situation” in both countries due to the increase in the price of carbon. This gives an investor a clear signal that the EU is willing to increase cost of carbon to meet their EU2050 targets. However, there is still uncertainty regarding security of supply in Germany.

6.1.3. Scenario 3: Green Growth

In the scenario “Green Growth” the high share of renewable generation is forcing Germany to implement a capacity market to ensure security of supply and the CO_2 price is increasing. The increasing CO_2 price has a greater effect on the electricity price than the price reduction from the increased share of renewables, resulting in a net increase in electricity prices. This change is higher than the change in the Norwegian prices. The electricity prices in UK are also increasing more than the Norwegian prices due to the increasing carbon price. As in the “Low carbon society” scenario, the drift rate is higher for Germany than for UK (see Subsection 6.1.2).

In this scenario market participants know how the authorities will handle the problem associated with security of supply and global warming. Therefore, the policy uncertainty is reduced in both countries. One of the main arguments why the cable to Germany has a higher volatility than the one to UK was the possible introduction of a capacity market in Germany (see Subsection 5.1). Since Germany has chosen to introduce a capacity market in this scenario, the volatility in the German market decreases. However, the volatility in Germany will still be higher than the volatility of the UK due to the uncertainty in the feed-in-tariff and how this will effect the portion of renewables in the energy mix (see Subsection 2).

6.1.4. Scenario 4: Stagnation

In future scenario “Stagnation”, a high share of renewables has forced Germany to implement a capacity market, as in the “Green Growth” scenario (see Subsection 6.1.3). Implementation of the capacity market results in lower uncertainty in the market. The price of carbon emission is low, so it has small effect on the electricity price and the merit order curve. The EU ETS scheme is still struggling with the problem of efficiently reducing the cap due to a surplus of certificates. We assume that the EU has not managed to meet their EU2020 targets, and there are uncertainties on what the future carbon emission scheme will look like. Investors are therefore postponing investments in generation, which makes the electricity price uncertain.

The only change compared to the ”Current situation” scenario, is the reduction in the volatility of the cable to Germany, due to the introduction of the capacity market. However, the volatility is larger than in scenario ”Green Growth”, because the market participants do not know how the governments will tackle the problem of global warming.

6.2. Result of the Valuation with Different Scenarios

The parameters for the different scenarios used in the rest of this analysis is given in Table 5. The volatilities (σ), dividend rates (δ), growth rates (α) and revenues from the capacity markets (CM) change in the different scenarios. The impact of scenarios on the investment decision are analysed in this subsection. The value of the option to invest for each scenario is given in Table 6.

From Table 6 “Low Carbon Society” and “Green Growth” are the most profitable. This is because they have higher growth rates (lower dividend rates) compared to the two others. As the dividend rate is lowered the opportunity cost of delaying investment is decreasing and therefore the option value of waiting is increasing.

The option values of the “Current Situation” and “Stagnation” scenarios are equal when using the base case starting revenues $R_1 = 176$ and $R_2 = 380$. The same is the case for “Low

Table 5: Parameters for the real options valuation with different scenarios

Parameter	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Unit
C_1	0	0	588	588	Mill.EUR
α_{R_1}	0.9	2.5	2.5	0.9	%
α_{R_2}	1.2	1.5	1.5	1.2	%
σ_{R_1}	30	25	20	23	%
σ_{R_2}	20	15	15	20	%
δ_1	3.1	1.5	1.5	3.1	%
δ_2	2.8	2.5	2.5	2.8	%

Table 6: Value of investment option with different start revenues (million €)

Start Revenues	Current Sit.	Low Carbon Soc.	Green Growth	Stagnation
$R_1 = 176$, $R_2 = 380$	6 531 mill.	6 996 mill.	6 996 mill.	6 531 mill.
$R_1 = 0$, $R_2 = 380$	6 531 mill.	6 996 mill.	6 996 mill.	6 531 mill.
$R_1 = 380, R_2 = 176$	5 478 mill.	8 210 mill.	8 718 mill.	6 019 mill.
$R_1 = 200, R_2 = 200$	2 798 mill.	3 801 mill.	3 821 mill	2 728 mill
$R_1 = 400, R_2 = 400$	7 694 mill.	9 779 mill.	9 700 mill	7 507 mill

Carbon Society" and "Green Growth", even though the volatility are different. The reason for this is that the option value is based on the tradeoff between immediately exercising and waiting. When the optimal decision is to invest immediately, the volatility has no impact on value. The optimal investment strategy is therefore to immediately exercise the option and build the cable to UK.

The option values to invest do not change due to a capacity market in Germany i.e. the value is independent of whether Germany has a capacity market or not. The reason for this is that we consider a mutually exclusive project, where one of the projects is more in the money than the other. The additional cash flows in one project (i.e. implementation of the capacity market in Germany), in this scenrio do not change the value of the option because they are not large enough to surpass or get close to the profitability of the other project. However, if we instead reduced the revenues from the capacity market in the UK, the option value would decrease.

The start revenues are an important factor determining the value of the option. Table 6 shows the value of the option to invest given various start revenues for project 1 and project 2 (R_1 and R_2). The first row of the table contains the base revenues used throughout this paper. By looking at the table, one can see that lowered start revenue results in a lower option value. When the start revenues are doubled (i.e. changed from 200 to 400 mill euro) the option value almost triples its value. This result leads to the conclusion that there is no linear relationship between the option price and the start revenue.

In this sensitivity analysis we have chosen to model a higher CO_2 price as an increase in revenues. When the revenue increases it will cause the option value to increase. The CO_2 price and option value should therefore have a positive correlation. Further, if investors expect that the CO_2 price will increase it will create an incentive for waiting instead of immediately exercising the option. This can be illustrated by considering the scenario "Low Carbon Society" with increased yearly revenues. If R_1 and R_2 would increase to 250 and 400 mill. €/year, the optimal strategy would be to wait (see Figure 6b).

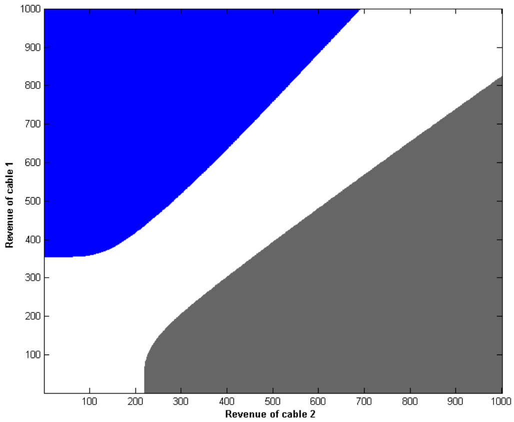
The option values obtained by changing start revenues also shows that when the difference between the start revenues reaches a certain limit, the value of the option only depends on one of the projects. In these situations, the effect of the other project is neglectable since the value of this project is significantly less than the value of the other project. This explains why the option value does not decreases when the start revenues of R_1 goes from 176 to 0 (see Table 6).

The effect of the capacity market on the option value can be analysed by comparing the option values of the "Current Situation" when switching the start revenues of the two projects. Table 6 shows that the option value decreases, even though the start values are the same, just switched. In this situation the optimal investment strategy would be to wait (see Figure 3a). The reason for the drop in option value is caused by the effect that the capacity market only adds an extra value to the UK investment projects. When this project gets less in the money than the German project, the option value for holding both projects decreases since the German market does not have any added revenue from a capacity market.

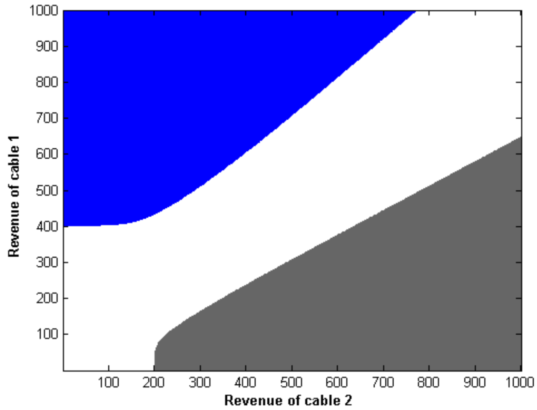
The timing of investment is also an important factor when determining the value of an option. From the "Current Scenario", which is the same case as we analysed in Section 5, we saw that the option value was equal to the value of immediately exercising the option. Figure 6 shows the exercise boundaries for the four scenarios. The blue and grey colors regions illustrate where it is optimal to immediately invest in project 1 and project 2. The white region is the waiting region i.e. the region where it is optimal to delay the investment.

For all scenarios in Figure 6, given the revenues from the cable in year 2020 (see Table 3), it will always be optimal to invest in the cable to UK in year 2020. It is never optimal to wait for more information, because the dividends forgone by waiting are higher than what we gain from waiting. However, the start revenue for UK is based on revenues from 2013. This year, the revenues were high compared to the rest of the years in the data set. The reason for this was a high gas price and that the inflow to the Norwegian hydro system was large, which resulted in an increased spread between the electricity prices in the two countries. If the confidence interval for the start revenues is set to 80 %, it would not be optimal to immediately exercise in all scenarios, i.e. for scenario "Current Situation" and "Low Carbon Society" it would now be optimal to wait.

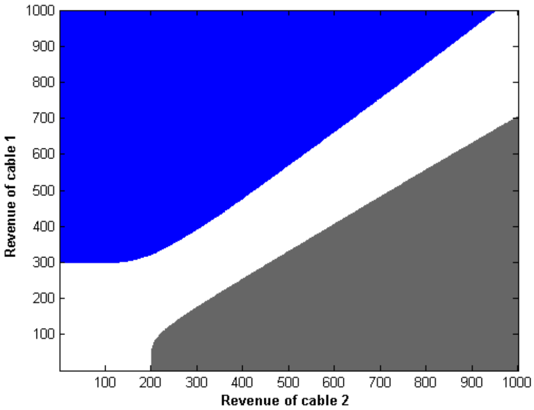
From "Current Situation" to "Low Carbon Society", the drift rate increases while the volatility decreases. A decrease in volatility makes it less valuable to wait, so one would expect that the waiting region decreased [23]. The opposite is expected when the drift rate increases, because it is possible to gain more from waiting with the higher expected growth rate and with the decreased cost of waiting you are also more willing to wait [21]. From Figure 6a to b, we observe that the waiting region increases. However, one can observe that the blue exercise region increases and the grey decreases. One can observe that the significantly higher change in drift rate for cable 1 compared to cable 2 decreases the exercise region more for cable 2 than cable 1. This shows that an increase in drift rate of one asset



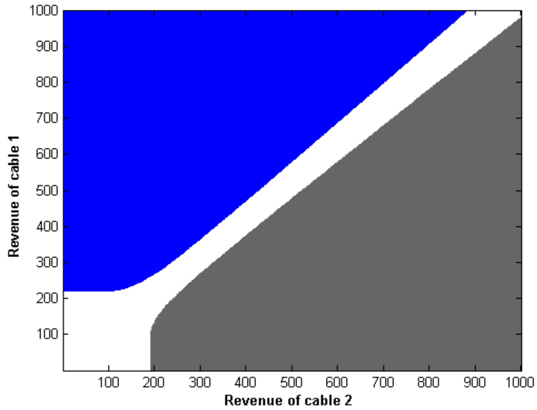
(a) Scenario 1: Current Situation



(b) Scenario 2: Low Carbon Society



(c) Scenario 3: Green Growth



(d) Scenario 4: Stagnation

Figure 6: Exercise boundaries for the scenarios

has a bigger impact on the waiting region of the other asset than its own waiting region. In other words, we are now more willing to wait and see if the revenue of cable 1 increases compared to those of cable 2.

The parameters of "Green Growth" differs from those in the "Low Carbon Society" scenario, only by lower volatility and the launch of a capacity market in Germany (see Subsection 6.1.2 and 6.1.3). From Figure 6 b to c, we observe that the waiting region has shrunk, and that both exercise regions have increased. Though, the blue region has increased more than the grey. This was anticipated due to the decrease in uncertainty of cable 1, that will affect both regions, but to a greater extent the blue region (see Subsection 5.2.2). The intuition behind this is that the investment decision is less risky, and it would give an incentive to invest in one of the two projects earlier compared to a case with higher volatility. Also, the added revenue from the capacity market will make us more willing to invest in cable 1.

The effect of changing volatility (σ) can also be illustrated by comparing the "Current Situation" scenario with "Stagnation". From "Current Situation" to "Stagnation" (see Figure 6 a and d) the only difference is the decreased volatility of cable 2 and the introduction of a capacity market in market 1 (see Subsection 6.1.1 and 6.1.4). What can be observed is that the waiting region is significantly reduced and that the first possible start value for exercise is reduced for both cables, though, significantly more for cable 1. Figure 6d also shows that the decrease in volatility has a larger impact on the exercise region than that of the capacity market. The financial implication of these findings are that market participants will experience less uncertainty and can gain only a small value of waiting for more information. This causes the waiting region to decrease, making it more attractive for investors to invest early (see Subsection 5.2.2).

We have also tried to remove the capacity market in the UK by setting $CM_2 = 0$, and it is still optimal to build the cable to UK in 2020. By including the capacity market in the UK, the option to invest in cable 2 only gets further in the money. This also results in increased start revenue for the interconnector to Germany, causing the waiting region to increase. What this result implies is that the effect of a capacity market on the investment decision depends on the difference in value between the two mutually exclusive projects. We have also seen that if one project is more profitable than the other, (i.e. it would never be optimal to invest in the other) an introduction of a capacity market in the less profitable market has little impact on the option value. This is the same result as in Table 6. From this we conclude that a capacity market alone will have no impact on which cable the investor chooses to invest in, given that the value gained from participating in this market is small compared to the total value received by the annual revenue streams. The capacity market will only affect how valuable it is to invest in the chosen cable.

7. Conclusion

This paper analyses the option to invest in one to two mutually exclusive interconnectors, by using real option valuation. The investment alternatives under consideration are an interconnector from Norway to either Germany or the UK. The real option approach considers both the timing and location of the investment. The timing of the investment is extensively covered in the literature. However, the flexibility of choosing between different locations as mutually exclusive projects has not been considered in any papers of our knowledge. When considering location we argue the importance of looking at the differences in the policy schemes between the two locations. In this paper we consider the risk from the EU ETS and a possible introduction of capacity markets.

This paper contributes to the real option literature by considering investments in mutually exclusive transmission assets. To this day, there are few research papers considering investments in electrical transmission assets. One of the explanations is that transmission companies have for a long time been considered a monopoly. With the changing market structure transmission companies pay more attention to their costs and ROI. Transmission investments are generally characterised by high initial sunk cost and uncertain revenue streams. Therefore, considering the investment as a real option can add value by creating flexibility to postpone investment.

The result of our analysis is that it is optimal to immediately exercise the option to build the cable to UK. The interconnector project to UK dominates the alternative of investing to Germany in all future scenarios considered in this paper. We conclude that holding the option to invest in mutually exclusive projects only has a value when the difference between project values is small. If one of the projects are considerably more in the money than the other, the parameters of the other project has no major impact determining the option value. In such situations, the option value can be modelled as a call option.

Our model gives an important finding regarding the effect of volatility on the option value. The finding indicates that the option value does not necessarily increase when the volatility increases. This has already been shown in the literature, but not for the type of option considered in this paper. The result therefore contributes to a deeper understanding of the relationship between volatility and the value of a basket option.

An additional finding is how the growth rate affects the exercise boundary. The results show that if one of the growth rates is kept constant and the other is changed, the exercise regions of both cables are affected, though to a higher extent for the cable with the constant growth rate. To our knowledge, this has not been discovered in other articles and is an important contribution to the real option literature.

The effects of several uncertainties, including political uncertainties, on the investment decision are two fold. An increase in the CO_2 price, due to EU ETS, will result in an increased spread between the electricity prices. This will increase the value of the option, but also postpone investment, because the investors face higher uncertainty. Our results also conclude that a capacity market alone will have no impact on which interconnector we choose to invest in.

We find that for the given estimate of the cable start revenues, the optimal value is equal to the intrinsic value of the cable to UK. In other words, the value of the option is equal to the net present value. We would argue that the value of using a real option approach is that it confirms that the option to invest in the cable to UK in 2020 is the optimal investment strategy. A general net present value approach would only conclude that the investment is profitable, not at what time to invest. The value of the real option approach is also evident when the uncertainty increases and results in a recommendation to postpone investment beyond the net present value break-even price because of price uncertainty. We would argue that even though our result does not contradict a net present value approach, a real option analysis has value when considering an analysis of two mutually exclusive projects.

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