Impact of Climate Change Policy Uncertainty on Energy Sector Investments

Pilot Phase Report

William Blyth

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Sustainable Development Programme

Chatham House
10 St James’s Square
London SW1Y 4LE

www.chathamhouse.org.uk

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1. Introduction

“Significant uncertainties that are unclear or unmanageable lead us to make decisions not to invest in projects affected by such uncertainties. One uncertainty that fits this description is the risk of adverse governmental laws or actions. In general, we choose to invest in markets where the regulator has made the commitment to develop rules that are transparent, stable and fair. The rules do not have to be exactly what we want, so long as we can operate within their framework. Consequently, we look for markets where the rules of competition are clear, encouraged and relatively stable.”


“Probably the greatest uncertainty for investors in new power plants will be controls on future carbon dioxide emissions….The unknown value of carbon emissions permits and the mechanism chosen to allocate permits will become a very large and potentially critical uncertainty in power generation investment. This uncertainty will grow in the future, as restrictions on levels of carbon dioxide emissions beyond the first commitment period of the Kyoto Protocol are unknown”

IEA 2003b Power Generation Investment in Electricity Markets

This report presents the results of the pilot phase of the project “Impact of Climate Change Policy Uncertainty on Energy Sector Investments”. The aim of the overall project is to explore the response of companies to policy uncertainty, to see to what extent the behaviour referred to in the quotes above is likely to be manifested, what the consequences of this might be for the power sector, and what policy-makers could do through improved policy design to alleviate the problems. The main phase of the project will as far as possible introduce a quantitative element to the analysis, including modelling of the impact of uncertainty on the cash-flow for typical investment projects.

The pilot phase was carried out between October 2004 and March 2005, and was jointly funded by the International Energy Agency and the UK Department of Trade and Industry. The pilot phase does not include any modelling or quantitative results. The aim has been to scope out potential ways of carrying out a quantitative analysis, and to carry out some of the qualitative background analysis that will facilitate the main phase of the project. Specifically, the objectives of the pilot phase were:

i) Review the different risks facing investments in the energy sector
ii) Review the different techniques used in the energy and finance sectors to quantify these risks,
iii) Investigate different approaches and models to quantify impacts of climate change regulation uncertainty
iv) Draw preliminary conclusions about the magnitude of climate change regulation risk compared to other risks, and about potential policy design options that could reduce the risks
v) Identify next steps for the main phase of the work towards more realistic models and analysis

¹ http://energy.senate.gov/hearings/testimony.cfm?id=548&wit_id=1386
Section 2 of this report outlines the results of the review covering points i)-iv) above. Point v) above is covered by Section 3 of the report which provides a revised project plan.

In addition to the above explicit objectives, an important part of the work in the pilot phase has been to put together the funding for the main phase. A summary of the current situation regarding funding is given in Section 3.1 of the report.
2. Climate Policy Uncertainty and Business Risk

2.1. Business Response to Risk and Uncertainty
Businesses routinely deal with risk and uncertainty in their daily decision-making processes. The range of risks facing energy sector investments is illustrated in the IEA’s World Energy Investment Outlook (2003), reproduced below.

<table>
<thead>
<tr>
<th>CATEGORY</th>
<th>TYPES</th>
<th>EXAMPLES</th>
</tr>
</thead>
<tbody>
<tr>
<td>ECONOMIC RISK</td>
<td>Market risk</td>
<td>• Inadequate price and/or demand to cover investment and production costs</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Increase in input cost</td>
</tr>
<tr>
<td></td>
<td>Construction risk</td>
<td>• Cost overruns</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Project completion delays</td>
</tr>
<tr>
<td></td>
<td>Operation risk</td>
<td>• Insufficient reserves</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Unsatisfactory plant performance</td>
</tr>
<tr>
<td></td>
<td>Macroeconomic</td>
<td>• Abrupt depreciation or appreciation of exchange rates</td>
</tr>
<tr>
<td></td>
<td>risk</td>
<td>• Changes in inflation and interest rates</td>
</tr>
<tr>
<td></td>
<td>Regulatory risk</td>
<td>• Changes in price controls and environmental obligations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Cumbersome administrative procedures</td>
</tr>
<tr>
<td></td>
<td>Transfer-of-profit</td>
<td>• Foreign exchange convertibility</td>
</tr>
<tr>
<td></td>
<td>risk</td>
<td>• Restrictions on transferring funds</td>
</tr>
<tr>
<td></td>
<td>Expropriation/</td>
<td>• Changing title of ownership of the assets</td>
</tr>
<tr>
<td></td>
<td>nationalisation</td>
<td></td>
</tr>
<tr>
<td>POLITICAL RISK</td>
<td>Documentation /</td>
<td>• Terms and validity of contracts, such as purchase/supply, credit</td>
</tr>
<tr>
<td></td>
<td>contract risk</td>
<td>facilities, lending agreements and security/collateral agreements</td>
</tr>
<tr>
<td></td>
<td>Jurisdictional risk</td>
<td>• Choice of jurisdiction</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Enforcement risk</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Lack of a dispute-settlement mechanism</td>
</tr>
<tr>
<td>LEGAL RISK</td>
<td>FORCE MAJEURE RISK</td>
<td>• Natural disaster</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Civil unrest</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Strikes</td>
</tr>
</tbody>
</table>


Whilst this seems like a formidable set of risks to face, capital markets in most OECD countries have developed to the extent where they provide an efficient way of handling such investment risks. In principle, firms or projects that are exposed to greater levels of risk simply need to provide a higher return on investment in order to attract capital. The level of risk faced by a particular project or for a company as a whole is therefore reflected in its cost of capital.

The standard way in which financial markets determine the required returns on investment in the equity capital of a firm is through the Capital Asset Pricing Model (CAPM). This relates the expected return on the investment $E[r]$ to the risk-free rate of return $E(r_f)$, usually measured against government bonds or other ‘zero-risk’ assets, and $E[r_m]$ the expected rate of return for the
market as a whole (i.e. the return rate for fully diversified equity assets). The CAPM is expressed as:

\[ E[r] = E(r_f) + \beta (E[r_m] - E(r_f)) \]

where \( \beta \) is the covariance between returns on the risky asset and the market portfolio, divided by the variance of the market portfolio. In other words, the return on a ‘risky’ equity holding is the risk free government bond rate, plus a premium for equity assets scaled by \( \beta \). If \( \beta = 1 \), then the expected return and associated risk of the asset is on a par with the equity market average. If \( \beta < 1 \), the asset is less risky than the market average, and if \( \beta > 1 \) it is more risky than the market average.

An important feature of this equation is the dependence of \( \beta \) on the covariance of the risky asset with the market as a whole. The capital market is assumed to be fully diversified, holding a portfolio which reflects total market returns. In assessing whether to add a new firm or project to this portfolio, the key concern is whether the riskiness of the whole portfolio is increased or decreased by the addition of the new project, hence the focus on covariance.

A key assumption of the CAPM is that investors diversify their stock holdings by combining risky securities into portfolios. By doing this, they eliminate risks that are specific to each individual investment. In this context, specific risks are considered to be non-systematic risks – i.e. relating to risks of events that are unique to a particular company or project, and are not related to the general market or economic factors. Examples from the above table might include parts of the construction or operating risks. Because specific risks are not related from one company / project to another, the CAPM indicates that an investor holding a diversified portfolio does not need a premium to compensate holding this type of risk.

The market, macroeconomic and political risks listed above are more likely to be correlated between firms, and this type of risk does attract a premium. These types of risk that cannot be diversified away in a portfolio are termed ‘market’ or ‘systematic’ risks.

In general, the presence of these risks does not in itself create a barrier to investment – as long as there is a sufficiently deep, liquid and diversified capital market which can make capital available to the firm or project. In most cases then, risk should be considered a ‘natural’ part of the investment decision, with well established market mechanisms for handling it, with no need for government intervention to mitigate the effects. Different levels of risk for different industries are recognised by the market, and will usually be reflected in their costs of capital. Examples are shown in the table below.

<table>
<thead>
<tr>
<th>Industry</th>
<th>( \beta )</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utilities (elec, gas, sanitary)</td>
<td>0.47</td>
</tr>
<tr>
<td>Oil refining</td>
<td>0.63</td>
</tr>
<tr>
<td>Oil and gas extraction</td>
<td>0.80</td>
</tr>
<tr>
<td>Banks</td>
<td>1.61</td>
</tr>
<tr>
<td>Professional services</td>
<td>2.00</td>
</tr>
</tbody>
</table>

Source: Kaplan and Peterson, (1998)

So although risk in general does not require policy intervention, a possible exception is risks created by government policy itself. Government decisions can have important implications for systematic / market risk, such as those relating to macro-economic policy and will be one of the risk factors taken into account in such appraisals. More specific regulatory actions on the other hand may affect individual sectors, or even individual firms with less impact on the general market.
What attempts have been made to identify how important this source of risk is? Typically, the CAPM approach prices risk by looking at historical stock values for the class of asset being considered. This factors in all aspects of risk, and it is not therefore possible through the CAPM approach to directly quantify the individual contributions of each element of risk listed in the above table to the cost of capital.

NERA (2002) provides a useful review of attempts to quantify regulatory risk. They distinguish between risks posed by different types of regulatory regime (e.g. regulated vs. competitive markets) and the risks posed by unpredictable regulatory events or action by the regulator. On the question of regulated vs. competitive markets, conventional wisdom suggests that price regulation reduces the market risk to which a utility is exposed. Recent literature however suggests that factors such as regulatory lag, imperfect price adjustment, imperfect information on behalf of regulators and corresponding inconsistency can actually increase the cost of capital for regulated utilities above that which would be observed in competitive markets.

Differences between different regulatory approaches are also explored, and can be an important determinant of risk. In the power sector, various types of regulation have been used for monopoly utilities. These typically try to incentivise cost-efficiency in some way, but the strength of these incentives vary depending on the type of regulation used. It turns out that the riskiness of the business increases for those types of regulation which introduce strong cost-efficiency incentives. ‘Rate-of-return’ type regulation sets upper bounds on the profit that can be made from the business, and is considered to give relatively low incentives for cost-efficiency, whereas RPI-x sets prices to decrease at some pre-determined rate (x) relative to the retail price index (RPI), but does not restrict profit levels, and is considered to give strong cost-efficiency incentives. The relative riskiness as measured in a cross-country comparison of company β’s of these types of regulation are shown below, showing the effect of regulation on risk and therefore cost of capital.

<table>
<thead>
<tr>
<th>Strength of cost-efficiency incentives</th>
<th>β</th>
</tr>
</thead>
<tbody>
<tr>
<td>High (e.g. RPI-x)</td>
<td>0.57</td>
</tr>
<tr>
<td>Medium</td>
<td>0.41</td>
</tr>
<tr>
<td>Low (e.g. rate of return regulation)</td>
<td>0.35</td>
</tr>
</tbody>
</table>

Source: NERA 2002

Again, the presence of these regulatory risks should not necessarily be seen as a barrier. Nevertheless, since the risks are determined by policy, the pro’s and con’s of different regulatory approaches, including the effects of risk, should be taken into account. Regulatory approaches which introduce greater risk could be appropriate, but only if there are other benefits which outweigh the increase in risk and associated costs.

Regulatory risk can also increase as a result of frequent policy or rule changes, which would tend to increase the rate of return required from firms and new investments. In the case of a fully liberalised electricity market for example, such increases in rates of return might be met through increases in electricity prices to consumers. Political and regulatory uncertainty, while not necessarily creating barriers to investment, can in principle therefore have undesirable outcomes, and where appropriate should be minimised.

The NERA review calls this ‘regulatory intervention risk’ – risks associated with unpredictable events or actions by the regulator. Empirical evidence of the effects of an unexpected re-visiting of the price review process for the twelve regional electricity companies in the UK in 1995 shows that for eight of the twelve there is a marked impulse increase in share price volatility after the date of that decision, and that the increased volatility displayed some persistence, which suggests...
that events increasing perceptions of unpredictability of a regulatory regime can increase volatility of returns and could have implications for a company’s cost of capital (Robinson and Taylor 1998). It is argued that regulatory asymmetries may also be important, as there may be a tendency to claw back excessive returns, without commensurately subsidising returns that are low (or perhaps vice versa in circumstances where bankruptcy of firms could cause security of supply concerns). Such asymmetries of risk are not well handled by CAPM in its basic form, and additional risk premiums may be required to deal with these. The paper also reviews the impact of regular price review processes under different regulatory regimes, and notes that these regular decision points can have important effects on companies’ market values and impact on the cost of capital by changing their $\beta$ values.

2.2. Managing Price Risk in the Power Sector

Probably the most fundamental risk for power generation companies, particularly in competitive market conditions, is price risk. Different electricity markets have different types of price formation process, ranging from regulated companies through to competitive markets based on a pool or markets based on bi-lateral contracts. Whatever the price formation process, the primary short-term concern of power generation companies is to maximise profits by optimising the use of their generation assets given the price they can receive at any given time. Operational decisions on a day-to-day (or even hour-to-hour) basis are driven by this optimisation requirement, determining the rate at which each plant in the portfolio will be run in any given period. Supply and demand are balanced in real time by ensuring that companies are incentivised to correct any shortfall or over-supply relative to expected levels, with various mechanisms for creating these incentives.

When it comes to longer-term decisions, companies have to decide whether to build new power plant in response to expected increases in demand, as well as deciding how and when to retire old plant. Because of economies of scale and the historical development of the sector towards large centralised generating plant with very long lifetimes, these investments tend to be focussed on large, capital intensive and long-lived investments. Firms have to be confident they will have buyers at a sufficient price to support the financial case in order to justify such investments. Given the long timescales that can be required to repay the capital, these decisions have to be taken with quite significant levels of uncertainty, particularly relating to the price and volume of electricity sales, as well as the price of input fuels (particularly sensitive for gas plant).

In principle, the financial risk surrounding such decisions could be hedged by selling / buying forward contracts for the electricity off-take / fuel inputs. If forward markets were long and deep enough, the cash flow from a project could be guaranteed (barring technical and operational risks) by fixing the price of the electricity and input fuels prior to taking the decision to build. In fuel and power markets dominated by regulated monopolies, such an approach is often used to underpin new investment, typically by setting up long-term contracts, struck in bi-lateral deals rather than on open forward markets. Such long-term contracts can be beneficial to the fuel suppliers as well as the power companies, as it allows them certainty on volume and price which in turn can help to underpin new supply projects (e.g. new gas pipelines / mine developments etc). This is the traditional model under which many power generation projects were developed in IEA countries prior to market liberalisation.

In competitive markets, the role of such long-term contracts has diminished, and it is an open question about whether they are needed or not for creating stable investment conditions. Typically, forward contracts for electricity and gas do not go out far enough into the future to allow hedging of investment risk for most large-scale power projects. Forward gas markets in the UK typically go out to around 3 years, and some deals may be done based on these markets which stretch to 5 years (Leppard 2005). This may be sufficient for small-scale projects, including some industrial CHP projects (Gardiner 2004), but is not sufficient for large-scale power projects. One of the effects of increased competition in gas markets is an increased volatility in gas prices. This has created a reluctance to agree long-term contracts, since effectively the risk premium
becomes prohibitive. The US gas market volatility has increased markedly since the 1990s, although there is some sign of volatilities levelling off, albeit at higher prices.

A paper by the IEA (IEA 2001) describes the increasing trends in volatility in a number of different energy markets, and identifies an increasing concern that volatility could act as a barrier to investment. The paper tests the link between volatility levels and investment rates in exploration and production in the oil sector, and identifies an elasticity of investment change with respect to changes in volatility of -0.11. In other words, a 1% increase in oil price volatility results in 0.11% decrease in investment.

Focussing on electricity markets, the IEA produced a publication identifying the way in which investment risk is handled in liberalised markets (IEA 2003b). Risks identified arise fundamentally as a result of inherent uncertainty about electricity prices. This can affect choice of technology, favouring those with low capital costs and high operating costs (e.g. gas generation) to reduce exposure to the high levels of capital employed. Uncertainty may also need to be weighed against the economies of scale which in the past have favoured large plant. The combination of long lead time, uncertain growth in demand for electricity and price, and uncertainty in the total cost of financing construction all act to increase risks for larger projects. Projects that can be phased in as several smaller power plants in response to market conditions will be more flexible, and less exposed to these risks, and may therefore be preferred even if they do not achieve the same economies of scale. Possible changes in the market rules themselves are also identified as a source of risk, as well as significant risks posed by uncertainty around future greenhouse gas controls. The book goes on to review different ways in which governments have responded to high price volatilities, and warns against simplistic actions such as price caps which can create significant investment barriers. Other methods more compatible with open markets are explored, such as helping to increase demand elasticity.

Electricity futures and forward contracts in the UK and Germany typically go out 1-2 years. In the Nordic market, forward contracts for electricity go out up to 3 years ahead. These forward contracts are mainly used to manage operational risk, and help companies plan their operations to balance supply and demand, with year-ahead being a typical planning horizon for many companies. The reason the Nordic market may be slightly longer is that there is a heavy reliance on hydro power, and water levels may vary over periods longer than 1-2 years. In any case, such contracts do not help companies hedge investment risk, for which the relevant time period is much longer.

Another way in which firms have tended to hedge their operational risks to balance supply and demand is to aggregate along vertically integrated lines. Generation companies have tended to
combine with supply companies who can ensure a certain level of sales for the electricity. Clearly, if there is full competition at the retail end of the market, and if consumers are able to change their supplier without cost, such arrangements do not give guaranteed price for the electricity, since retailers need to remain competitive on price. Nevertheless, given that there is usually some inertia amongst consumers (particularly for small-scale / households) vertical integration does give some protection from short-term volatility of prices. This is evidenced by the relative success of the vertically integrated companies compared to independent power producers who suffered from price risk exposure in both UK and US markets.

It may be argued that the absence of long-term contracts leads to uncertain (and therefore unstable) investment conditions. The recent investment decision\(^2\) by a consortium of companies in Finland to build a new nuclear plant backed up with 15 year electricity off-take contracts is a striking exception to the trend. The financing of nuclear plant is particularly sensitive to the period of amortisation of capital because of the highly capital-intensive nature of the technology, so such long-term contracts are likely to be particularly valuable in such a case.

But does the Finnish nuclear example set a precedent for a wider move back to long-term contracts? The expectation of most market players in the Nordic market is that it does not (Stridbaek 2005). The investment risks are expected to be borne by the power companies, based on their expectations of future prices. They face the risk of losing money if they make the wrong decisions, but this is balanced by the incentive of making greater returns if their decisions are good ones. Hedging the risk through long-term contracts could be seen as handing over these opportunities for greater returns to other parties who arguably are not in such a good position to make the decisions as the power companies themselves. In this sense, although the absence of long-term contracts may lead to increased uncertainty, it may not be appropriate to consider this as introducing unstable investment conditions. Whilst the investment decision itself becomes more exposed to risk, the rewards are balanced against these risks. The system should therefore provide a sound basis for investment decision-making as long as potential investors are able to form rational expectations of future prices that are not subject to manipulation by incumbent power companies, and also assuming that they will be given fair access to the grid to sell their electricity in the market.

Power sector investments tend to be large, and the ability to manage investment risk by holding a portfolio of different assets favours the existence of large companies. The default choice for new generation will be to opt for the technology that gives them the lowest long-run marginal cost of production. However, considerations of risk should also be incorporated into these decisions, and companies with a portfolio of different generating assets will want to consider the benefits of combining different generating technologies with different risk profiles.

Portfolio theory provides a basis for optimising the holdings of different generation assets based on their risk-return characteristics. An investor will try to choose an investment in a stock or a project that maximises return and minimises risk. In general, if there are two or more possible projects in which she can invest, the investor will get a better rate of return for a given risk, or a lower risk for a given rate of return if she holds a combination of these projects / stocks than if she holds any one on their own. The theory provides the quantitative understanding behind the common sense rule of not ‘putting all your eggs into one basket’.

Different generating assets come with different types of risk. For example, coal plant are very capital intensive, but the fuel costs (and therefore operating costs) are relatively low, and traditionally coal prices have had very low volatility. Coal plant are therefore more exposed to the financial risks of whether they can re-pay the capital based on the volume / price of electricity off-take from the project. Renewable technologies such as wind and solar power have zero fuel cost, and therefore low operating costs, and again, the cost is mostly up-front capital. Gas generation on the other hand has relatively low capital costs which reduces financial exposure, and generation tends to be quite flexible which adds to the technology’s advantages. On the other

\(^2\) http://rhino.digia.com/ktm/bulletin.nsf/headlinespubliceng/F285C5EFF6D8D83FC2256BC30038A525 Impact of Climate Change Policy Uncertainty on Energy Sector Investments

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hand there is exposure to uncertainty in gas prices which form the largest part of the project's cash flow. Taking into account these different risk profiles may lead companies to develop a broader portfolio than might be suggested based on individual project-by-project financial analysis (Awerbuch 2003).

Companies will use their own techniques for assessing investment risks, and deciding how to balance individual project risk against their own strategic concerns. Typically though, the financial case will ultimately be based on some forward expectation of prices, with some estimates of upside and downside risk around these expectations. It has been pointed out that a fair comparison of the costs of different technologies should as far as possible compare like-for-like taking due account of risk premiums valued at market rates. An attempt to do this was made by Bolinger et. al. (2003). They compare forward gas contracts for 2-10 years ahead, and show that prices are consistently higher than prices forecast by the Energy Information Administration and other forecasters. They argue that this difference can be interpreted as reflecting the risk premium that the market charges given uncertainty about future costs, and that this market valuation of risk should be incorporated into the investment analysis when comparing with other investments that are not exposed to fuel price risk. When incorporating these risk premiums, they conclude that long-run marginal costs for gas-fired electricity production might be 0.3-0.6 c/kWh higher than without the risk premium. Significantly, this range spans the gap between traditional estimates of long-run marginal cost of gas-fired plant and significant volumes of renewables (specifically, wind, geothermal and some forms of biomass) across parts of the US, and indicates that if such effects were taken into account by planners and investors, there could be a re-balancing required between gas-fired generation and renewables.

In competitive markets, producers receive a signal to invest through the product price – when supply is becoming tight relative to demand, prices should rise creating the incentive to invest in new capacity. In the power sector, because of the time taken to bring a new plant online, in reality this process requires some judgement in advance of likely impending shortfalls in the market, and timing of investment can become critical. White (2005) describes how price behaviour in competitive markets will tend to spend periods of time at low prices (close to short-run marginal cost) which are too low to encourage new entry. As plant retires or demand increases, the market gradually becomes tighter until prices spike up above the threshold for new entry. At this point, there is a race to bring new plant on-line to make the most of the higher prices. Firms who can do so at the beginning of a period of higher prices stand to make considerable gains. Firms who wait for the price signal in order to invest and who bring their plant on-line later are liable to miss the boat. The period of higher prices leads to greater capacity which once again returns the market to a period of low prices and low investment until the next price spike. The price behaviour is shown schematically below, following the form in White 2005.
Such pricing behaviour can be considered normal for an industry in dynamic equilibrium, and as long as a sufficiently long time perspective is taken, the behaviour is sustainable (a mathematical treatment of this behaviour is given in Dixit and Pindyck 1994). However, in practice, such behaviour creates challenges both for companies and policy makers. Companies need to judge their investments carefully with respect to the occurrence and duration of price increases in order to ensure they benefit from the periods of higher price. On the other side, it challenges policy-makers who have to hold their nerve that the market will deliver the required investment to meet demand, and not intervene either during the periods of low price and low investment (when there is a temptation to provide additional incentives for investment), or during the periods of high price (when there may be a temptation to intervene in order to protect consumers). An expectation of policy intervention in either of these ways is likely to create additional uncertainty and in the long-run create additional barriers to investment.

2.3. Climate Change Uncertainties

In the field of climate change, uncertainties abound. Fundamentally, there is uncertainty about the potential physical impacts of an increase in greenhouse gas concentrations in the atmosphere. A convenient shorthand which summarises the climate response is the climate sensitivity parameter – the increase in global mean temperature in response to a doubling of atmospheric concentrations. This sensitivity parameter is typically quoted as being in the range 1.5-4.5°C, the range quoted in the IPCC Third Assessment Report. This range for mean temperature response has a strong effect on the emissions reductions required to achieve policies framed in terms of meeting maximum warming rates (Caldeira et al 2003).

The uncertainty in the headline figure for temperature response feeds into an even wider range of possible physical outcomes in terms of regional impacts on the climate. Even if these physical outcomes were known for certain, the economic impacts of climate-related damages would themselves be uncertain and difficult to quantify, not least because the largest damages occur in the future, and there is considerable disagreement about how future damages should be discounted in terms of present value. Eventually, these damages will make themselves felt in the economy, and will feed back into emissions levels. However, this feedback mechanism is much too slow to be effective, hence the need for policy intervention.

In addition to climate sensitivity and economic impacts, a third important source of uncertainty is the cost of technology for reducing emissions. This feeds into policy-making decisions as well as directly into the costs that companies will face in meeting mitigation requirements. One of the interesting aspects of this source of uncertainty is that both the level of cost uncertainty, and the actual cost of the technology are likely to decrease as a result of increased deployment, both of which should act to encourage policy action to promote uptake (Papathanasiou 2000). These various sources of uncertainty are shown schematically in the figure below.

Mitigation policy is affected by uncertainties in climate response, economic impacts and technology costs. Companies are affected by the resulting uncertainty in the mitigation policies, as well as uncertainty in technology cost. In the long term, there will also be a direct economic impact from physical aspects of climate change.

Decisions on mitigation action taken in the form of government policy to internalise these externalities, will have to contend with these fundamental uncertainties. The result is that the extent and form of government policy is itself uncertain. Power generation companies are amongst the biggest emitters of greenhouse gases, and are therefore amongst the most exposed companies when it comes to regulatory risk. It is in these early stages of climate change policy development when the uncertainty is highest that regulatory risks are receiving particular attention in this sector, and are therefore the primary focus of this study.

Various attempts have been made to ascertain the relative contributions of different sources of uncertainty. Nordhaus and Popp (1997) modelled the value of improving knowledge in various aspects of the climate-economic system, and made the case that economic uncertainties were more important than the scientific uncertainties, therefore warranting more research effort. Of seven uncertain parameters they modelled, the two most significant uncertainties were the cost of climate change damages, and the cost of mitigation, with the climate sensitivity parameter coming third on their list. Nordhaus suggests that research resources to tackle uncertainties should be allocated on this basis. However, this conclusion should perhaps be tempered by consideration of the likelihood of reducing the uncertainty associated with climate damages. Jacoby (2004) reviews attempts to evaluate climate damages and notes that it may be impossible to define a single measure of damages (or benefits of climate policy).

Modelling of the different sources of uncertainty by Webster et. al (2003) indicates that uncertainties in the emissions profile of greenhouse gases over the coming century are at least as important as uncertainties in the underlying science. Their modelling of with and without
greenhouse gas restrictions indicates that introducing policy can narrow the uncertainty range, and in particular tends to reduce the upper end of the probability distribution of outcomes, making the more extreme outcomes less likely.

The shape of the probability distribution of climate damage may also have important policy implications. The existence of low-probability high-damage outcomes of climate change ("nasty surprises") gives climate damages a skewed probability distribution towards the ‘right’ (i.e. higher damages). Schneider (2000) argues that the significant chance of such nasty surprises should cause a higher level of optimal abatement than if policy was directed simply at the most likely outcome (such as is assumed in e.g. Nordhaus 1992). In other words, policy should take some account of the insurance benefits of reducing the probability of the highest damage outcomes.

Having said that, the probability of very high-damage catastrophic events is likely to be constrained by the fact that the rise in greenhouse gas concentrations in the atmosphere are likely to be transient. Most models of the long-term effects of climate change assume atmospheric stabilisation at various concentrations, but more likely emission scenarios would suggest that atmospheric concentrations would peak at some level and then decrease again. This has important implications for reducing the chances of some of the very long-term events that create some of the greatest uncertainties around climate damages (Frame 2005).

Some commentators argue that there is a value to waiting until some of these inherent uncertainties are resolved before making decisions on restricting emissions of greenhouse gases. This result arises because of the irreversibility of abatement decisions related to long-lived capital stock. This argument says that the expectation of learning more information in the future should lead to higher emissions now in order to avoid a situation where greater abatement actions were taken than proved necessary. A converse argument in the literature suggests that the irreversibility of climate damages dominates, and therefore the prospect of learning in the future should lead to lower emissions now (in order to avoid higher-than-expected damages). This literature is reviewed in Webster 2002, who draws the conclusion that the ability to learn in the future can lead to either more restrictive or less restrictive policies, and pointing out that different positions taken in this debate over the role of learning tends to be driven mainly by preconceptions over the cost of reducing emissions: those expecting higher costs tend to favour waiting, those expecting lower costs tend to favour early action.

Nordhaus (1997) concludes that rational decisions by policy makers should be made by maximising the expected value of utility conditional on the current state of knowledge, and that uncertainty should not be used as an excuse either to do nothing or to use the precautionary principle of minimizing regret. In his paper, he indicates a wide range for the optimal taxation policy of between $0.04 and $34 per ton of carbon. Yohe et. al. (2004) on the other hand consider the value of hedging against uncertain future climate impacts, suggesting that an initial policy equivalent to $10/tC ($36/tCO$_2$) rising over time at the rate of interest would be a robust initial response in the face of the prevailing uncertainties.

Other studies have tried to assess the value of taking early action in the face of these uncertainties by assessing the potential impacts on technology cost, recognising that technology cost may be uncertain, but is in any case expected to reduce as utilisation increases. Papathanasiou and Anderson (2000) argue that technology policies in particular tend to be quite robust in the face of uncertainty due to this positive feedback effect on technology costs. In this sense, kick-starting investment in new technology creates opportunities for ‘pleasant surprises’ that could act as a counterweight to the possible ‘nasty surprises’ coming from climate change impacts.

On one hand, the presence of uncertainty in climate change outcomes and costs tends to create a pressure to maintain policy flexibility in order to allow it to respond appropriately to new information. If governments are too fixed in their approach, they risk committing to actions which turn out to be either too stringent or not stringent enough. An estimate of the value of such flexibility could be derived from work done on the value of new information (Nordhaus 1997).
Nordhaus puts this value in the region of $45-108bn. These figures represent the discounted value of the benefit to the global economy of obtaining information relating to these uncertainties 50 years early — they therefore give some indication of the value of acting with perfect foresight, and the value of acting in a flexible manner with the ability to adjust to improved knowledge.

On the other hand, this flexibility may in itself create an additional cost to companies who will have to make decisions based on a changing policy environment. The cost of such policy uncertainty is one of the key themes of this study. Work carried out already by EPRI suggests that these costs may be significant, possibly adding a premium of more than $10/tCO$_2$ to project costs. As a very crude measure of the significance of this risk, if this premium is multiplied by global emissions, the total ‘cost’ of uncertainty would be in the region of $250 bn per year. Clearly this is an upper bound, and it is too simplistic to assume that total global emissions are subject to this same risk premium, and also it should be recognised that only part of the risk premium relates to policy flexibility. A possible lower bound on the overall effects might be gained by looking at the investments required to meet global energy needs over the next 30 years (IEA 2003), and to assume that policy risk only applies to new investment, not existing capital stock. Globally, around $180 bn per year is required for new generation plant in the power sector. If a $10/tCO$_2$ policy risk premium was added to the expected operating costs of these projects, this would add around $5/MWh (10%) to the price of the resulting electricity. Since the new investments would add around 1bn MWh of additional electricity supply to the system each year, the total policy risk premium would therefore be in the region of $5bn per year. Cumulating this over several decades brings this estimate into comparable order of magnitude with the $45-108 bn overall benefits flexibility identified above.

It is the aim of this project to define more carefully the magnitude of this risk. Nevertheless, these simple comparisons suggest that a balance needs to be achieved in terms of the policy response to climate change between flexibility and certainty, an issue which will be explored further in this study.

Any move towards favouring policy certainty over policy flexibility may need to take greater account of the potential for ‘nasty surprises’, since under policy certainty, the ability to respond to evidence of nasty surprises would be constrained, so the possibility of their occurrence would need to be built in to the policy to a greater extent. In other words, a consequence of moving towards greater policy certainty may be that the optimal abatement level is actually higher than if a fully flexible policy approach was taken.

### 2.4. Investment Decisions in the context of Climate Policy Risk

This project aims to develop quantitative analysis of the effects of climate policy risk on investment decisions in the power sector. The basis for this analysis will be a ‘real options’ approach to quantifying the effects of uncertainty. This section provides a brief introduction to real options, and how they provide a useful tool for considering climate policy risk.

Real options theory is a way of analysing investment decision-making under uncertainty. Before launching into a description of real options, it is useful to review the traditional theory explaining how investment decisions are made. The standard approach is to develop a discounted cash-flow (DCF) model for the proposed new investment. The first step is to set up the cash-flow model, which identifies each individual stream of income and expenditure for the project going out into the future for the expected duration of the project. Elements in this cash-flow model might include electricity prices, fuel prices, environmental charges, taxes, tax credits and other fixed and variable operating costs. For each period in the model, these different streams are combined to give a single estimate of the expected cash-flow of the project. The decision on whether or not to invest depends on the present value of the project’s future income compared to the initial capital outlay. The present value of a future stream of cash-flow is determined by discounting the future income at some discount rate, and then aggregating the total income for the project’s life. The simple investment rule is that if the present value of the cash-flow is greater than the initial capital
outlay for the project (such that the ‘net present value’ NPV is positive), then the project should go ahead. If it is not, then the project should not go ahead.

The following example gives an illustration of how this approach might be applied to draw conclusions about investment behaviour in response to an expected evolution of carbon prices. Suppose that an operator of a coal-fired power plant has known that CO₂ is going to become regulated, perhaps through emissions trading or a tax, and expects that the effective price of carbon is going to increase in the future. Let us assume that the most cost-effective option for reducing emissions in response to this new regulation is to re-power the plant from coal-firing to gas-firing, and that this involves an irreversible technical change to the plant requiring capital outlay. The operator knows that the marginal cost of producing electricity from coal is currently cheaper than for gas, but that as the price of carbon increases, this situation will reverse, since coal-firing emits more CO₂ than gas-firing. At what point should the switch be made? Using simple discounting, the levelised cost (i.e. including both operating and capital costs) of producing electricity with the existing plant can be compared to the levelised cost using the new gas-fired plant for a range of different carbon prices, as shown in the figure below. This gives a breakeven price at which it would be cheaper to switch — in this example the breakeven price for the investment is taken to be €25/tCO₂.

Based on this calculation of the breakeven price, forecasts can be made about the likely timing of an investment, taking account of expected rate of increase of carbon prices. Under certainty, suppose that the evolution of carbon prices follows a smooth upward path, leading to a predictable investment response once the price crosses the €25/tCO₂ threshold, as illustrated below.
In reality of course, carbon prices will not evolve in such a smooth manner. To illustrate the effect of uncertainty, we can add some volatility to the expected evolution of carbon price. The breakeven points calculated under certainty (i.e. using the NPV rule) are shown in the figure. In the presence of uncertainty (i.e. the wiggly line), intuition suggests that the investment will not be made the first time the price crosses the €25/tCO₂ threshold line, but that it will be delayed until the investor is sufficiently convinced that the price will remain above the threshold for long enough to justify the investment.

Several questions arise from such anticipated behaviour. If investment is delayed by the presence of uncertainty, does this constitute a barrier to investment? If so, is it possible to describe in quantitative terms likely behaviour in the presence of such a barrier? Is it possible to describe a policy response to reducing this barrier?

The problem with the simple NPV rule is that it is not easy to adapt it analyse decision-making under uncertainty. Viewed from the perspective of an NPV framework, the presence of uncertainty does appear to act like a barrier, causing a delay and a price premium relative to expected ‘rational’ investment behaviour. The problem with such a viewpoint is that if the observed behaviour in the presence of uncertainty looks ‘irrational’, then it is hard to describe it in quantitative terms, and difficult to base any policy recommendations on how to improve the situation.

Fortunately, it turns out that if a more sophisticated approach is taken to analysing investment decision-making under uncertainty, then behaviour in the presence of uncertainty can continue to be considered as rational, and the apparent delays and price premiums can be quantified. The appropriate framework is provided by ‘real options’ analysis (Dixit 1994, Trigeorgis 1996).

Real options theory borrows from the theory of pricing financial options. Financial options give the holder the right, but not the obligation to buy a stock at some specified future maturity date at some specified price (the ‘strike price’). Because of the right without obligation to exercise, options have a non-symmetric risk profile: if the price of the stock at maturity turns out to be lower than the strike price, then the holder will not exercise, the option is worth zero, and no loss is incurred. If the price of the stock at maturity turns out to be higher than the strike price, then the holder will exercise the option, buying at the lower strike price with the ability to make an immediate profit. As soon as it is exercised, the option is used up, and has no further value. In order to find a counter-party willing to sell such an asymmetrical option, an initial payment must
be made for the option. The value of a financial option depends amongst other things on the volatility of the underlying stock price. If there is no volatility (i.e. full certainty), then options are worthless, since there is no value to hedging downside risk. Conversely, option values increase under conditions of greater volatility.

The analogy with investments in ‘hard’ assets may not be immediately obvious, but is actually quite strong. Consider a company facing a decision to invest in a new plant, and assume it has the freedom to choose whether or not to proceed with the investment at any time over a period of time, say 5 years. If the investment is made, it is more-or-less irreversible, since the plant cannot be re-sold without losing considerable value. If during those 5 years conditions justify the investment, then the investment will be made, and a positive return will be made (analogous to the returns gained by exercising the financial option). If on the other hand, conditions are not favourable, the investment will not be made, and no loss incurred (analogous to the financial option not being exercised). The ‘option’ to invest therefore has the same characteristics as a financial option – once exercised it is binding and irreversible, and it has an asymmetric pay-off which gives it an inherent value. So, the ‘option’ to invest in a new plant has a value of its own, over and above the financial pay-off of the project itself.

There is one important difference between a financial option and a ‘real’ option. To acquire a financial option, one has to purchase from a counter-party. By contrast, a company with the option to invest in a new plant will already own the option – perhaps by having invested time and money in project planning, gaining permits to build etc. Even though it already owns the option, the option nevertheless has an inherent value, which, as is the case for financial options, depends on the volatility or uncertainty surrounding the investment decision. Once the decision is taken to invest, this option is used up and has no further value, just as in the case of exercising of a financial option.

A simple but powerful result emerges from making this analogy, which is the basis for analysing how companies respond to uncertainty:

Because the option to invest has value, and because the act of investment uses up this option (reducing its value to zero), the present value of future income from the project has to cover not only the initial capital cost, but also the additional option value of the investment opportunity.

This result is intuitively clear when it is considered that the act of investment moves the company from a position of flexibility (i.e. prior to investment it can choose whether or not to invest), to a position where having made the investment, it is locked-in to a certain irreversible course of action. The company will need to be recompensed for giving up this flexibility, and this is the source for the ‘option value’ effect.

In order to extend the intuition a little further, we can observe that in the absence of uncertainty, the option value reduces to zero (as was the case for financial options), since there is not value to maintaining flexibility when the future is fully known. In this case, the pay-off from the project only has to cover the initial capital cost, and it is comforting to note that this replicates the NPV rule.

The advantage of casting the issue of uncertainty in terms of option value as opposed to dealing with it in terms of barriers is that there is a wealth of analysis that can be borrowed from financial option theory on how to quantify the effect. The distinction is also important from a policy point of view. Whereas the presence of barriers seems to indicate some kind of market failure, in this new formulation, where the behaviour is seen as purely rational, a different policy response may be warranted. Exploring these policy implications is a major part of this study, and the qualitative insights that this new way of looking at the problem brings may bring as much value as the actual quantification of the effects.

Such approaches have been used before to model the effects of regulatory uncertainty on the power sector, and have been useful in helping to explain deviations from investment behaviour that might have been expected based on a simple NPV model (Ishii 2004).
It is useful to introduce a simple graphical representation of the option value effect. The figure below shows how the value of a company’s option to invest $F(V)$ increases in relation to the expected value of the revenue $V$ from the project. The straight line represents the case of investing under certainty. In this case, the option of investing in a project that is expected to yield less than the initial capital outlay ($I$) is zero, and the company will choose not to invest. Once the expected value $V$ of the revenue increases above $I$, the option to invest is worth $V-I$, and given a certain positive pay-off, the company will choose to invest. The investment case under certainty therefore simply replicates the NPV rule as expected.

Under uncertainty, the situation is rather different, as represented by the curved line. Here there are three areas of interest. Firstly, at low values of expected revenue, the option value is positive even for values of expected revenue $V$ that are lower than the initial capital outlay $I$. This is because under uncertainty, circumstances could change favourably, making the project viable in the future. In these circumstances the company will want to hold on to the option to invest, even if it means paying some fees to do so (e.g. these could include licensing, rent, R&D etc). Secondly, when the value of expected revenue is at or slightly above the initial capital outlay, the value of the option is greater than the net project pay-off ($V-I$) as shown by the fact that the curved line lies above the straight line. This means that the company would rather hold on to the option than make the investment, and investment will no longer take place at the threshold point where $V=I$. Thirdly, for high values of revenue, the curved line meets the straight line at some threshold value, and above this threshold the option equals the net project pay-off ($V-I$), and the company will make the investment. The threshold value where the two lines meet represents the new optimal investment point, and this can be considerably higher than the capital cost $I$ which is the optimal point indicated by the simple NPV rule.

![Graph showing option value effect](image)

The response of investors to this option value can take a number of different forms:

- Delaying investment
- Delayed plant closure / replacement
- Greater preference given to phased investment
- Greater preference for flexible / modular plant over economies of scale

The intuition behind all of these responses is that investors, faced with a risky irreversible decision, will value the opportunity to wait for new information as it arises about what the future might bring.
Theoretical analyses show that the optimal trigger point for investment can be significantly higher (by a factor of 2 or more) than the trigger point indicated by an NPV rule for reasonable levels of uncertainty / volatility of prices. EPRI modelling confirms this. Using a similar real options approach to look at the investment decision for re-powering a coal-fired power station to natural gas, their results suggest that the required carbon price that would be needed to trigger the investment would increase from $35/tCO$_2$ under certainty to $55/tCO$_2$ in the context of current climate policy uncertainty in the US.

Through collaborating with EPRI on this project, the real options modelling techniques used in their model will be available to this project team, and will be used as the starting point for the work described in Section 3.2.

2.5. Implications at the Aggregate Sector level

It is useful at this stage to explore a bit further how the option value logic applies at the sector level. Uncertainty may be specific to a particular firm, or it may be industry-wide. If a risk is firm-specific, then the incentive to wait for more information about how circumstances will develop applies as previously described. Sector-wide risks on the other hand have similar effects, but for rather different reasons (Dixit 1994), which depend on the price-formation process for the industry.

With several firms facing similar uncertainty over the possibility for upside or downside risk, the benefit of waiting no longer applies, since by deferring investment in the face of a market that appears favourable, they may hand over an advantage to their competitors. In a competitive market, ignoring variations in input fuel price for the moment, the balance of supply and demand determines power prices. An unfavourable demand shock leads to lower power prices, whereas a favourable demand shock leads to higher prices. First mover advantage will accrue to companies who take an early advantage of such market conditions.

So the presence of uncertainty in competitive markets has a different effect – it no longer creates an incentive to wait. Nevertheless, uncertainty still creates the conditions where investment will occur at a higher trigger price than would be indicated by a simple NPV rule. This occurs because the price variation risks are not symmetrical – if the price increase is high enough, it will cause new entry or expansion of firms, thus dampening the price increase. This asymmetry reduces the expected payoff from investment, since the firm cannot access the higher prices that would otherwise occur in the absence of new entry.

It turns out that the additional threshold on the trigger price for companies in a competitive market matches that for individual firms facing firm-specific risks, and so the same techniques can be used to evaluate these differentials. However, because of the different implications for investment behaviour, it will be important to incorporate considerations of the structure of the market (i.e. monopolistic vs competitive) when trying to understand the effect of uncertainty on behaviour at the sector level.

It is at the sector level where the effects of climate policy uncertainty will be most relevant from a policy perspective. Of obvious interest for climate policy makers will be the effects on greenhouse gas emissions. If investments in new technologies are deferred as a result of policy uncertainty, this could affect the emission reductions path of the sector. Under an emissions cap, the emissions reductions will have to be made in any case, but may take place at higher carbon prices than expected. Subsidy or tax programs on the other hand may not produce the emission reductions expected, if investment is deferred.

For energy policy makers, deferral of investment at the sector level is also a major policy concern. One of the key issues in energy policy regarding the power sector is to ensure that there is sufficient investment in generation capacity to meet demand. Anything that threatens the achievement of sufficient investments in reserve capacity is a source of policy concern. Also of interest from an energy policy perspective will be the balance of different technologies and fuel types used in any new capacity build. Diversity of fuel sources is an important indicator of
security of supply for a country (IEA 2004), and the generation portfolio in the power sector is an important contributor to a country's overall mix.

It is also at the sector level that the balance between policy flexibility and policy certainty will have to be made. As discussed in Section 2.3, the trade-off between flexibility and certainty will depend on the total cost to companies of dealing with the risks posed by policy uncertainty, versus the benefits to government (and the economy as a whole) of maintaining a flexible policy position from which they can respond to increased knowledge about the optimal mitigation response to climate change.

Essentially, this comes down to an argument about who is best placed to hold the irreducible elements of risk associated with the uncertainties outlined in Section 2.3. On the one hand, companies are traditionally in a strong position to manage risk, and through various markets mechanisms are able to share risk in an efficient way between the different market players. On the other hand, climate change risks are rather different from most of the risks managed by companies. They are long-term, and dependent on relatively subjective decisions about greenhouse gas abatement that are based on a balancing of uncertain mitigation costs against uncertain adaptation costs. It is arguable that in this context, governments are the only ones capable of taking on / underwriting such long-term risks (Donovan 2005). Such a situation would not be unique to climate change risks – governments have typically needed to maintain responsibility for long-term liabilities associated with nuclear power plant for example. Deciding on this balance of risk between government and the private sector will need to be a central part of the debate on how to form long-term policy on climate change mitigation.
3. Project Plan for Main Phase

3.1. Project Aims and Status

The study aims to explore in detail climate change regulatory risks, their impact on investment decision-making in the power sector, and the consequences for climate change policy designs and wider policy concerns in the sector. Key objectives of the study are to provide:

- Analysis of the effect that climate change policy uncertainty may have on individual investments in the power sector
- Insights into the consequences of policy uncertainty for the evolution of the power sector and associated outcomes for policy objectives such as greenhouse gas emissions and energy security
- Recommendations on how the adverse affects of climate change policy uncertainty may be reduced through improved policy design.

The project provides opportunities for investors and energy companies to engage in dialogue with policy-makers about the impacts of, and solutions to, regulatory risk and uncertainty.

This pilot phase of the project has been funded by the International Energy Agency and the UK Department of Trade and Industry. The objectives of the pilot phase were two-fold – firstly to research possible different approaches and to scope out the project, and secondly to promote the project and secure funding for the main phase of the work.

During the promotion of the project, various research groups have expressed interest in working on this topic, including the Development Bank of Japan, Centre-CIRAD in Paris, ECN in the Netherlands, researchers at Helsinki University, Imperial College UK, and Hyder consulting in Australia. The intention will be to maintain contact and share ideas with these groups as the work progresses to maximise the influence of the work, as well as to draw on the ideas and results of these other groups for the benefit of the project funders.

It was recognised at the meeting on December 2nd that this project is only a first step, and that there are many different avenues to explore. The IEA is likely to carry out other work on this subject, both during the period of this work, and as follow-up. Chatham House is also likely to have several projects on-going that will be relevant to the work, and the research team will endeavour to keep project participants up to date with other developments in the field. The final project report will where possible draw on this other experience, as well as recommending future steps. Example areas of future work could include:

- Impact of policy uncertainty on competitiveness of companies and efficiency of markets
- Insights for the analysis of multiple climate change policies, and policy overlap
- Extension of the analysis to cover additional technologies / policy areas (including for example other parts of the energy sector, renewables and downstream energy efficiency)

3.2. Draft Work Plan

The project will include four main tasks:

1. Analysis of investment decisions, incorporating a robust treatment of uncertainty, implemented through spreadsheet cash-flow models. This analysis will focus on the key investment choices in the power generation sector, quantifying the option value effects of uncertainty on these decisions.
2. Exploring the effect of different policy types and designs on uncertainty impacts, looking quantitatively at a few broad categories of climate policy, then bringing these results into context through qualitative assessment of a range of different policy options.

3. Investigating the way companies manage risks arising from climate policy uncertainty, including how risks are allocated between different parties to the investment, the cost of bearing risk, and how climate policy risk compares to other investment risks.

4. Aggregating the results of the individual investment-level analysis to understand the implications of policy uncertainty at the sector-level – particularly how uncertainty may affect technology choice at an aggregate level over the short-, medium- and long-term, and implications for policy objectives for the sector including both climate change and energy security.

This structure is illustrated in the following schematic. Each element of the project is described in more detail in the following plan.

![Schematic of project structure]

3.2.1. **Task 1 – Modelling Individual Investment Choices**

A key element of the project is an approach to evaluating the role of risk and uncertainty in individual investment decisions based on real options. This allows uncertainty to be evaluated in financial terms, effectively providing an estimate of the ‘cost’ imposed by uncertainty.

Real options valuation uses the same theoretical basis for valuation as options in financial markets and applies them to real assets. This approach has found its strongest applications in the energy sector, although it is not used routinely in the evaluation of investment decisions, not least due to the complexity and large amount of information required to accurately evaluate risk. For this study however, accuracy of evaluation is not the primary objective. In order to gain insights into the role of policy uncertainty in the energy sector, approximate figures for the magnitude of policy risks are adequate, and the real options approach provides a useful way to understand how the effects differ between different types of investment decisions and between different policy designs.
It should be noted that whilst the theoretical basis for real options is robust, the assumptions and approach taken in evaluating policy risk in this analytical work will be quite generic and broad-brush. As with many modelling exercises, the greatest value is expected to come from engaging in the process of quantifying this important aspect of decision-making, rather than necessarily from the quantitative results themselves. Drawing out the policy-relevant insights will also involve other qualitative activities described in the later parts of the project plan.

This part of the work will focus on developing an analysis of various individual investment decisions that could be taken in the power sector, taking account of risk and uncertainty. Decisions to be analysed fall into 2 categories: those facing existing plant, and new-build options.

Investment choices facing existing fossil-fuel fired plant (coal, gas and oil) include:
- Converting coal plant to gas firing
- Converting oil to coal or gas
- Heat rate improvement
- Biomass co-firing
- Early abandonment
- Extension of plant life

Choices for new build include:
- CCGT
- Ultra-super-critical coal plant with FGD / SCR, with and without carbon capture and storage
- Nuclear
- IGCC (coal gasification), with and without carbon capture and storage

The analysis will involve developing cash-flow models for each investment option, incorporating stochastic (randomly varying) price processes for the key elements of the cash flow including:
- Electricity prices
- Fuel prices – gas, coal, oil
- Carbon prices
- Technology cost (capital)
- Build time
- Other operating costs (e.g. environmental charges, labour etc)
- Mothballing / shut-down costs
- Load factor during operation

Inputs to the model on investment costs will be drawn from a range of public-domain sources, including IEA, EPRI, EIA etc. Correlation in the variations between different elements of the cash flow (e.g. between gas, power and carbon prices) will be accounted for using appropriate correlation coefficients. The cash-flow model will be run as a Monte Carlo simulation, evaluating the real option value associated with uncertainty through a dynamic programming approach.

For each of the generation technologies to be analysed, a module will be set up in which the base case cash-flow is defined assuming no investment decision is made. The module then defines the investment opportunities, along with the resulting cash-flows and capital outlays required as a result of taking the investment decision. The ‘option value’ of each of the investment opportunities is then calculated by running the Monte Carlo simulation which incorporates the randomly varying prices as described above. This gives information on the threshold price at which an optimal investment decision would be taken, taking account of the volatility and uncertainty of the different elements of the cash-flow.

In order to explore how important the uncertainty in carbon costs is compared to other cost uncertainties, the models will be run in four ways – firstly with all the uncertainties switched off
(i.e. so there is no option value), secondly with all the other uncertainties except carbon value switched on, but carbon uncertainties switched off, thirdly with carbon uncertainties on, but other uncertainties off, and finally with all the uncertainties switched on. This will allow the contribution of carbon uncertainty to the total to be examined explicitly for each of the generation technologies.

For many of the generation technologies, it will be important to establish the sensitivity and robustness of the results to key assumptions. The main sensitivities to be tested will be relating to the expected prices and volatilities for the main cost elements, namely power and fuel prices. Sensitivity runs will therefore be carried out for each module with high/low price assumptions and high/low volatility assumptions.

For a few key technologies, additional sensitivity cases will be run in order to test the robustness of the results. These will include testing the assumptions about co-variance of carbon prices with electricity prices and input fuel prices. Assumptions about technology cost and the effects of learning in reducing costs may also be explored as a sensitivity case.

In this task, the aim will be to work closely with companies in order to reality-check the generic cash-flow models, and to broaden experience of how investment cases are developed for these technologies in the real world. This may take the form of detailed case studies if companies are willing to be involved in such an exercise, or alternatively peer review of modelling assumptions and results through a workshop involving several power companies.

A key part of the work will be to develop a suitable way of representing climate policy risk within these cash-flow models. Unlike many of the parameters used in rigorous financial options modelling, there is no long historical time series of data relating to climate policy risk from which to draw experience about likely future risks. Instead, the approach will be to develop a series of scenarios describing how certain policy types and designs might be consistent with different carbon price processes, as described under Task 2.

It should be recognised that whilst real options provide a rigorous theoretical basis for this work, the assumptions that will be made in the representation of climate change policy risks will be rather coarse. An important aim of the project is to be able to differentiate between different policy designs, but this will only be achievable in a quantitative way for a few broad generic policy types. Task 2 includes work that aims to apply the lessons of this generic analysis to more specific policy cases.

3.2.2. Task 2 – Impact of Policy Design

The aim of this Task is to assess the extent to which the adverse effects of policy uncertainty depend on the type and design of the policy. This will involve both quantitative analysis (testing different policy designs in the real options cash-flow model), together with reviews of existing policy designs and development of policy case studies. In the quantitative assessment, climate change policy will be represented as having an effect on carbon prices, typically with step changes at times when specific policy decisions are made. This is illustrated schematically below.

In reality, policy will take a wide range of different forms, with complex decisions to be made in the detail of the policy. For the purposes of this quantitative assessment, these complexities need to be reduced such they can be represented by the overall effect of the policy on the carbon price.
Not all climate change mitigation policies act directly through a carbon price, but for the purposes of this study it is assumed that a price can be defined which represents the effect of the policy on the investment decision, analogous to a 'shadow' carbon price, often used in policy modelling.

However, this quantitative modelling exercise will only represent the price effects associated with different policy designs in a stylised manner, without attempting to introduce too much policy detail. While the process of obtaining quantitative results will provide valuable insights, the application of the results to practical policy-making situations will require elaboration through a more qualitative approach.

The implications of different policy designs will be assessed at both the installation level and sector level. Examples of different generic policy types that will be examined quantitatively using the real options model include technology-standards type policies, taxes, tradable permits, and design elements within trading schemes (e.g. length of permitting periods, different allocation modes, price caps etc). These will be represented in the cash-flow model by using a range of different carbon price processes. A descriptive story-line approach will be used to relate different policy types and designs to the different price processes used.

In addition to the quantitative analysis, a review of existing policies will be undertaken in order to draw experience from the way in which different policy designs have been used to manage issues arising from uncertainty. This review will focus mainly on environmental policy-making, but will also draw experience from other policy areas where relevant.

In order to bring the results onto a more practical level, an additional set of policy ‘case-studies’ will be developed where specific national- or regional-level policies will be examined in the light of the results of the modelling work to draw out lessons about potential impacts of uncertainty and potential ways to improve policy design to reduce adverse affects. An expert review meeting would be held to support the work of this task.

3.2.3. Task 3 – Managing the Risks

An important part of this project is to ensure that the modelling results are brought into a real-world context, and that is the main objective of this task. Understanding how companies currently manage risks is key to determining the extent to which the addition of a new source of risk (in this case climate change mitigation policy risk) will affect investment behaviour. The aim of this Task will be to explore the following issues:

- How is risk and uncertainty currently handled by different types of investor?
- How much does risk and uncertainty add to investment costs?
- How important is climate policy risk compared to other risks faced in the sector?
This part of the work will build an understanding of how risk is allocated between different parties to an investment, how policy risk may affect these parties differently from other regulatory and market risks, and the extent to which climate policy risks are retained by different parties as opposed to being passed on to the consumer.

Four different types of company will be investigated in this part of the work: vertically integrated power companies, merchant power companies, banks / debt providers, and equity providers. In addition to the allocation of risk between the different commercial players, the implications for risk exposure for governments and consumers will also be investigated.

This part of the work will be carried out mainly through company interviews and workshops ensuring as wide a coverage as possible of different national circumstances and technology types. Two 1-day workshops are planned, one in Europe, and one in North America, that will further explore risk-management at the individual investment level. It is expected that by bringing companies together into a workshop setting, valuable information will be generated that is not accessible from individual company interviews.

In addition, there may also be an opportunity that a survey of Japanese companies carried out in parallel by the Development Bank of Japan could feed into this part of the work.

### 3.2.4. Task 4 – Aggregate Effects at Sector Level

A key question we wish to explore in this Task is how policy uncertainty might affect the development of the power sector as a whole during the process of capital stock turnover. In particular, the question to be assessed is how this evolution might be different from expectations based on aggregate models of the power sector typically used in policy analysis. Factors of interest include:

- Technology choice
- Fuel choice
- Cost of carbon
- Cost of capital
- Market dynamics (pricing, entry & exit, competition etc)
- Rate of new building

In order to answer these questions, we need to utilise the insights gained in the analysis of individual installation-level investment decisions, and aggregate these up to the sector level in order to deduce potential impacts on overall trends in investment. It will be important in this process to take account of whether the market is based on monopoly generators or on a competitive structure, as this can affect behaviour in the face of uncertainty, particularly with respect to timing of investments.

We propose to aggregate the results by comparing the investment thresholds in the face of uncertainty with the investment thresholds assumed in existing business-as-usual scenarios in aggregate energy models such as the IEA model and other regional / national models. We do not propose to re-run the aggregate energy models with the new data, but rather to make a more qualitative assessment based on expert judgement about how the results of the model might be affected by the introduction of different investment threshold levels. This will require the cooperation and input of modelling teams, and will effectively comprise case-studies showing potential effects at the sectoral level for the geographical region covered by the aggregate models in question.

In addition to working with the relevant modelling teams, a broader workshop session will be organised to engage in a peer review of assumptions and results of likely impacts at sector level. This workshop will also attempt to draw out the key policy-relevant conclusions that would be...
applicable to as broad an audience as possible beyond the geographical regions represented in the case studies. Results of the work in Task 3 on how risks are managed will be an important input. The results of Task 2 will also be incorporated, giving an idea of the sensitivity at the sector level to different policy types and designs.

This task will analyse policy implications of uncertainty at the sector level, focusing not only on climate mitigation policy implications such as emissions of CO$_2$ and carbon prices, but also broader energy policy concerns. In particular, policy objectives to be analysed include, security and reliability of supply, investment rates in new capacity and electricity costs. The question of balance between policy flexibility and certainty, and who is best placed to hold the risks associated with uncertainty will also be explored as part of this Task.
References


Kaplan and Peterson, Financial Management, Summer Issue 1998


