Examining the Business Case of Voluntary Emissions Reductions: A Robust Optimisation Approach

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Doctor of Philosophy Declaration

"I, John Walter Symons, declare that the PhD thesis entitled *Examining the Business Case of Voluntary Emissions Reductions: A Robust Optimisation Approach* is no more than 100,000 words in length including quotes and exclusive of tables, figures, appendices, bibliography, references and footnotes. This thesis contains no material that has been submitted previously, in whole or in part, for the award of any other academic degree or diploma. Except where otherwise indicated, this thesis is my own work."

Signature [redacted] Date: 28 Sep 2014

Abstract

Climate change is an important issue both for society and for companies which invest in long term projects. However, climate change futures are inherently uncertain, and this raises important questions about how companies should take account of such climate effects and uncertainties in choosing investment projects. In some circumstances voluntary emissions reductions, that is reductions in emissions not directly mandated by predictable financial returns, can be privately beneficial for the firm on a net basis, in addition to generating broader social benefits not directly captured by the firm.

This thesis develops methods by which firms can include these future climate effects and uncertainties into capital budgeting and investment appraisal, and uses these methods to explore the conditions in which voluntary emissions reductions might provide net benefits to firms. The methods developed are of the robust optimisation form. For capital budgeting over a suite of potential long-term investment projects for a given firm, two models are developed and compared with the conventional linear programming NPV model. Two decision criteria are employed for each of the models, a maximin criterion and a minimax regret criterion.

These models are applied to case study data from a single company. Despite the limitations of the particular case study it is found that these forms of robust optimisation model seem to be viable tools for firms to use for incorporating climate effects and uncertainties into capital budgeting and project selection. It is also concluded that, for a portfolio with significant variation in emissions intensity across potential projects, there are likely to be significant benefits to the firm from using such models to take account of possible long term climate futures.

Overview

Climate change is an important issue, not only for the human community but also for companies which invest in long term projects that generate significant levels of greenhouse gas emissions. But climate change futures, and how they will impact on such projects in the longer term (e.g. through a price on carbon), are inherently uncertain. This raises important questions about how companies should take account of such climate effects and uncertainties in choosing investment projects. It has been widely argued that positive benefits can accrue to firms from voluntary emissions reductions through several channels, one of which is increased shareholder value as a result of recognition by the market that the company is adopting an eco-efficiency approach. In some circumstances, it is argued, voluntary emissions reductions and other environmental initiatives can be privately beneficial for the firm on a net basis, in addition to generating broader social benefits not directly captured by the firm.

It is not clear, however, how the firm should evaluate such uncertain benefits and incorporate them into its decision making. This thesis sets out to develop methods by which firms can include these future climate effects and uncertainties into capital budgeting and investment appraisal, and to use these methods to explore the conditions in which voluntary emissions reductions might provide net benefits to firms. The literature suggests that such benefits might accrue through four channels: the anticipation of regulatory changes (e.g. in relation to carbon prices), the avoidance of stranded assets, the option value of enhanced investment flexibility and the value for the firm of improved reputation and market perception.

The methods developed are of the robust optimisation form. For capital budgeting over a suite of potential long-term investment projects for a given firm, two models are developed and compared with the conventional linear programming NPV model. The first is an emissions cost model, in which a future emissions price is included in the project selection process, while the second is an emissions quantity model, in which percentage reductions in emissions over time are imposed on the projects. A wide range of scenarios are created by variations in the relevant variables (such as emissions prices and quantity reductions, and the discount rate), and project selection is analysed over these scenarios to determine the most robust solution, i.e. the most robust selection of projects. Two decision criteria are employed for both of the models. One is a maximin criterion, in which the solution which generates the highest minimum NPV across all the scenarios is chosen. This solution provides the firm with the best outcome in the ‘worst case’ scenario. The other is a minimax regret criterion, in which the solution which minimises the opportunity cost foregone (the NPV foregone) across all scenarios is chosen.

These models are applied to case study data from a single company with eleven different long-term projects from which to choose, subject to a capital budgeting constraint. Twenty seven scenarios are constructed by variations in the relevant variables (including three emission price or three emission reduction cases for the appropriate models, together with variations in discount rates and in cash flow generated). The conventional NPV, maximin and minimax solutions are calculated over the 27 scenarios, and a range of analyses are undertaken to bring out the implications of the results for the issues at hand.

For the emissions cost model the maximin and minimax regret solutions proved to be the same, with the same set of projects chosen (suite 5). The differences between this solution and the conventional NPV solution were striking: the maximin solution generated a positive NPV across all scenarios, ranging from $2,811 million to $52,167 million across scenarios, whereas the conventional NPV solution generated negative NPVs in 11 out of 27 scenarios, with a largest NPV loss of $153,963 million. The maximin and minimax regret solutions also had a lower NPV regret than the conventional NPV solution in virtually all scenarios, with a maximum regret of $64,085 million by comparison with a maximum regret of $173,231 million in the conventional NPV case. These results show how the emissions cost model and these solution methods can be used to analyse the potential costs of future regulatory change, by identifying the possible costs of standard solutions in the face of a given level of change, as conveyed by emissions prices.

In some scenarios the conventional NPV solution would leave the firm with significant *stranded assets*, in many of the 11 scenarios in which this solution generates negative NPVs, some of which are very large. If climate change accelerates, or if the regulatory authorities decide to take enhanced action to limit emissions, the NPV solution would leave the firm with substantial assets employed in unprofitable uses. What is more these are likely to be stranded assets, in the sense that the ongoing regulatory change is likely to rule out other uses of these emissions-intensive assets, and hence heavily reduce their value. The robust optimisation methods can help the firm to identify the risks of stranded assets.

This solution selected by these two decision criteria for the emissions cost model was the one which generated the largest reduction in emissions, so that for this set of projects minimising emissions resulted in maximising the minimum NPV and minimising regret. Given the findings of the literature in terms of the value of reputation, choosing the low emissions path should have some significant value to the firm in terms of *reputation and market perception effects*. But these benefits accrue to firms, reflecting their position relative to other firms, and not to sets of projects, and so these benefits cannot be quantified by this form of analysis. Firms would need to use other methods, taking account of their specific corporate circumstances, to estimate the value of the reputation effect accruing from the low emissions solution. These results show that, if the set of projects available were the only projects of the firm and the reputation effects in the literature apply, then the firm could expect its market valuation to increase in the vicinity of 7%.

The preferred suite 5 of the emissions cost model left a significant part (17.6%) of the capital budget unspent, giving rise to an *option value from deferral and enhanced investment flexibility*. However, real options calculations in such circumstances are challenging to undertake, but nevertheless consideration of real option value can indicate a way for management to consider investments in a suite of low emissions projects even if these do not appear as profitable under current market conditions. The robust optimisation modelling maximin solution identifies potential deferral option value without calculating that value.

The emissions quantity model is a different model from the cost model, as it is not maximising NPV in various conditions but jointly maximising NPV and minimising emissions, using multiple objective linear programming with robust optimisation. This approach was necessary due to the incompatible units between revenue and emissions.

In the emissions quantity model the maximin and minimax regret solutions also proved to be the same, with the same set of projects chosen (suite 11). The emissions quantity model selected a very similar set of projects to the emissions cost model (projects 1, 4 & 10 and projects 1, 4, 9 and 10 respectively). Due to the nature of the construction of the model all results were positive as permit costs were not included in the calculation of the NPV. Consequently the emission quantity model solutions ranged from $1,898 million to $27,778 million across all scenarios. Using the same modelling approach, the conventional NPV solution ranged from $7,996 million to $138,475 million, however, these figures do not include the cost of emissions permits. For the two solutions to be equivalent the cost of emissions permits would range from $189 to $1,998 per tonne or $21 to $222 per tonne depending upon which level of emissions reductions were mandated. The lower figures represent realistic values for emissions permits, however, due to the nature of this model the financial implications of the model are not as obvious and identifying stranded assets is more difficult. This suggests that the emissions cost approach is more likely to be a more suitable method to use than the emissions quantity model.

Nevertheless, if the emissions quantity solutions were chosen similar reputation and market valuation effects of 7% increased market valuation could be expected due to similar eco efficiency improvements as the emissions cost model.

The preferred emissions quantity suite 11 left a large part (71.7%) of the capital budget unspent which also gives rise to an option value from deferral and enhanced flexibility. Such a figure is dramatically larger than the emissions cost model and highlights the difficulty in calculating the optimal level of investment and deferral. Whilst this figure is not identified, the model does highlight the level of penalty that would be necessary for given levels of regulated emissions reductions

Clearly the broad implications of these results are limited by the characteristics of the particular case study to which the models have been applied. Nevertheless four conclusions emerge, as follows:

i. These forms of robust optimisation model do seem to be viable tools for firms to use for incorporating climate effects and uncertainties into capital budgeting and project selection, with the emissions cost model more effective in illustrating the costs and benefits.
ii. For a portfolio with significant variation in emissions intensity across potential projects, there are likely to be significant benefits from taking these effects into account, and hence potential gains to the firm in using such models in their planning process given ongoing uncertainties about climate change.
iii. Option value from deferral and increased investment flexibility may well be significant and are likely to be of greater significance if the level of uncertainty is higher. However, such values are difficult to calculate and this thesis does not calculate this value. Nevertheless, whilst the value is not calculated, some studies in the literature suggest maximin and minimax regret modelling can theoretically optimise option value from delaying projects without specifically quantifying the value.

While it is hard to relate the value of reputation effects arising from the pursuit of lower emission paths to the capital budgeting process (because they accrue to the firm rather than the project, and because of the difficulty of relating an increase in market value of the firm to the NPVs of individual projects), they will tend to work in the same direction as the other effects. If the projects studied were the only projects in the firm and if the full 7% were realised for the market valuation of the firm, then this would represent a significant gain for the firm.

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Chapter 1 Introduction

1.1 Introduction

Climate Change is shaping as one of the biggest challenges to face society and the economy in the 21st century and has potentially devastating effects. These effects include flooding due to sea level rise and increased rainfall in some areas with droughts in others, as well as habitat and species loss. Some economic impacts from Climate Change are predicted to have a substantially negative impact on the outputs of most economies (Stern, 2006). There will be a reduction in clean water and food supplies will also lead to security issues with enormous numbers of people moving from lower lands in an attempt to escape flooding (Barnett, 2003).

The potential impacts of Climate Change have led to various responses from governments around the world in an attempt to constrain emissions. The European Union (EU) introduced an Emissions Trading Scheme (ETS) in 2005, many states in the USA have introduced legislation promoting renewable energy and emissions trading schemes and it is likely an ETS will be introduced in Australia in the near future when the fixed price scheme is replaced with a floating price (Department of Climate Change, 2013).

The environmental, economic, social and security impacts due to Climate Change are related to, but distinct from, the business impacts associated with Climate Change (Carbon Trust, 2004). Climate Change affects businesses' reputation, shareholders, regulations and legal standing.

Corporations invest billions of dollars annually in projects that contribute to anthropogenic Climate Change through their emissions, thereby contributing to Climate Change and the dangers that it presents to the environment and society as well as the business impacts from emissions from the projects (Walsh, 2006).

Nearly all corporations select projects through the use of capital budgeting techniques (Graham and Harvey, 2002). At present there appears to be an absence of capital budgeting models in the Climate Change economics literature which examine voluntary reduction of greenhouse gas (GHG) emissions. This represents a significant gap in the knowledge required for the efficient allocation of funds in a carbon and financially constrained world.

1.1.1 Anthropogenic Climate Change

The Earth's atmosphere contains certain molecules which have the effect of increasing the average global temperature. This phenomenon is known as the greenhouse effect and was discovered by Joseph Fourier in 1824 (Cowie, 2007) and first reported quantitatively by Svante Arrhenius in 1896 (Crawford, 1996). Without the Greenhouse Effect it is estimated that the global average temperature on Earth would be approximately –18° Celsius, whereas with the Greenhouse Effect the global average temperature is approximately 14° Celsius(IPCC, 2013).

The molecules which cause this Greenhouse Effect include (in decreasing strength of effect): water vapour, carbon dioxide, methane and ozone as well as nitrous oxides and chlorofluorocarbons. The quantity of these molecules and the amount of Greenhouse Effect has varied throughout the Earth's history(IPCC, 2013). Currently the molecule of most interest is carbon dioxide (CO_2) as this is the molecule which human activity has increased in atmospheric concentrations. Paleo-climatic studies suggest the level of CO_2 has varied from 180 parts per million (ppm) through to 300ppm over the course of millions of years. The concentration was 270ppm before the Industrial Revolution began in the late 1700s. Since the Industrial Revolution atmospheric levels of CO_2 have been increasing as has the level of radiative forcing(IPCC, 2013). This is due to CO_2 being released into the atmosphere through the combustion of fossil fuels such as coal, oil and gas which led to the theory of an Enhanced Greenhouse Effect (Hansen, 2005).

1.1.2 Enhanced Greenhouse Effect (Callender Effect)

The Enhanced Greenhouse Effect was first proposed by Guy Callender in 1938 and is known as the Callender Effect (Fleming, 2007).

The concentration of CO_2 has increased from 270ppm prior to the Industrial Revolution to approximately 400ppm in 2013 (IPCC, 2013). The increase in CO_2 levels has been due to the strong correlation between economic development and energy consumption (Cleveland et al., 2000). This increase in CO_2 concentration and the corresponding Callender Effect has been the subject of an enormous amount of research over the past 25 years. The Callender Effect has become more widely known as Anthropogenic Climate Change or more simply Climate Change (Bolin, 2007).

1.1.3 Social, Economic and Environmental Impacts of Climate Change

The consequences of Climate Change include increased numbers of floods and droughts, sea level rise due to melting glaciers and thermal expansion of the oceans, destruction of habitat and associated species loss as well as the spread of tropical diseases such as malaria (Harvell et al., 2002). Ocean acidification due to increased absorption of CO_2 will have major effects on marine ecosystems as well as cause the loss of coral reefs due to increased temperatures (Orr et al., 2005). Agricultural yields could change significantly, increasing in some areas but decreasing in others (Olesen and Bindi, 2002).

The social and economic consequences of Climate Change will differ between developed and developing countries but both will experience issues of displacement, food and water security and damage to infrastructure (Stern, 2006).

The Commonwealth Scientific Industry Research Organisation (CSIRO) has undertaken research that suggests Australia is especially susceptible to the impacts of Climate Change and these impacts will have severe and extensive effects on the Australian economy (CSIRO, 2005).

1.2 Australian Greenhouse Gas Emissions

The GHG emissions produced in Australia are reported by the National Greenhouse Gas Inventory (NGGI) which is based on international reporting standards developed by the Intergovernmental Panel on Climate Change (IPCC). Under these reporting standards Australia is obliged to produce estimates of the emissions of six of the major GHG, namely carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), and sulphur hexafluoride (SF_6) (Department of Climate Change, 2009b). These gases have varying amounts of effect on Climate Change, stay in the atmosphere for different lengths of time and consequently are described as having different Global Warming Potentials (GWP). GWP is usually measured relative to CO_2 over a 100 year period and gives a CO_2 equivalent (CO_2e) value to estimate how much GWP a particular gas has (Armstrong, 2006).

Carbon dioxide is the most important GHG after water vapour, but as humans have no control over the amount of water vapour in the atmosphere it is CO_2 that all gases are measured against. CO_2 represents approximately 70% of the CO_2e emissions. Methane comprises the next largest contributor with 22% (Armstrong, 2006).

1.2.1 Greenhouse Gas Emissions Projections

Australia's per capita GHG emissions are amongst the highest in the world relative to Organisation for Economic Cooperation and Development (OECD) countries and they represent almost twice the average OECD per capita emissions (Garnaut, 2008). They have also increased markedly in the past two decades with the energy sector's emissions increasing by 36% between 1990 and 2005. These very high emissions are due to high emissions intensity from energy use as opposed to an energy intensive economy or very high per capita income. This is primarily due to the heavy reliance upon coal for electricity production which is exemplified in the state of Victoria which uses brown coal to produce electricity. Brown coal produces the most amount of emissions for electricity production than any other form and without any policy in place to mitigate emissions, Australia's emissions are set to quadruple by 2100 (Garnaut, 2008).

1.3 The Economics of Climate Change

Climate Change clearly has economic repercussions. Climate Change has an anthropogenic cause due to increased CO_2 emissions which stem from economic activity. This can be interpreted as a form of market failure where markets have not included the damage to the atmosphere that increased economic activity has caused and continues to cause. This is an example of a negative externality. Consequently, to address the problem of Climate Change an economic approach may be considered appropriate. While great uncertainty exists regarding the exact consequences of Climate Change, the general direction of these impacts and consequences are known. To address these impacts, mitigation (reducing CO_2 levels) or adaptation (adapting to the changed climate conditions) will be required(IPCC, 2013).

Some studies argue that adaptation will be forced upon business as they plan for the reality of increased extreme weather events (Mills, 2005); however, mitigation is a more vexed issue. Complex regulatory regimes have been established in some countries in order to facilitate this mitigation, with over 30 countries or regions having a price on carbon (Fekete et al., 2013) , and are proposed in others such as 2014 in China (Han et al., 2012). These regimes have been implemented as it is believed that, left to their own devices, firms will not voluntarily reduce emissions to the extent required to avoid runaway Climate Change.

There currently exist two main market-based approaches to Climate Change mitigation; emissions trading schemes and taxes on carbon dioxide emissions (Han et al., 2012). These regulatory changes will have a major impact on business. Other factors to impact on business stem from the reputation a firm may gain from its action or inaction to Climate Change. Reputation is an important issue for businesses with some scholars suggesting that up to 80% of the market value of corporations is due to non-tangible factors such as reputation (Kiernan, 2007). Consequently another factor for firms to consider is how shareholders may respond to any actions, or lack thereof, they may take with respect to Climate Change. Shareholders may also respond to any potential litigation a firm may encounter from negative actions on Climate Change; however, such litigation appears to be limited to the stationary energy sector.

Given that firms will face these issues in the future, this raises the issue of firms undertaking short-term costs for long-term gains as argued for in the Corporate Social Responsibility (CSR) literature (Kakabadse and Kakabadse, 2007, Weber, 2009). Many studies in this branch of corporate social responsibility literature suggest that it does pay for a firm to incur short-term costs where it is beneficial to either society or the environment or both (Jones and Bartlett, 2009).

However, there are many studies that suggest the opposite and that it is never in a firm's interest to incur such costs. One study incorporates both conclusions by suggesting that sometimes it may be in a firm's interests to incur some costs while in other conditions such costs will only reduce economic performance (Schaltegger and Synnestvedt, 2002). This is represented by two curves: one is an inverse U curve, indicating some CSR induced actions will improve economic performance while the other curve show only decreased economic performance with more CSR actions.

In this study, the short-term costs are in the form of voluntary emissions reductions, while the long-term gains manifest themselves through the beneficial effects of anticipating regulatory changes, improved reputation and positive shareholder response, avoidance of stranded asset and option value. In particular, this study examines the case of voluntarily reducing emissions incorporated into the assessment of large-scale, long-term projects. This assessment nearly always employs capital budgeting techniques.

This is an interesting case study to explore in terms of examining a potential method for assessing the benefits as large-scale long-term projects have the potential to define the emissions profile of a firm for up to several decades and therefore, given the context of Climate Change, a firm should give considerable attention to this issue in order to investigate the implications for the firm of such emissions.

1.3.1 Capital Budgeting

In the realm of corporate finance and investment capital, budgeting is an important topic (Bierman and Smidt, 2007a). Pike and Dobbins (1986) conclude that capital budgeting decisions can be some of the most difficult ones facing managers and decision-makers. The long-term repercussions of such decisions exemplify the difficulty and importance of the decision as significant sums of money are involved for long periods of time (Dayananda et al., 2002).

While this analysis does not include environmental aspects such as Climate Change, it does indicate the broader analysis that managers must undertake when making capital budgeting decisions. In addition, it emphasises the importance such investment decision have for society as a whole and it is logical to extend this conclusion to include Climate Change (Freeman and Ramakrishna, 2008).

1.4 Traditional Investment Decision Models

Traditional investment models based on return on investment (ROI), payback period (PB) and discounted cash flow methods (DCFM) are widely used to evaluate investment projects in practice. Theoretically DCFM, that is net present value and internal rate of return, are the most preferred methods for evaluating investment decisions. To use DCFM three estimates are required:

- A forecast of annual net cash flows;
- A discount rate; and
- An estimated life of the project (Dayananda et al., 2002).

In theory a company should invest in the project if the Net Present Value (NPV) at the target discount rate is greater than zero or if the Internal Rate of Return (IRR) is greater than the firm's cost of capital (Bierman and Smidt, 2007a).

However, the use of traditional DCFMs for assessing all forms of potential projects has been subject to criticism. This has been focused on the need for quantitative data that may not necessarily capture intangible benefits and costs as well as being biased towards particular investments through the use of high discount rates which reinforces investment in projects with short payback periods and penalises long-term projects (Pinches, 1982, King, 1975, Pike, 1989).

This suggests that while DCFMs are theoretically sound in a market free from additional factors such as Climate Change, the very existence of Climate Change alters the investment setting and requires such factors to be included in the project assessment stage.

In addition, DCFMs traditionally incorporate a project's risk by setting an arbitrarily high hurdle discount rate. There are two main criticisms of this approach. Firstly, setting a high hurdle rate makes the approach even more heavily skewed towards short-term projects. The discount rate is supposed to encapsulate the time value of money and the riskiness of expected cash flows, rather than some unspecified project risk. As the risk involved in a project includes other factors as well as cash flows such as Climate Change risks, the use of a high discount rate to assess a project's risk is inappropriate. Also, adjusting the discount rate reflects the decision-maker's attitude to risk as opposed to an objective assessment of the project's risk (Abdel-Kader, 1997).

1.4.1 Investment and Climate Change

The assessment of Climate Change issues in project appraisal is inherently complex due to the uncertainty of Climate Change. Nearly all aspects of Climate Change have large degrees of uncertainty in many dimensions: the amount of climate change that may be expected from given level of concentration of GHGs in the atmosphere, the economic effects of that change, the emissions concentration trajectory, the severity of the regulatory response in attempting mitigation, and so on. The list of uncertainties is extensive and diverse. This analysis is also complicated by the conclusions drawn by some studies that an increase in regional temperatures may have a local beneficial effect, for example through increased crop yields. The economic study of Climate Change is further complicated by the concept of irreversibility. Irreversibility was first discussed by Arrow and Fisher (1974) in their landmark study concerning environmental preservation, uncertainty and irreversibility. Arrow and Fisher suggested that if the damage to a particular environmental asset was likely to be irreversible (for example, species extinction or forest cover) and the relative benefits of conservation and development were uncertain then preserving that asset had a value, an option value, in order to keep options open in the future, and this value should be taken into account when assessing such a development. Such logic applies to Climate Change as its effects are considered to be irreversible in the time frame of human civilisation. However, irreversibility has two facets; environmental irreversibility (discussed above) and financial irreversibility. Financial irreversibility is commonly thought of as sunk costs; once an investment is made, it may be all but impossible to retrieve those funds should the project be unsuccessful. Financial irreversibility concerns the sunk cost of environmental degradation; while environmental irreversibility is related to the sunk cost of environmental policy. The two irreversibilities pull in opposite directions: financial irreversibility leads to more pollution and a lesser or later policy while environmental irreversibility generates less pollution and a larger or sooner policy.

The relative importance of both should be examined in order to provide a comprehensive analysis of a project. However, irreversibility can also be viewed by its reciprocal, flexibility, which is simpler to model. Increased irreversibility means decreased flexibility, and decreased irreversibility means increased flexibility. Consequently where Climate Change is concerned it would appear that an approach that increases flexibility is prudent.

Therefore if Climate Change is to be included in the assessment of large-scale, long-term projects, Climate Change factors should be included in the project appraisal. This presents a difficult task, because when assessing the case of voluntarily reducing emissions it is uncertain how strict regulations may become and also uncertain what the optimal level of emissions reductions are. In addition, it is uncertain what type of regulatory response will occur, be it a price instrument or a quantity instrument. Consequently, if a firm decides to voluntarily reduce emissions it is unclear how big a reduction they should undertake, and if they should also maintain investment flexibility should the level of emissions reduction undertaken prove either too large or too small.

The standard form of project appraisal is capital budgeting which examines projected cash flows at a given discount rate to arrive at a net present value. Linear programming techniques are often employed in capital budgeting calculations when capital rationing is present. Linear programming involves maximising or minimising an objective function given certain constraints. However, such an approach does not take into account uncertainty, not does it consider competing goals such as minimising pollution while maximising NPV.

Traditional linear programming has been extended in recent times to goal programming and multiple objective linear programming which specifically take into consideration multiple goals. Multiple objective linear programming is suitable here given the aim of reducing emissions while also maximising net present value.

1.4.2 Modelling Uncertainty

With respect to uncertainty, there are several modelling techniques to take into account when making investment decisions. These include, but are not limited to, sensitivity analysis, Monte Carlo simulation, Stochastic Programming and Robust Optimisation. Unfortunately, most of these techniques are inappropriate for an investment decision model which includes Climate Change. Sensitivity analysis is an ex post instrument which assesses the impact of small changes on the decision that has already been made and therefore does not incorporate uncertainty into making the actual decision, rather this approach assesses small changes in parameters after a decision has been made.

Specifically, sensitivity analysis with linear programming models can provide the range of values the objective function can assume without changing the optimal solution, the impact on the optimal solution due to changes in constraints as well as the impact on the optimal objective function value of forcing changes in the values of certain variables away from their optimal values. However, this analysis must be performed ex post and analyses the sensitivity of a decision that has already been made as opposed to incorporating uncertainty into the making of the decision. If this were the case, a very different decision may have been made.

Conversely Monte Carlo simulation does take uncertainty into consideration when making a decision; however, Monte Carlo simulation has two drawbacks which make it unsuitable for such a model. First, it requires probability distributions in order to generate the simulations and with Climate Change such probability distributions are unknown and unknowable. Second, once a simulation has been generated a single figure representative of the central tendency, for example, the mean or median, must be used in making the decisions. In the case of Climate Change, central figures are of limited use as they weigh against high impact, low probability scenarios which should not be discounted due to their importance in climate settings and, by extension, their potential importance in generating regulatory responses to the state of the climate.

Stochastic Programming is able to take such extreme scenarios into account during the decision-making process due to the incorporation of scenarios; however, the traditional Stochastic Programming model is a recourse model. The recourse form of modelling involves an initial decision, a random event defined by a probability distribution follows and then a recourse decision is made in light of the random event. This form of modelling is not applicable to one-off decisions as opposed to two stage decisions as well as problems lacking a meaningful probability distribution. Unfortunately, the data available for this study does not specify recourse decisions nor have probability distributions for the reasons outlined above. Given these limitations, for the purposes of this study this leaves Robust Optimisation as a preferred approach

1.4.3 Robust Optimisation

Robust Optimisation makes use of scenarios but does not assign probabilities to the scenarios and consequently does not weigh a solution against a less likely but catastrophic scenario. The parameters for the scenarios are determined by the decision-maker, as are the values for the parameters for each scenario. Consequently, the successful implementation of robust optimisation is dependent upon judgements made by the decision-maker, or expert advice to that effect, as to which parameters are pertinent and the values of those parameters. The parameters and values of the parameters constitute the uncertainty set. Uncertainty sets take many forms, such as finite distributions within an oval set space to discrete point values. This study utilises discrete point values.

There are different forms of robust optimisation known as constraint robustness and objective robustness. The difference between the two lies in where the variable parameters are located in the model. If the variable parameters are in the constraints of the model then it is constraint robustness and objective robustness if they lie in the objective function.

The variable parameters in the models to be developed in this study lie in the objective function and consequently the models employed are examples of objective robustness.

Decision Criteria

Within the Robust Optimisation framework there are several decision criteria, namely Absolute Robustness, Robust Deviation and Relative Robustness. Absolute Robustness compares the performance of the optimal solution for each particular scenario in all other scenarios. The absolute robust decision criterion selects the solution that has the best worst case performance in all of the scenarios.

Robust Deviation compares the optimal solution for each scenario with other scenarios by assessing how much less the value of that solution is compared to the optimal solution for a given scenario. This determines the level of regret and the robust deviation decision criterion selects the one which minimises the maximum level of regret. Relative Robustness is calculated in the same way as Robust Deviation but instead of absolute values the figures are first converted into percentages and then the level of regret is calculated. For this study the Absolute Robust and Robust Deviation decision criteria will be utilised to examine the implications of the two approaches.

Variable Parameters

The variable parameters relevant to assessing the business case for voluntary emissions reductions or long-term, large-scale investments include a price on GHG emissions or a physical GHG emissions reduction. In addition, given the study utilises capital budgeting, additional parameters included are the discount rate and cash flow.

Whether a given price is allocated to GHG emissions or a specific emissions reduction quantity is mandated is uncertain itself, as well what level that price or physical reduction might be. Consequently, for a firm to evaluate whether it is in its own interests to voluntarily reduce emissions such uncertainty must be taken into consideration. Consequently two models will be developed, one which incorporates a price on GHG emissions and another which models absolute GHG emissions reductions.

The discount rate is included as a variable in the study as the selection of a discount rate is a contentious issue, especially in the context of the environmental implications of projects. Many studies have suggested that for the welfare of future generations to be given equal weight then a discount rate of zero should be used, while others suggest that the discount rate should reflect the cost of capital or the government bond rate as the riskless rate (Dasgupta, 2008, Schillizi, 2003). The argument for the inclusion of a risk premium in addition to the riskless discount rate is rejected in this thesis and the use of the discount rate as a variable parameter suitably examines the impact of the discount rate on the value of a given suite of projects. In this thesis a range of values for the discount rate will be included in the uncertainty set to explore their impact on project appraisal due to the uncertainty of the cost of capital.

Cash flows are also included as a variable parameter, as cash flow projections are routinely inaccurate and are often overstated by a large percentage (Berkman et al., 2000). As cash flows are central to the calculation of a net present value, their variability must also be captured in the model.

In order to provide a baseline to compare these models against, a conventional NPV model will also be created which has no reference to emissions in its construction and does not incorporate any variability in either discount rate or cash flow.

The emissions cost model and the emissions quantity model will both have two decision criteria, the Absolute Robust and Robust Deviation criteria, resulting in four investment decision solutions to be evaluated.

The solutions from the decision criteria will then be examined in terms of the flexibility of such solutions, as flexibility is the reciprocal of irreversibility. If the decisions increase investment flexibility then irreversibility is decreased and vice versa. This is a form of real options analysis of the solution, whereby increased flexibility has an option value (Pommeret and Prieur, 2009).

In addition, the potential benefits for a firm due to eco-efficiency improvements are also examined. This benefit is believed to derive from corporate social responsibility (CSR) actions to improve environmental performance which, in turn, lead to an improved reputation. Reputational gains are difficult to measure but some studies have linked reputation and eco-efficiency rating. Such an analysis has been undertaken by Guenster, Bauer et al. (2010) who examined the Tobin's *Q* of firms as per their eco-efficiency and market valuation. Guenster, Bauer et al. analysed a large database of monthly eco-efficiency values and established a positive but non-linear relationship between eco-efficiency and a firm's Tobin's Q. They suggest that the relationship strengthens with time and conclude the market responds to environmental information with a drift. They state poor environmental performers exhibit a significant underperformance which can be up to a 7% difference in market valuation.

The approach of examining the emissions levels, the net present value, the flexibility of the investment decision and the reputational benefits due to eco-efficiency benefits, enables the possibility to explore the conditions in which voluntarily reducing emissions by incorporating GHG emissions in the appraisal of long-term, large-scale projects is in the interest of the firm. This idea is illustrated by Schaltegger and Synnestvedt's (2002) inverted U curve that compares economic value and CSR initiatives.

1.5 Structure

This thesis is divided into 8 chapters in order to develop a conceptual framework and model to examine the business case for voluntary GHG emissions reductions.

Chapter 2 examines the literature of corporate governance, capital budgeting and economic modelling of Climate Change.

Chapter 3 deals with the development of a new conceptual framework involving theories and principles applicable to corporate governance and in particular CSR and Climate Change. It also provides a detailed theoretical justification of the elements of the approach to evaluate the business case of voluntary emissions reductions.

Chapter 4 introduces the research methodologies in this field and the process involved in model building and data collection.

Chapter 5 details the specific model constructed and the justification of the methodology chosen for the model used. It also describes the procedures for the proposed model as well as the assumptions, data sources and method for data collection for both models.

Chapter 6 deals with results from the two models using the case study data. The results and comparisons of the different versions of the models will provide the empirical data for the analysis in Chapter 7.

Chapter 7 discusses the implications and recommendations obtained from the results and analysis.

Chapter 8 summarises the preceding chapters and draws conclusions about the business case for voluntary emissions reductions and model developed to assess it, the implications of the model developed, its efficacy and applicability for the corporate world.

1.6 The Scope

The model and plan will not be limited to a specific industry but rather be a generic model and policy which may be applied to any sector of the economy. However, the scope of emissions examined will be limited to Scope 1 and 2 emissions for each potential project being examined but not Scope 3 emissions. Scope 1 and 2 emissions refer to the direct and indirect emissions generated by a project. Scope 3 emissions refer to the emissions produced by all suppliers to a particular organisation (Bolin, 2007). To establish scope 3 emissions normally requires an organisation to survey their entire supply chain which is an administratively complex, expensive and difficult process to undertake. Therefore Scope 3 emissions will not be included in the assessment of projects in this model and framework.

Chapter 2 Literature Review

The purpose of this chapter is to review the literature relevant to the research being undertaken. The aim is not only to discuss the results of previous studies but also to highlight the conflicting evidence and controversies identified by other scholars in the field.

Climate Change is a well-recognised problem within the scientific community and is becoming more recognised within society and the business and economics community (Ridehalgh, 2007). As a result research has been undertaken to address the issues presented to business by Climate Change (Walsh, 2006). Different perspectives and approaches have been taken to address these issues. Some research has viewed the problem through corporate governance (CERES, 2006), some through risk management (AGO, 2006) but the literature examining the business case for voluntary emissions reductions is lacking.

As the current literature in the area is limited and unfocussed, this chapter will explore the different elements of the approach which will be described in subsequent chapters. This will demonstrate the contributions the various approaches can make towards both providing a theoretical justification for the approach taken and informing the construction of the model.

Corporate governance literature will be examined in the way it addresses Climate Change, how environmental accounting methods have considered the issue of Climate Change as well as capital budgeting techniques for investment decisions. While it appears Climate Change is not an issue that has been addressed in the capital budgeting literature, understanding the state of the research and methods used are paramount for adapting existing techniques to address these issues..

The review will first describe the basic concepts and then the literature in each area will be examined.

2.1 Basic Concepts

In this section the concepts of Climate Change, corporate governance, corporate social responsibility environmental initiatives, uncertainty, irreversibility and option value will be analysed in order to understand the basic issues and the methodologies concerned with examining Climate Change and voluntary emissions reductions for business.

2.1.1 Climate Change

Climate Change is any long-term significant change in the average weather of a region or of the earth as a whole. Average weather may include average temperature, precipitation and wind patterns. It involves changes in the variability or average state of the atmosphere over durations ranging from decades to millions of years (Forest et al., 1999). These changes may be caused by dynamic processes on Earth, external forces including variations in sunlight intensity (Willson and Mordvinov, 2003) and more recently by human activities (Cowie, 2007).

In recent usage, especially in the context of environmental policy, the term 'Climate Change' usually refers to changes in modern climate. The causes of recent Climate Change have been the subject of considerable research in the recent decades. This effort has focused on changes observed during the period of instrumental temperature record, when records are most reliable; particularly on the last 50 years, when the impact of human activity has grown fastest and observations of the upper atmosphere have become available (Solomon et al., 2009). The dominant mechanisms to which recent Climate Change has been attributed all result from human activities which include:

- Increasing atmospheric concentrations of greenhouse gases;
- Global changes to land surface, such as deforestation; and
- Increasing atmospheric concentrations of aerosols (Barnett, 2005).

Recent reports from the Intergovernmental Panel on Climate Change report (IPCC, 2013) have concluded that:

> "it is certain that increasing atmospheric burdens of most Well Mixed Green House Gases, especially CO2, resulted in a further increase in their Radiative Forcing from 2005 to 2011" (IPCC, 2013 technical summary p53)
>
> It is extremely likely that human activities caused more than half of the observed increase in global average surface temperature from 1951 to 2010 (IPCC, 2013 technical summary p80)

Whilst there have been dissenting views, the panel represents the broad consensus in the scientific community, defines 'very likely', 'extremely likely', and 'virtually certain' as indicating probabilities greater than 90%, 95%, and 99%, respectively. (IPCC, 2013 Technical Summary p36)

2.1.2 Corporate Governance

While different definitions of corporate governance exist, there is general consensus that it concerns the policies and customs as well as the laws and institutions that affect the way corporations are run or administered. Corporate governance is also considered to include the relationships between the many stakeholders and the goals of the corporation. The main stakeholders for corporations are the shareholders and the board of directors, as well as the employees, suppliers, customers, lenders, regulators, the broader community and the environment (Solomon, 2007).

2.1.3 Uncertainty and Climate Change Economic Models

Climate Change is characterised by uncertainty and the economic models constructed to examine Climate Change have had to incorporate this central tenet into their analyses. This is consistent with most environmental economic analyses. Economic analysis of Climate Change includes (whether implicitly included or explicitly stated) three stages:

- What state will the climate be in?
- What does a particular climate state mean economically?
- What is the optimal policy decision for emissions? (Szijártó, 2012)

The approach to answering these questions and the uncertainties inherent in them varies enormously.

2.2 Corporate Governance

In general, corporate governance involves the policies and structures of an organisation including factors such as processes, decision-making, accountability, control, and behaviour at the top of organisations. The Cadbury Report (1992) defined corporate governance as 'the system by which organisations are directed and controlled'. In the Australian setting, the Australian National Audit Office (1999) stated that it 'encompasses authority, accountability, stewardship, leadership, direction and control exercised in an organisation' while the Australian Securities Exchange Corporate Governance Council (ASX CGC) defines corporate governance as:

> … the framework of rules, relationships, systems and processes within and by which authority is exercised and controlled in corporations. It encompasses the mechanism by which companies, and those in control, are held to account.

> Corporate governance influences how the objectives of the company are set and achieved, how risk is monitored and assessed, and how performance is optimised. Good corporate governance structures encourage companies to create value (through entrepreneurialism, innovation, development and exploration) and provide accountability and control systems commensurate with the risks involved. (ASX CGC, 2007 p3)

The responsibility for corporate governance rests with the board of directors and, as a consequence, many guidelines and principles, including the ASX CGC, concentrate on the board structure and effectiveness. Most governance guidelines cover such things as board appointments and composition, board independence, board structure, systems and processes, voting methods, equity, values, codes of ethics, reporting and accountability, transparency, role of stakeholders, and performance evaluation and review (Standards Australia, 2004).

A commonly accepted set of principles have been established including:

- Rights and equitable treatment of shareholders;
- Interests of other shareholders;
- Role and responsibilities of the board, for example, being able to deal with an assortment of issues and challenge management performance;
- Integrity and ethical behaviour: this is important in terms of public relations as well as being an precondition for effective risk management and avoiding litigation; and
- Disclosure and transparency (Morck and Steier, 2005).

Despite these principles, the issue of corporate governance has remained important due to the collapse of several large corporations in the United States in the early 21st century. These collapses were largely seen to be due to corporate governance issues of supply and demand of accounting information, as well as monitoring costs (Clarke, 2008).

2.2.1 Corporate Governance Theoretical Frameworks

The study of corporate governance has led to the development of theoretical frameworks to understand the way corporations are managed and to make recommendations to improve management practices. These theoretical frameworks stemmed from Berle and Means' (1932) analysis of corporations which suggested that the ownership of corporations had become so widespread and dilute that managers were no longer accountable. This lack of accountability led managers (agents) to not always make decisions in the best interests of the owners of the firm (principals). Through various studies this manager-principal dichotomy eventually led to the formation of Agency Theory (Jensen and Meckling, 1976) which has become one of the dominant theories of corporate governance. The principals establish and use corporate governance mechanisms to deal with the agency problem. However, in the 1980s, managerial excesses due to corporate governance mechanisms which rewarded management with enormous share options and a focus on short-term share price prompted the development of Stakeholder Theory. This suggested that corporations had a wider responsibility than just to its shareholders (Freeman, 1984). Agency Theory and Stakeholder Theory will be discussed, as these corporate governance theories are central to the understanding of the way a corporation functions. While other theories exist, these are the most significant in theory and practice (Psaros, 2009).

2.2.2 Agency Theory and Stakeholder Theory

Agency Theory

Prior to the emergence of the managerial view of corporations or Agency Theory, neo-classical economic theory was the dominant conceptual framework when analysing corporations. Neo-classical economic theory was based on four key assumptions:

- Supply and demand determine price;
- Markets are perfectly competitive;
- The only objective of a firm is profit maximisation; and
- Firms have perfect knowledge about future events.

The managerial view of a company questions these assumptions. For example, if management was responding purely to the market to maximise profits then an owner or manager should act in the same way and consequently neo-classical economic theory could not explain differences between owner-managed and manager-controlled companies (Clarke, 2004).

By the 1970s, the work of Coase (1937) began to influence ideas about corporations. The central question proposed was if the market is the price setter, why does the decision-making process within firms come before price is set? Consequently Coase questioned two more assumptions of neo-classical economic theory with uncertainty considered to be an inherent part of process of negotiating contracts in the marketplace. Therefore, contrary to neo- classical economic theory, Coase concluded firms did not act with perfect knowledge and Coase consequently introduced a new term: 'transaction costs'. These costs were due to uncertainty. According to Coase, the way firms act is due to their attempts to minimise these transaction costs.

Authors such as Alchian and Demsetz (1972) criticised Coase's transaction cost theory by disputing the role of management and where their authority came from. Alchian and Demsetz suggested that the firm is a market place where managers do not direct or authorise but rather negotiate contracts; hence the corporation is a setting which involved a nexus of contracts. That is, the manager may order the worker to perform a task to do something but in return the worker orders the manager to pay him. In this conceptual framework, shareholders were the monitoring agents to keep the managers and workers from becoming inefficient.

Jensen and Meckling (1976) added to Alchian and Demsetz's nexus of contracts analysis by arguing that the relationship between shareholders and management was one of principal and agent, thereby formulating Agency Theory. However, as the manager knows more about the inner working of a particular firm than the shareholders there arose the potential for conflicting goals. This led Jensen and Meckling to propose a new concept of agency costs. Agency costs stem from the potential for managers to maximise their wealth at the expense of the shareholders, the tendency for managers to focus on short-term performance at the expense of long-term growth and the different attitudes managers and shareholders have towards risk. Attitudes to risk have been another area of considerable research based on a risk-averse assumption, as suggested by Von Neumann and Morgernstern (1944). This assumption was later disputed by Tversky and Kahnemann (1974), showing people demonstrate both risk- seeking and risk-averse behaviour depending upon the circumstances. Jensen and Meckling argued that shareholders will only bear agency costs if earnings flowing to them are more than these costs. However, measuring agency costs is very difficult. Nevertheless Jensen and Meckling suggest they are decreased by a number of market mechanisms, for example hostile takeovers, so managers have an incentive to keep agency costs down. This can be done through *ex ante* mechanisms such as share options, audits and non-executive directors.

Stakeholder Theory

The excesses of firms and managers' fees, combined with a recession in late 1980s, generated some disquiet about market solutions for stakeholders such as employees, consumers and the general public. As a response to this, stakeholder efficiency arguments began to appear and Freeman proposed Stakeholder Theory to explain the governance of a firm (1984). Freeman and Evans (1990) extended this argument saying stakeholders are risk takers like shareholders and the structure of the firm should reflect this.

Stakeholder Theory questions the assumption that the only important relationship is between the agents (managers) and the principals (shareholders) as proposed by Agency Theory (Freeman, 1984). Stakeholder Theory takes a much broader view of the firm, where shareholders are only one of many stakeholders which could include creditors, employees, government authorities, society at large and even the environment. The justification for development of this theory is that all of the above stakeholders are affected by the corporation, not just shareholders. Society and the environment are included in the list of potential stakeholders, as society provides the necessary infrastructure in which the corporation can thrive and society relies upon a healthy environment (Freeman, 1984). The development of this theory has been very important, as it gave critics of Agency Theory a conceptual framework not only to criticise Agency Theory but also to suggest an alternative approach. With increasing environmental concerns and questions about impacts on society, Stakeholder Theory could not only explain behaviour but give guidance for future action (Psaros, 2009). In addition to the moral argument that considering a broader range of stakeholders is the correct thing to do, Clarkson (1994) suggested that Stakeholder Theory can help a corporation achieve its goals.

As such Stakeholder Theory can be viewed as a descriptive theory, as it describes the way a corporation functions, as well as a normative theory as it recommends structures and practices, including the often neglected idea that not all stakeholders can be treated equally, nor be involved in all decision-making processes (Russo and Perrini, 2010).

Agency Theory Compared with Stakeholder Theory

There is no definitive conclusion as to the superiority of either theory and ultimately it is a judgement as to which theory is more valid. Agency Theory may be considered to come from a more traditional finance and economics perspective while Stakeholder Theory stems from a more socially oriented perspective. However, broader acceptance of Stakeholder Theory can be seen through the increasing impetus towards Corporate Social Responsibility (CSR), which is an expected development if a stakeholder perspective is accepted and recognises that good moral decisions make good business decisions. This is in stark contrast to the oft-quoted Milton Friedman (1962) who suggested the only responsibility of a corporation was to make as large a profit as possible.

Whichever view is taken, these studies have been critically important as they explore and prescribe the ways corporations behave. As the corporation has a central place in modern economic life these issues are also important.

2.2.3 Corporate Governance Models: Australia and Internationally

In addition to governance theories, corporate governance practice has been examined in the literature according to national traits, leading to the description of Insider or Outsider models. These terms refer to the extremes of a continuum of corporate governance practices, as every country exhibits their own unique form of corporate governance with some factors more pronounced than others. Ultimately the type of corporate governance is influenced by many issues ranging from, but not limited to, ownership structures, but also cultural and historical patterns, the legal system and the state of the economy (Solomon, 2007).

Despite this there are certain similarities in corporate governance practices and models that lead some countries to be grouped together. For example: Anglophone countries such as the United States, the United Kingdom and Australia are often grouped together as practitioners of the Outsider Model, whilst Germany, France and Japan are often considered to employ the Insider Model (Bebchuk and Weisbach, 2012).

Outsider Model

Central to the Outsider Model is the assumption that there is a separation between the ownership and control of the corporation. In addition, it is assumed that ownership is widespread and diluted, and therefore no one individual shareholder has sufficient ownership rights to influence the day-to-day running of the corporation. This is consistent with Berle and Means' (1932) analysis as well as the issues of transactions and agency costs described by Coase (1937) and Jensen and Meckling (1976) respectively. If shareholders are not happy with the way management is performing its duties it is assumed the most likely course of action is for the shareholder to sell their shares on a liquid and transparent share market (Clarke, 2008).

The overall theme of the Outsider Model is of a free market in a clearly defined and upheld legal framework with strong and liquid securities markets, where hostile takeover is the ultimate disciplinary tool for management. However, the weaknesses of the Outsider Model include the potential for Agency Costs, the short-term time frame for managers, especially CEOs who only last a few years in the position (Weimer and Pape, 1999, Goyal and Park, 2002) and the high cost of corporate failures (Clark, 2005).

Insider Model

The Insider Model, also known as the bank-based model or institutionally based model, takes a different perspective on Corporate Governance. Despite some differences, Germany, France and Japan are considered to practice the Insider Model of Corporate Governance (Clarke, 2008).

A major difference between the Insider and Outsider Models is that the degree of separation between owners and managers is much less with the Insider Model and as a result there are fewer agency costs. Another repercussion of banks having a major stake in a corporation is the inclination for banks to bail out the firm should it experience financial problems (Jo and Harjoto, 2011).

In Germany the structure of the board also differs from the Outsider Model as it has a two tier structure consisting of a supervisory board and a management board. The supervisory board consists of shareholder representatives and employee representatives (Morck and Steier, 2005); a practice that would be unthinkable with the Outsider Model and demonstrates the Insider Model is more consistent with Stakeholder Theory than the Outsider Model (Bhasa, 2004).

The idea of the fundamental purpose of the firm represents another significant difference between the two models. The Outsider Model presupposes that the purpose is strictly to create shareholder value whilst the Insider Model takes a wider view of the objective of the firm. With the Insider Model the firm is considered an economic and social entity with numerous participants striving for continuity of the firm as a whole (Weimer and Pape, 1999). In Japan shareholders also have a more symbolic and strategic attachment to shares other than simply as a vehicle to increase wealth (Psaros, 2009).

While the Insider Model reduces agency costs, it also has risks associated with it. In particular, the minimisation of the separation of ownership and control can be considered both a strength and a risk. The risk is that minority shareholders may be ignored, which may act as a barrier for potential shareholders investing in the company (Solomon, 2007). Also the Insider Model is usually associated with significant government input in the running of the company and consequently it has been suggested political imperatives may negate good managerial practice (Aguilera and Jackson, 2003).

Outsider Model Compared with Insider Model

Due to the many factors influencing the type of corporate governance model in any particular country, it is very difficult to proclaim which system is best. One type of corporate governance may suit one country but not another. It is also very difficult to rate the pros and cons of the two systems. Consistent with this, the OECD states that 'there is no single model of good corporate governance' (OECD, 2004 p13).

2.2.4 Corporate Governance and Economic Performance

The perceived benefit of good corporate governance practices is that they will lead to improved economic performance, by allowing the firm to operate more effectively and the management to make better decisions and lead to increased prosperity (Dallas and Bukspan, 2006).

The literature contains abundant studies that provide empirical support of the notion that good corporate governance leads to improved economic performance. Gompers, Ishii and Metrick (2003) constructed a good corporate governance index and showed that investment in firms in the top 10% on their index produced abnormally high returns. Brown and Caylor (2006) found that firms with good corporate governance were more profitable and had higher returns. However, the research is not conclusive, with numerous studies suggesting the opposite and that there is in fact no link between good corporate governance and improved economic performance (Kiel and Nicholson, 2003, Linden and Matolcsy, 2004). The conclusion to be drawn from this is that good corporate governance *may* lead to improved economic performance but the evidence is inconclusive. Despite this, good corporate governance does appear to play a significant role in improving transparency and accountability, with a great deal of empirical evidence to support this conclusion (Bonazzi and Islam, 2006, Morck and Steier, 2005). In addition, even if the direct empirical link between good corporate governance and economic performance is ambiguous, the appearance of good corporate governance would appear to be valued by investors (Psaros, 2009).

2.2.5 Corporate Social Responsibility

There are many definitions of Corporate Social Responsibility (CSR). However, common to most definitions is that it is more than just complying with the minimum legal requirements or a form of charity. Within the Australian setting, CSR has evolved from the field of corporate governance to include a responsibility towards the environment and society, including environmental and social reporting, as well as a commitment to consider the firm's stakeholders. CSR appears to have drawn heavily upon Stakeholder Theory as detailed above (McWilliams and Siegel, 2001).

A review of CSR practices in Australia by Anderson and Landau (2006) identified numerous CSR initiatives by businesses in Australia. These included, but were not limited to, CSR mission statements, employment policies, social and environmental reporting, pro bono work, employee volunteering, partnerships with non-profit organisations. However, doubts about the motives and extent of the CSR related activities remain. Nevertheless for some firms it would appear they increasingly take an integrated and strategic approach to CSR (Jo and Harjoto, 2011)

The international experience of CSR suggests that activities and attitudes vary widely from region to region (Zerk, 2006). Despite this, some generalisations can be made. It would appear that in North America and Europe CSR focuses on community and environmental activities as well as stakeholder engagement, whereas in Africa, for example, CSR activities centre on poverty reduction and health issues (Thilmany, 2007, Mackey et al., 2007, Kiernan, 2007, Berger et al., 2007). CSR has been viewed as an extension of the responsibilities that come from corporate governance obligations. This becomes apparent if corporate governance is viewed from a Stakeholder Theory perspective as described above.

2.2.6 Corporate Governance and Corporate Social Responsibility

As both Corporate Governance and Corporate Social Responsibility are concerned with the issue of firm's management practices and they have occasionally been confused with each other and whether CSR is part of Corporate Governance or vice-versa. It is generally accepted that CSR is based on self-regulatory principles linked to internal and external management of the company. As discussed above, corporate governance, is a broad issue of company management practices. It involves the conduct of board of directors and the relationship between the board, management and shareholders. The corporate governance framework is the widest control mechanism, both internally and externally to stimulate the proper and efficient use of corporate resources and in the same way to require accountability for taking care of those resources (Harjoto and Jo, 2011).

From this perspective Corporate Governance is the broader issue of management of a company than CSR. The Australian Parliamentary Joint Committee on Corporations and Financial Services considers CSR as a part of total governance framework where it states "corporate responsibility is only one aspect of an organisation's governance and risk management process. "In addition, CSR has also been mentioned as one the four pillars on which the edifice of corporate governance built. The four pillars are:

1. compliance with all regulatory requirements;
2. equitable treatment of all stakeholders such as suppliers, employees, consumers and so on;
3. full and fair disclosure of all material information with specific stress or emphasis on accurate and objective presentation of financial information; and
4. respects for norms of business and social responsibility (including environmental responsibility) (Harjoto and Jo, 2011, Lawrence et al., 2013)

2.2.7 CSR and Economic Performance

Research into the empirical questions has been beleaguered by many methodological difficulties such as issues of causality, but there has been some evidence to suggest a positive correlation between CSR and profitability (Kakabadse and Kakabadse, 2007). This is also supported by such indices as the Jantzi Social Index, which compares the performance of socially responsible investments to other portfolios (Willis, 2003). Vogel (2005) suggest that CSR initiatives are a function of an external market for virtue, and that markets vary in their demand for CSR from country to country and from sector to sector, just as they vary in their demand for other factors such as price and quality. According to this hypothesis, a firm may participate in a market which rewards CSR initiatives highly. Conversely customers, the financial markets or other stakeholders may have little interest in CSR. This inconsistency in the response to CSR suggests some markets can be characterised as being socially conscious while others fall into a more traditional standard economic framework, which is more sensitive to factors such as service, quality and price. According to Vogel (2005), this suggests that CSR does make business sense for some firms in some contexts, but not all companies in all contexts.

Further to this, it is argued that if a firm does undertake such activities then reaction from the market in the form of limited access to capital and hostile takeovers may cause management to reconsider such activities (Jensen and Meckling, 1976). Conversely some business people and scholars suggest that firms have a duty to society and the environment that goes beyond simply maximising wealth of equity holders. These business people and scholars suggest that such a restricted view of corporate goals will lead management to pay no attention to important stakeholders, including the environment. Sometimes the interests of these stakeholders should take priority over those of equity holders and this conflict can be resolved by socially responsible behaviour that improves the firm's value (Mackey et al., 2007).

The next section will specifically examine environmental aspects of CSR activities and how such actions relate to economic performance.

2.2.8 CSR Environmental Initiatives

The natural environment is increasingly being viewed as a pillar of CSR. Research on CSR and environmental sustainability in the management literature is converging because of shared environmental, economic, and social concerns (Montiel, 2008). In recent years, the environment has been one of the factors of greatest interest in terms of the market's attitude toward (Bird et al., 2007). Some reports point at improved financial performance as a result of environmental performance development. Similarly, Welford et al. (2007) and Kassinis and Vafeas (2006) found the environment to be the most important concern for stakeholders in a company's CSR efforts.

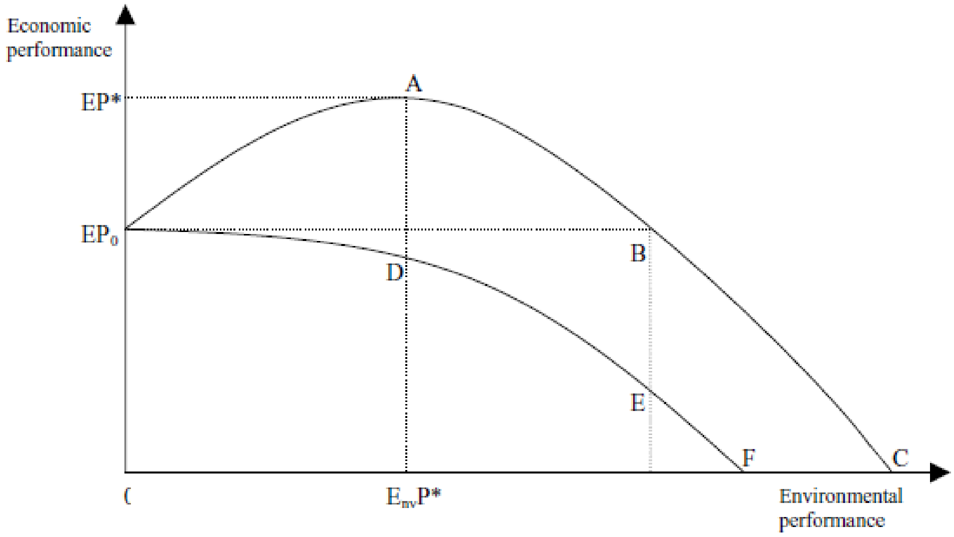
2.2.9 CSR Environmental Initiatives and Economic Performance

In response to the question 'Does it pay to be green?', numerous studies have come to widely varying conclusions and the only conclusion that can be reached is that the question can be neither accepted nor refuted in general terms, due to these contradictory conclusions (Wagner, 2001, Claver-Cort´es et al., 2005). Therefore, such a question sheds little light on the complex nature of the interaction between environmental actions and economic performance. The literature will be examined with respect to specific research questions, to draw out any patterns and examine in what context it environmental actions are profitable. However, such questions must be placed in an analytical framework to make sense of the varying conclusions. Such an analytical framework has been proposed by Schaltegger and Synnestvedt (2002) and is described in the following section.

Analytical Framework

Schaltegger and Synnestvedt (2002) developed a framework for analysing environmental performance with respect to economic performance in the form of an inverse U-shaped curve. Given their voluntary nature, for environmental initiatives to be justified they must generate economic gains for firms to promote environmentally responsible behaviour (Andrews, 1998, Rivera, 2002). According to Schaltegger and Synnesvedt (2002) there are two main perspectives on this issue. In one case, the current level of corporate environmental protection may conflict with other business objectives (as shown by curve EP_0–D–E–F in Figure 2.1). In the other, the current level of corporate environmental protection may result in increased economic performance (curve EP_0–A–B–C in Figure 2.1.

Figure 2.1 Possible Relationships between Corporate Environmental Protection



Source: (Schaltegger and Synnestvedt, 2002 p341).

As illustrated in Figure 2.1, beginning with a certain level of economic performance EP_0, curve EP_0–D–E–F represents a uniformly negative relationship between the environmental actions and economic performance. In this scenario, every environmental activity leads to decreased economic performance. This view is based upon neoclassical theory, where pollution abatement is predicted to produce increasing marginal costs, reducing economic success to levels below EP_0 for any environmental protection activity undertaken. In contrast, curve EP_0– A–B–C has two distinct sections, with the first section (EP_0–A) showing economic performance increasing with more environmental protection practices. However, after a certain point, A, net marginal benefits from environmental actions decrease (section A–B–C). Therefore, after a firm reaches point A, further environmental actions lead to economic losses. Evaluating the validity of each of these views requires performing statistical analysis to determine if positive gains accrue at the firm level. However, investigations linking environmental actions and firm performance have been a mix of firm and market studies. The statistical techniques are usually one of the three described in more detail in the next section.

Relationship between Environmental Actions and Economic Performance

There is a considerable body of research conducted over several decades that has been exploring empirical evidence to link environmental and financial performance. However, there has not been a consistent approach to these studies (Griffin and Mahon, 1997) which makes comparisons of results and conclusions problematic at best. However, in general there have been three main approaches to this issue:

- Event studies which analyse the impact of single incident proxies on short-term share price variability;
- Regression analyses which attempt to establish a relationship between CSR and share returns; and
- Portfolio studies which investigate the impact of including CSR into investment decision analysis.

Despite this substantial body of literature there has not been a definitive conclusion one way or the other on the link between environmental and financial performance. One reason for this is the lack of consistency in approach across many different variables, making it almost impossible to compare and contrast the results of these studies.

Event Studies

Event studies have most often provided the most direct link; such studies include Shane and Spicer (1983), Hamilton (1995), and Klassen and McLaughlin (1996). These studies describe how share market prices respond to news of environmental pollution. One of the conclusions reached by these studies is that share markets respond to positive environmental news less strongly than they respond to negative environmental news. However, such single incident studies do not capture the potential long-term effects of such factors as reputation and operational efficiency, or the impact of any proactive environmental initiatives.

Freedman and Jaggi (1982) examined the relationship between disclosure of pollution levels and financial performance and found shows no causation or significant correlation. Blacconiere and Patten (1994) analysed the market reaction to 47 chemical firms following the Union Carbide catastrophe in India in 1984. They argued that the catastrophe had a significant negative impact on chemical firms while the impact on those firms that produced environmental reports prior to the event was less severe. However, such a conclusion was not statistically strong. Blacconiere and Northcut (1997) studied 72 chemical firms and also concluded 'extensive environmental reports' are perceived as a positive sign by investors. Klassen and McLaughlin (1996) investigate the environmental management effect and establish that there is a positive return for 'good environmental management' and a negative return for 'pathetic environmental management' Jacobs, Singhal et al. (2008) argue that the market is selective in responding to 'environmental performance' declarations. They suggest that the market does not react to announcements of corporate environmental initiatives, nor to environmental awards and certification by third parties. However, it seems that the market responds significantly to certain types of announcements, such as when it responded positively to International Standards Organisation Environmental Management standard (ISO 14001) certification and negatively to voluntary emissions reductions. In addition, Fisher-Vanden and Thorburn (2011) found that the market significant losses with firms that announce voluntary emissions reductions and these losses may not be internalised by firms and conclude that regulation or taxation would be the only effective way to reduce greenhouse gases.

Regression Studies

Regression studies have explored the link between environmental responsibility and share price for a period up to several years. The results from these studies are mixed. Some, such as Spicer (1978), establish a positive link whereas Chen and Metcalf (1980) and Mahapatra (1984) do not find any evidence to support a link. Margolis and Walsh (2003) conducted an investigation of 127 regression studies between 1972 and 2002 that analysed the relationship between corporate environmental and financial performance and found that a slightly positive relationship did exist.

Johnson (1996) employed measures including examining the return on assets and return on equity based on the US Toxic Release Inventory (TRI), and found specific types of environmental performance in a particular industry sector are positively associated with better financial performance. Thomas and Tonks (1991) tested the relationship between share returns and environmental actions by using a sample of United Kingdom (UK) firms and found environmental policies adopted by firms linked with strong pollution actually improves their stock returns. However, during the period 1995 to 1997 the excess return was reduced which raises the issue of whether such gains are permanent or transitory. Doh, Howton et al. (2010) report a consensus has emerged where "virtuous" firms are rewarded by the marketplace, however, they were not able to identify the mechanism, nor the veracity of the claims by firms with regard to their environmental performance.

They highlight the importance of institutional assessments in understanding the link between CSR and financial performance as do Barnett & Hoffman (2008), Lopez et al. (2007) and Siegel and Vitaliano (2007).

Portfolio Studies

Portfolio research normally involves a comparison of two risk-adjusted portfolios with company specific characteristics as the differentiating feature. However, the literature is sparse on examining the link between environmental performance and financial performance. One study is Cohen, Fenn et al. (1997) who suggest there is no difference between environmental portfolios and other portfolios, whereas King and Lenox (2001) found that green portfolios did outperform other portfolios. Kempf and Osthoff (2007) found a positive relationship between CSR and above normal share returns whilst Derwell, Guenster et al. (2004b) suggested that ecologically (eco) efficient companies provide above normal returns relative to less eco efficient firms.

Guenster, Bauer et al. (2010) also argue that eco-efficiency is positively related to market value. They suggest that a major factor in analysing such relationships is the 'positive and time varying relationship between eco-efficiency and firm valuation as measured by Tobin's Q' (Guenster et al., 2010). This result suggests share prices of eco efficient firms may be undervalued at the beginning of the period in which eco-efficiency measures are undertaken but after a period of time the share value undergoes a upwards price adjustment.

Sinkin, Wright et al. (2008) argue that firms which follow eco efficient strategies have lower costs while their profit is increased and they are valued highly by the market. They define eco efficient firms as those that have external certification and auditing (ISO 14001) and Corporate Reporting (CR). From their sample of firms only 95 were eco efficient. They report that eco efficient firms have 'positive market value' compared with non eco efficient firms. Pogutz and Russo (2009) provide some evidence that firms that care about environmental issues have increased market value as well as an improved financial performance in the short term.

2.2.10 Specific Research Questions

Nearly all reviews of the literature have organised the review around these three approaches; however, due to the different national contexts, variables, time frames and methods very different conclusions have been made. In attempting to answer whether it pays to be environmentally responsible with a categorical yes or no, these studies have not drawn out the issues and contextual factors which may influence the results. Consequently, such studies do not provide insight into such issues. Such a conclusion was drawn by Blanco, Rey-Maquieira et al. (2009) when examining the pertinent questions. They (2009) argue that such reviews should be based around whether environmental and economic performance are related, whether voluntary environmental actions are worth pursuing, what factors are relevant and what level of environmental activity is optimal. Some of these issues are addressed in this thesis.

2.2.11 Which Green Initiatives Pay?

There are broad ranges of environmental initiatives among which firms can choose. Each alternative has different costs and benefits and, from an efficiency criterion, firms should choose environmental actions that produce rates of return higher than that of the opportunity cost of their required capital investment.

The literature that addresses this research question indicates that different economic consequences are associated with alternative environmental initiatives. Studies that address pollution control versus prevention estimate significant economic improvements from pollution prevention methods (Hart and Ahuja, 1996, Klassen and Whybark, 1999, King and Lenox, 2002, Gonzalez and Gonzalez, 2005) and insignificant (Hart and Ahuja, 1996, King and Lenox, 2002) or negative results (Klassen and Whybark, 1999) deriving from pollution control methods. Hart and Ahuja (1996) suggest these economic differences are due to the fact that retro fitting pollution control is expensive and entails investment in non-productive equipment, while pollution prevention increases productivity and efficiency and at the same time avoids investments in end-of-pipeline equipment. However, some studies suggest these results are due to a spurious causality relationship as first suggested by Bragdon and Marlin (1972), then continued with Hamilton (1995), King and Lenox (2001), then Telle (2006).

Nehrt (1996) extends the literature on the pollution control versus prevention debate by considering the influence that timing has on the economic results of investment in pollution prevention technologies. Based on the first-mover advantage literature, Nerht focuses on potential consequences from learning effects and time compression diseconomies.

Learning effects refer to situations where first movers hold an advantage over later adopters since they have a more favourable position on the learning curve, which can be the case for a long time. By introducing interacting effects between the intensity and timing of abatement investments, Nehrt (1996) obtains a significant positive effect of investing early in pollution-reduction equipment and also of investing early and intensively. However, Nehrt finds a significant and negative effect of intense investment if the investment is not early.

Russo and Fouts (1997) conclude there is a significant correlation between proactive environmental initiatives and improved financial results. They also suggest that their results are consistent with the notion that such results stem from proactive firms having a range of tangible (for example, physical assets and technology), intangible (reputation for leadership in environmental concerns and capacity to influence public policies) and personnel-based resources (organizational commitment and learning, cross-functional integration, skills and participation) that contribute to improved economic performance. However, Gonzalez and Gonzalez (2005) obtain less conclusive results. Their findings show a positive correlation of different proactive environmental actions on firms' operative performance (measured in terms of costs, flexibility, quality, reliability and productive processes) and their commercial performance (reputation and capacity to adapt to market requirements) but this is not associated with increased financial performance. Gonzalez and Gonzalez suggest this is due to other factors such as previous strategic decisions, the macroeconomic environment or insufficient financial reward for operational improvements due to environmental initiatives.

The studies in this section show that there is not a common economic consequence resulting from all types of environmental management alternatives. However, a general theme does emerge that proactive pollution prevention methods to environmental management are more likely to enable firms to obtain economic benefits while reactive pollution control measures are more likely to be economically damaging.

How do Green Initiatives Pay?

In order to ascertain how green initiatives pay, Mackey, Mackey et al. (2007) suggest such actions can be viewed as a 'product' that corporations sell to current and potential shareholders. They suggest that the demand and supply for such CSR goods and services determine when socially responsible actions that reduce a firm's cash flows will impact positively or negatively on that firm's market value. This suggests that managers do not require especially strong socially responsible values so long as demand for socially responsible investments is greater than the supply of such investments. In this case managers looking to maximise the value of the firm will make such investments.

Some studies suggest that the economic benefits depend on the nature of the environmental performance. For example, mere regulatory compliance does not allow a firm to distinguish itself from its competitors. Significant benefits are likely to come from more rigorous, i.e. proactive and voluntary, forms of environmental performance which require changes in operating procedures and forward looking management styles.

Consequently the theoretical mechanisms for how green initiatives pay include:

- Reputational benefits which can attract high quality employees (Turban and Greening, 1997), as well as sales increases and improved relationships with suppliers and lenders (Berens and van Riel, 2004);
- Positive effects on employee motivation and retention (Weber, 2009);
- A proxy for management skills valued by markets (Bowman and Haire, 1975);
- Reflection of innovativeness and a proactive approach in the firm and also valued by markets (Russo and Fouts, 1997);
- Cost savings (Epstein and Roy, 2001); and
- Revenue increases from higher sales and market share (Weber, 2009).

When Does it Pay to be Green?

Another area of research investigates the internal or contextual factors of firms that enable them to generate increased economic results from environmental management This research assumes that, in the market, firms trapped in trade-offs between being green or being competitive (curve EP_0–D–E–F) coexist with firms that are endowed with particular characteristics that enable them to increase their economic results for certain abatement efforts (represented by curve EP_0–A–B–C).

A theory supporting competitive advantages of green firms is the resource-based view of firms (Russo and Fouts, 1997, Klassen and McLaughlin, 1996) where environmental management is argued to generate tangible, intangible or personnel-based resources that can confer a competitive advantage for firms (Russo and Fouts, 1997). Additionally, the literature has evaluated the influence on the environmental–economic relationship by taking into consideration the context of the firm. Wagner (2001) and Darnall, Jolley et al. (2007) find that the country in which the firm is located significantly modifies the economic consequences of environmental action.

In addition to the country in which a firm is located, some studies suggest the nature of the industrial sector affects the economic success of environmental actions (Rennings, Ziegler et al. (2006). This suggests that few economic incentives exist for firms to improve their environmental performance as any environmental initiatives that an individual firm might implement would also be implemented by all other firms in the same sector and hence the original firm would derive no benefit relevant to the sector as a whole. However, other studies reach the opposite conclusion, for example (Nehrt, 1996, Klassen and Whybark, 1999, Christmann, 2000, Wagner et al., 2002, Clarkson et al., 2004). In addition, Russo and Fouts (1997) and Konar and Cohen (2001) found that while the sector in which a firm is found can modify the economic consequences of environmental initiatives, there is still a positive relationship between environmental and economic performance.

The results of these studies show that different combinations of resources and managerial decisions are relevant in determining the economic consequences of environmental initiatives. Thus, firms should examine their existing resources, capabilities and context before designing their preferred environmental strategy. As a result, research should then devote effort to improving the understanding of the firm-level characteristics that determine the sign of the relationship between environmental and economic performance.

What Level of Green Initiatives Pay?

In addition to the previously discussed questions, some literature has also addressed the maximum pollution abatement effort that firms are capable of implementing while still reaping economic benefits from their voluntary action. A firm's private optimum level of green initiatives varies according to the type of firm and the particular type of environmental management actions applied. However, empirical research on the private abatement optimum is very difficult as identifying the specific optimum abatement level of each firm depends on its functional form as well as relevant data being confidential. These functions depend, in turn, on their available abatement strategies, capabilities and resources, amongst other things. The empirical literature has limited its research efforts regarding the question 'to what level of abatement effort does it pay to be green?' to analyses of the functional relationship between economic success and abatement efforts and comparisons with legal requirements (Iraldo et al., 2011).

Hart and Ahuja (1996) find economic results of firms in their sample to be positively associated with emission reduction. However, they find that for a sub-sample of low polluting firms, environmental initiatives have no significant effect on economic results, while for the sub-sample of higher emitting firms (with lower protection levels), positive and significant estimates are obtained. This suggests that firms undertaking new abatement initiatives are in the stretch EP_0–A in Figure 2.1 while firms that have already undertaken more environmental protection actions are already close to point A. Hart and Ahuja (1996) suggest this as an example of 'low-hanging fruit', that is easy early pollution abatement, which is only available for high polluters. This advantage is expected to exist only temporarily, consistent with Spicer's (1978) dynamic component of the environmental–economic relationship. With subsequent abatement efforts, these 'low-hanging fruits' are expected to be depleted, when approaching the optimum level of environmental protection as suggested by Peloza and Shang (2011) who state that CSR investment beyond a certain point can be destructive to financial performance A second group of studies addresses the research question in this section without entering into the functional forms but by comparing the economic results from various environmental performances with those corresponding to complying with legal requirements. The evidence that has been gathered until now generally supports the argument that firms might improve their economic performance by strengthening their environmental behaviour with respect to legal requirements (Cormier et al., 1993, Cohen et al., 1997, Dowell et al., 2000, Konar and Cohen, 2001, Thomas and Tonks, 1991). It is shown that pressure from regulators is strongly related to reductions in environmental impacts and that the costs to organizations to cope with these regulations may be offset if firms improve their environmental performance (Darnall et al., 2007).

In addition, Konar and Cohen (2001) conclude that major corporations voluntarily over- comply with environmental regulations, in order to portray themselves as being environmentally concerned in order to obtain a positive response from the share market. However, other authors obtain weaker estimates in the same direction (Cormier et al., 1993, Cohen et al., 1997, Johnston, 2005). Consequently, firms may be capable of generating economic gains by over-complying with environmental standards. Exploring the situation of the optimum abatement level in an industry or the whole economy is a complicated task. Each firm has a specific optimum abatement level depending on its marginal cost and benefit abatement functions, which depend, among other things, on their available abatement strategies, capabilities and resources.

Do Share Markets Reward Green Firms?

A significant proportion of the benefits deemed to accrue to firms from environmental action come from increased valuation in share markets, thus this question is of paramount importance. As increasing market value is a highly significant interest of firms, the way shareholders view environmental initiatives is highly relevant for the creation of economic incentives to voluntarily undertake environmental initiatives.

Most empirical studies conclude that financial markets have an inability to value environmental information efficiently. Some studies have obtained lower abnormal returns for environmental laggards (Cormier et al., 1993, Yamahita et al., 1999, Clarkson et al., 2004, Guenster et al., 2010) or higher abnormal returns for environmental leaders (Diltz, 1995, Rennings et al., 2006, Derwall et al., 2004b, Guenster et al., 2010).

Derwall, Guenster et al. (2004a) show that firms that are more eco-efficient obtain average abnormal returns of approximately 6% in excess of their counterparts; Yamashita et al. (1999) assess a 2.66% increase in risk-adjusted return for one upgrade in the environmental ranking.(2010) calculate a 3.2% increase in the sample average Tobin q per one-point increase in eco-efficiency Innovest Strategic Advisors ranking.

Dynamic aspects of the environmental and economic relationship are examined by Guenster et al. (2010), who suggest there are strong time variations in the difference between the valuation of high eco-efficient and low eco-efficient firms. Their results show that, although eco-efficient firms are not selling at a relative premium at the beginning of the sample period, the premium increases strongly over time, consistent with an increased perception by investors of the value of environmental initiatives.

A study by Jacobs et al. (2010) analysed the stock market reaction associated with announcements of environmental performance, and found that some categories of environmental performance announcements (for example, announcements of philanthropic gifts for environmental causes and announcements of ISO 14001 certification) are associated with significant positive market reaction, whereas certain types of announcements (for example, announcements of voluntary emission reductions) are valued negatively. Cañón-de-Francia and Garcés-Ayerbe (2009) also analysed whether ISO 14001 certification is a sign valued by the market. As a contrast to the Jacobs, Singhal et al. (2010) study, they found that the certification has a negative effect on market value in the case of less polluting and less internationalized firms. Lo and Sheu (2007), for one, investigated in the US context whether corporate environmental sustainability has an impact on market value using Tobin's Q as the proxy for firm value, and found that corporate sustainability is strongly associated with market value.

Consequently, it has been suggested that firms with good environmental practices and reputation serve as a signal for institutional investors of good managerial practices. It is frequently argued that environmental aspects can also influence Agency Theory. This aspect has been investigated by Berrone and Gomez Mejia (2009) , who investigate the relationship between environmental features and Chief Executive Officer (CEO) compensation in the United States (US). They observe a positive association between environmental performance and CEO pay, suggesting that such firms denote survival capabilities and therefore compensate CEOs.

However, a study of 523 US firms stated there is a significant, negative link between environmental pro-activism and security analyst earnings-per-share performance forecasts over the short-term (one to five years) (Cordeiro and Sarkis, 1997).Wagner, Van Phu et al. (2002) focused in their study on one particular industry, the European paper industry. They found evidence of a negative relationship between environmental performance and economic performance.

Consequently, the results are mixed with some studies suggesting a positive link and others a negative link between environmental initiatives and share market response.

2.3 Uncertainty and Climate Change Economic Models

2.3.1 Uncertainty and Climate Change

Within the literature there appears to be general agreement that Climate Change is one of the most pressing environmental problems to face society. Also, there is agreement that large uncertainties must be incorporated into any serious analysis of Climate Change and that such uncertainties must be included in any policy suggestions for meaningful recommendations (Peterson, 2006).

This literature centres on what state the climate will be in, what the economic impact of a changed climate will be, what impact the state of the climate will have in economic terms and what is the best way to control emissions. These basic questions have led to the examination of four categories of uncertainties in the literature:

- Uncertain emissions path;
- Uncertain climate state, for a given emissions path;
- Uncertain climate impact, for a given climate state; and
- Uncertain optimal policy (Molander, 1994, Heal and Kristrom, 2002, IPCC, 2013).

There have been several broad approaches for incorporating the uncertainty of Climate Change used in economic models. These include sensitivity analysis, where one factor is changed while the others are held constant (Peterson, 2006). Such an approach is ex post as opposed to ex ante, i.e. this form of sensitivity analysis is not incorporated into reaching the initial decision, but rather examines the impacts of changing constraints or variables after a decision has been reached.

Another approach to incorporate uncertainty is Monte Carlo simulation where certain parameters have distinct probability distributions and these values are then transmitted through the model to capture uncertainty. Generally these models do not incorporate learning and are heavily dependent upon the underlying probability distributions (Pindyck, 2000, Pizer, 1999).

Another common approach includes sequential decision-making under uncertainty. This usually involves stochastic programming with recourse

Stochastic programming is a framework for modelling optimisation problems that involve uncertainty. Whereas deterministic optimisation problems are formulated with known parameters, real world problems almost always include some unknown parameters. Stochastic programming utilises probability distributions governing the data are known or can be estimated. The purpose is to reach a decision that is feasible for nearly all possible data values instances and maximizes the function of the decision variables (Schultz, 2011).

Stochastic programming often takes form of two-stage linear programming model where a decision maker makes a decision in the first stage, after which a random event occurs affecting the outcome of the first-stage decision. A recourse decision is then made in the second stage that compensates for any negative effects that might have been eventuated as a result of the first-stage decision. The optimal approach from such models is a single first-stage policy and a collection of recourse decisions defining which second-stage action should be taken in response to each random outcome (Adeyefa and Luhandjula, 2011).

Three types of learning are analysed in the literature:

- Active learning: where the effect of a decision is observed to inform further decisions;
- Purchased learning: through research and development; and
- Autonomous learning: through the passage of time (Baranzini et al., 2003, Fisher and Narain, 2003, Gollier et al., 2000b).

Despite the inclusion of uncertainty in the analysis, most studies are deterministic or involve 'guestimates' due to the lack of detailed probability distributions of the relevant variables (Peterson, 2006).

Uncertainty characterises most economic questions with environmental impacts and this is especially the case with Climate Change. Therefore, it has been argued these uncertainties are greater and more critical than usual economic uncertainties (Pindyck, 2007).

The uncertain relationship between emission concentrations, temperature distributions and economic impacts of different emission levels all affect the benefits of reducing emissions.

Therefore the benefits of reducing emissions depend on:

- Expected emission levels without abatement;
- The rate of GHG concentration growth with a given level of emissions;
- How higher concentrations change the climate; and
- What is the economic impact of Climate Change (Peterson, 2006).

Many models have been constructed to assess these uncertainties as well as the costs and benefits of reducing emissions. Nordhaus (1994b) produced one of the first estimates of the costs and benefits with an extensive survey of scientists and economics. Subsequent studies have developed climate-economy models to assess policy implications such as Pizer (1999), who included 19 parameters in the model. Of these parameters, six were based on historical data and thirteen based on subjective analysis indicating the difficulty in capturing the uncertainty related to Climate Change. Similar models using subjective analysis have included Heal and Kristrom (2002) and Goulder and Pizer (2006). However, the complicated way in which uncertainty interacts with irreversibility has led to research which examines both factors in order to arrive at optimal policy instruments.

Traeger (2012) illustrates the importance of uncertainty under intertemporal risk aversion and ambiguity. Traeger shows uncertainty has an almost negligible impact on project value in the standard economic model, however, a rigorous evaluation of uncertainty and uncertainty alters this view markedly. This is illustrated with the discount rate, which is the fundamental determinant in balancing immediate costs against future benefits, and the single most important determinant of optimal mitigation policies in the integrated assessment of climate change.

Social cost of carbon studies such as Nordhaus (2008) and Anthoff et al. (2009) assume the climate and economy evolve deterministically and ignore uncertainty which is unrealistic. While the US Government Interagency Working Group on Social Cost of Carbon (IWG, 2010) estimated some uncertainty on the cost of carbon with a value between $5 -$65 with a central figure of $21, this results was based on deterministic studies including Nordhaus (2008) and Anthoff et al. (2009).

Only a few models rely on an intertemporal optimisation problem assuming the climate and economy are mutually dependent which include the MERGE model by Manne and Richels (2005). However, such models are restricted to parametric uncertainty. This approach means the value of key variables such as climate sensitivity are unknown and a deterministic Monte Carlo analysis is performed using an estimated probability distribution. Such an analysis assumes perfect knowledge about all parameters. However, such an approach focuses on modelling uncertainty, as opposed to uncertainty faced by the decision maker. Nevertheless some studies have taken a stochastic approach such as Crost and Traeger (2011) whose results differ significantly from the traditional Monte Carlo approach indicating the significance of uncertainty.

This result is consistent with studies by Lontzek, Cai and Judd (2012) who use the same model as Nordhaus (2008) but use a stochastic formulation of abrupt and irreversible climate change and obtain completely different results. The possibility of a low probability and low impact tipping event results in a flat profile for the additional carbon tax, while Webster et al. (2012) found the same result.

Another study by Cai et al. (2013) found the threat of a tipping point induces immediate stringent carbon pricing even for a low probability and low impact tipping event. They also found that uncertainty about damage is also a critical factor leading to a sharp increase in carbon pricing. This is consistent with Weitzman (2009) who shows that the economic consequences of fat-tailed structural uncertainty (along with unsureness about high-temperature damages) can quickly and overwhelmingly outweigh the effects of discounting in climate-change policy analysis.

2.3.2 Irreversibility and Climate Change

Some literature concerning the irreversible effects of Climate Change tends to downplay the importance of this phenomenon (Wesseler et al., 2003). The anthropogenic addition of greenhouse gases to the atmosphere may change the climate to such a degree that it is impossible or near to impossible to return the climate to its original state, hence these changes are deemed irreversible

(Scheffer et al., 2001, Schneider, 2004). Due to the complexity of the climate and its unknown thresholds, in the case of Climate Change, irreversibility means it is only possible to cross the threshold once (Wesseler et al., 2003) and the exact nature of these consequences are almost impossible to ascertain.

The issue of irreversibility in economic studies was first addressed by Arrow and Fisher (1974) and Henry (1974). These papers suggest that if the environmental value of a good is uncertain, then an option value should be included due to the benefit of protecting that environmental good. By extension if the decision to develop occurs then the flexibility that option entails is lost. The other type of irreversibility (mentioned previously), financial irreversibility or sunk costs, leads to a more development based decision due to lost income.

However, irreversibilities only matter if there are uncertainties as if there is no uncertainty, the correct decision can be made and the irreversible nature of the decision does not matter as it is the correct decision which takes into account all aspects of irreversibility. This is the source of a growing literature (for eg Kolstad, 1996, Ulph and Ulph, 1997). These studies suggest that, with respect to Climate Change, irreversibilities will affect decisions if such decisions constrain future options and that financial irreversibilities are more important than environmental irreversibilities as the model of climate change they studied they found the irreversibility effect does not apply to greenhouse gas emissions. In their model the possibility of future learning led to increased current period emissions. They suggest the reason for this is that more flexibility with respect to the level of greenhouse gas emissions due to more restrictive policies involves higher abatement costs. However, these studies ignore the possibility of catastrophic damage to the environment. Nevertheless, there is no consensus in the literature on the importance of irreversibilities due to the inherent difficulty in modelling a complex system as the global climate and its impact on society and economics. Most of the studies have limited time periods such as Kolstad (1996), Nordhaus (1994a) and Fisher and Narain (2003). They conclude there should be less emissions abatement due to the high abatement costs. These conclusions are heavily dependent upon the structures of the models where the time periods are small and temperature build up is minute from one period to the next, consequently the environmental irreversibility is less significant. However, studies that do consider catastrophic irreversible damages linked with emissions (Clarke and Reed, 1994) state pollution should decrease now.

Conversely, Fisher and Narain (2003) develop a model examining irreversible damages of unknown magnitude. They found the effect of sunk capital is stronger than the effect of greenhouse gas irreversibility or that of endogenous risk. However, this study highlights the question of scenario and sensitivity selection. Schneider (2004) highlighted the importance of sensitivity of selection of the particular scenarios and climate sensitivities used which adds urgency to further examination of the impact of irreversibilities assuming different scenarios. Selection of different scenarios or sensitivities can produce distributions that could easily be misinterpreted by policymakers as containing expert subjective probabilistic analysis when, in fact, they do not until a judgment is formally made about the likelihood of each storyline or sensitivity. This issue is partially addressed by Pommert and Prieur (2009) who also examine the tension between the irreversibilities of environmental degradation and environmental policy where environmental policy irreversibility leads to more pollution and a less/later policy while environmental irreversibility generates less pollution and a more/sooner policy. They examine which irreversibility has the dominant effect and the overall impact of both irreversibilities on pollution and policy design. As opposed to Fisher and Narain (2003) they found that the irreversibility associated with the adoption of a pollution policy prevails and optimal pollution is smaller than in the absence of any irreversibility.

As mentioned previously Cai et al. (2013) (Cai et al., 2013) also include irreversibilities in their analysis and conclude that even low probability, low impact irreversible climate change necessitates the action in the form of the introduction of carbon pricing.

As environmental irreversibilities, including those connected with Climate Change are mirrored by investment irreversibilities, where large-scale investment in low emission technologies may become stranded assets if predictions turn out to be false. The investment irreversibility risks associated with such decisions complicate decision-making even further (Fisher and Narain, 2002, Schneider, 2004).

The combination of climate uncertainties and irreversibilities necessitates decision makers must incorporate several issues into the management of their Climate Change risks (Schneider, 2004). These issues include the timing and sequencing of decisions to maintain the degree of options available to them as well as whether damage caused by Climate Change will increase steadily at a linear rate or abruptly in a non-linear fashion once certain thresholds are exceeded (Neumayer, 2007).

Overall, the studies that do not consider catastrophic consequences suggest making less emissions abatement, while those studies that do, suggest there should be more abatement, therefore the conclusions regarding the optimal policy have been heavily influenced by the model designs (Pindyck, 2007).

Choice of Policy Instrument

The uncertainties described above affect policy design both in terms of the type of instrument;(that is an emissions cost-based instrument or an emissions quantity based instrument), and in terms of intensity, (that is the size of the cost or quantity reduction as well as the timing of implementation) (Peterson, 2006).

Much research has been undertaken as to ascertain the most advantageous Climate Change policies under uncertainty. Kann and Weyant (2000) suggest that such an analysis should include output variables with probability weighted values, optimal decision with imperfect knowledge, an evaluation of risk, and the value of information as key variables. Answering such questions for Climate Change is improbable. Nevertheless other researchers have further analysed the optimal decision aspect. The optimal decision can be analysed by considering:

- How much to reduce?
- When to reduce?
- How to reduce?
- Who should reduce?
- Who should pay? (Baranzini et al., 2003)

Work by Weitzman (1974) showed that the optimal choice of instrument depended upon the relative slopes of the marginal cost and benefit functions. If the marginal benefit function is steeply sloped but the marginal cost function is flat then a quantity based instrument is best, while if the opposite is the case, then a cost based instrument is preferable. If there is uncertainty about the slopes and the cost and benefit functions differ considerably then the choice is crucial. However, subsequent research has showed that a hybrid of the two instruments can be preferable but this depends on the type and degree of the uncertainties as well as the shape of the cost and benefit functions (Pizer, 2002, Roberts and Spence, 1976, Weitzman, 1978, Jacoby and Ellerman, 2004).

2.4 Conclusion

The literature examined in this chapter is of a wide and varying nature. This is due to the multidisciplinary character of the study. The areas require examination separately and conclusions from each field of literature need to be drawn separately also.

The starting point for this research is that Climate Change is a significant problem that must be addressed. There is agreement about this from nearly all of the serious academic scientific literature. Whatever disagreements that exist within the scientific community refer mainly to the extent or timing of the negative consequences of Climate Change. This highlights the uncertain nature of Climate Change, about which there is also general agreement.

The same cannot be said about the economic literature that addresses Climate Change. Due to the inherent and cascading uncertainties with respect to Climate Change and its economic impacts there is little consensus about what policy should be enacted or even if any policy should be implemented at all. Such studies suggest that no action should be taken and a 'wait and see' approach is warranted due to the risk of losing sunk costs on unnecessary abatement investment. However, such models do not take the possibility of catastrophic damage into account; models that do, generally suggest urgent action is required, though there is still not a complete consensus on what instrument is best.

There is little doubt that Climate Change will impact on corporations and it is incumbent on management to address it. The corporate governance issues that Climate Change raises highlights some the controversy within the corporate governance literature. The two main theories within the corporate governance literature of agency theory and stakeholder theory suggest very different approaches to the issue. Agency Theory indicates that Climate Change is only of material importance to the management of the firm if it directly impacts on the profitability of the firm. On the other hand Stakeholder Theory says there are more stakeholders other than the shareholders and they must be considered also. This has led to the concept of CSR where a corporation takes into consideration factors other than just the financial bottom line. However, there is little agreement in the literature about exactly what CSR is, other than a consideration of factors other than revenue. In some countries CSR means philanthropy, while in others it is the consideration of all stakeholders, including the environment when considering a corporation's actions. Corporation's actions include what investments they make.

Corporate investments are usually determined through a capital budgeting process and the discipline of capital budgeting has matured in recent decades with few significant developments. There is general agreement within the literature about the validity of discounting, though this is more controversial for some environmental economists who believe that discounting, especially discount rates of 10% or more, fails to value future generations sufficiently for optimal decisions to be made for a long-term future. There is also disagreement about the most appropriate measure when assessing prospective investments; however, most researchers appear to support the Net Present Value (NPV) measure as opposed to the Internal Rate of Return (IRR).

The calculation of NPV requires project information such as cash flows, but if prospective projects are to be considered within the context of Climate Change additional project information is required. The information required centres on the emissions associated with prospective projects. This is the field of environmental accounting. Environmental accounting is a relatively new field of research but has already gained some degree of consensus. It evolved out of the traditional accounting field when environmental consciousness grew in the 1960s (Arrow and Fisher, 1974). Environmental accounting has developed two branches: management and financial environmental accounting, both of which deal with physical measures and financial measures. The existence of two different types of measures has created some disagreement within the environmental accounting literature as two different types of measure mean it is impossible to produce a single measure that indicates the environmental impact of a project. Some measures such as eco-efficiency, which is a ratio of aggregated financial value added divided by aggregated environmental impact added, have been developed. But there is still debate as to whether this is a valid measure as it does not measure the absolute environmental impact or risks. Such risks form only one of many risks that a corporation must manage.

2.4.1 Does it Pay to be Green?

The review above has analysed empirical studies that consider the relationship between the voluntary environmental management and performance of firms and their economic results.

It has been argued that the question of whether or not it pays to be green cannot have an unconditional positive or negative answer (Reinhardt, 1999) and that the main issue is to identify the most important determinants of the relationship between environmental and economic variables. Consequently, the traditional question of whether it pays to be green or not has been extended into more specific questions of examining the how, why, what and when it pays to be green in addition to the context of firms. This approach allows clarification of the variability in results, and has shown that there is evidence that proactive pollution prevention methods may result in positive economic results as opposed to reactive end of pipe pollution reduction approaches, which appear less likely to have positive economic results. There is also some evidence to support the concept of firms being able to improve economic performance by larger abatement efforts than are legally required, as well as some further evidence to show share markets do reward green firms in the capital markets, though it is not yet possible to determine whether this valuation is permanent or only temporary.

2.4.2 Limitations of the Literature and Future Research

Most of the studies examining the link between environmental actions and economic performance focus on finding a relationship between the variables and defending the causality by means of theoretical arguments. However, it appears that the causal relationship may be more complex than most authors conclude. There remains the possibility not only that environmental performance affects economic results or that economic results affect environmental performance, but also that mutual interrelations between the variables exist (Wagner et al., 2002).

Given the current state of the literature it is not possible to clearly assert whether firms' environmental initiatives occurred prior to or after improvements in economic results. In addition, the effects of time variation need to be studied further, to determine whether economic benefits remain in the long term following the implementation of environmental initiatives.

There is also little agreement concerning the time requirements for environmental efforts to positively affect the bottom line. Several authors have included different lags for the variables in their analyses, without a clear pattern in results hence further research is needed in this area (Jaggi and Freedman, 1992, Hart and Ahuja, 1996, Cohen et al., 1997, Russo and Fouts, 1997, Dowell et al., 2000, King and Lenox, 2001, Konar and Cohen, 2001, Johnston, 2005, Bowmar and Wireman, 2007, Ziegler et al., 2007, Darnall et al., 2007, Fisher-Vanden and Thorburn, 2011).

Chapter 3 Conceptual Framework

This chapter introduces the key question of this thesis regarding the short-term costs and long-term benefits of voluntary emissions reductions. A topical example is introduced, namely voluntary emissions reductions and the business issues that arise from Climate Change, are discussed in this chapter. The difficulties associated with existing approaches to the question of voluntary emissions reductions are discussed and a conceptual framework is then developed to approach these issues when evaluating investment in large scale projects. This conceptual framework draws upon the concepts of corporate social responsibility, environmental economics and cost-benefit analysis, Capital Budgeting, multiple objective linear programming and Robust Optimisation. Incorporation of these concepts and techniques leads to the development of methods to a new way to evaluate the costs and benefit of voluntarily reducing emissions when investing in large scale projects.

3.1 The Business Case of Actions with Short-term Costs and Long-term Benefits

When is it in the business interests of a firm to incur short-term costs for long-term benefits? This is a question that is routinely faced by firms when assessing prospective investments. Normally this question has been in the realm of financial analysis and assessed using conventional discounted cash flow techniques. If the present value of the financial benefits are greater than the present value of the financial costs, both evaluated at an appropriate discount rate, then the project should be undertaken. However, for business projects such analyses have conventionally only included costs and benefits to the firm in monetary measures and have not included the assessment of the social benefit or environmental objectives associated with a particular project. If social or environmental analyses are included in a project appraisal they usually involve cost-benefit analysis to assess the social utility of a public project. But what is a firm to do if the social benefit or cost of a project impacts on the private benefit or costs of the project? Furthermore what should a firm do if the social costs and benefits lead to private costs and benefits which are not measured in monetary values?

Social and environmental cost-benefit analysis is used in many fields such as health, transport and the environment (Asafu-Adjaye, 2005). For example, environmental issues such as decreased biodiversity, increased pollution and species extinction are often weighed against economic issues of financial return. Some studies argue that the long-term social benefits from preserving biodiversity outweigh the private costs associated with foregoing short-term potential revenue, especially when any effects are irreversible (Persha et al., 2011) .

The principle that acting in a way to promote social benefits may lead to private benefits has often been argued for under the auspices of CSR. Many studies have suggested that CSR pays for itself (that is, there is a business case for CSR). The studies that argue in favour of the business case for CSR suggest that a firm may derive private benefits, such as improved stakeholder relations, in addition to conventional monetary benefits from acting in a way which promotes long-term social benefits (Kakabadse and Kakabadse, 2007, Jacobs et al., 2010, Cañón-de-Francia and Garcés-Ayerbe, 2009, Reinhardt et al., 2008).

A contemporary example to explore this question is whether, and when, it is in the business interests of a firm to make voluntary greenhouse gas emissions reductions. That is, whether, and when, the short-term private costs of an environmentally and socially beneficial action (emissions reductions) are outweighed by the long-term private benefits associated with such reductions? In this circumstance the private benefit is considered to be a by-product of the social or public benefit; the public benefits of a stable climate conducive to current patterns of life would appear to be obvious and a firm may derive a private benefit from acting in such a way that contributes to this public benefit.

This question has been discussed in numerous reports by internationally recognised consultants and non-government organisations in the grey literature (Carbon Trust, 2004, Carbon Trust, 2006, CERES, 2006, Cogan, 2003, Dunn, 2002, Hoffman, 2006, Mansley, 2002, Walsh, 2006).These reports discuss the issue from a generalised point of view and come down firmly in favour of voluntary emissions reductions but, to the author's knowledge, this issue has not been explored in the academic literature nor have empirical case studies been published but rather only in the grey literature such as(CERES, 2006, Cogan, 2003, Hoffman, 2006, PJC Report, 2006, Walsh, 2006, Kiernan, 2007, Mansley, 2002). This is in direct opposition to some articles in the academic literature suggest it is specifically against the interests of a firm to voluntarily reduce emissions (Fisher-Vanden and Thorburn, 2011, Blanco et al., 2009).

Consequently, this study will investigate these claims about the implications of implementing voluntary emissions reductions by examining a case study of potential large-scale, long-lived investments where emissions reduction is included as one of the criteria in the project assessment in an attempt to capture some of the public and private costs and benefits. This chapter will provide the theoretical justification and explain the guiding principles in the approach taken to this issue.

3.2 Limitations of Existing Studies

There is very little in the academic literature regarding assessing potential investments through a CSR perspective. One of the few that the author is aware of is Weber (2009) who proposes a company level measurement approach for CSR. This includes a theoretical multi-step model, with various Key Performance Indicators (KPIs) such as brand value and employer attractiveness which will be assessed. However, this study does not indicate how the KPIs might be assessed but does provide a case study of a firm investing in child poverty reduction programs. Such a study provides little insight for firms wishing to assess the business case for voluntary emissions reductions.

Nevertheless, there are many studies that examine the link between environmental performance and financial performance of a firm. The conclusions of these studies have varied from strong support to complete opposition to the notion that there is a positive relationship between the environmental and financial performance of a firm (Weber, 2009, Jones and Bartlett, 2009, Reinhardt et al., 2008, Kolk and Pinkse, 2007, Benn and Dunphy, 2007, Assadourian, 2005).

These studies are generally divided into three types that examine the link between environmental and financial performance:

- Event studies which analyse the impact of the single incident proxies on short-term share price variability;
- Regression analyses which attempt to establish a relationship between CSR and share returns; and
- Portfolio studies which investigate the impact of including CSR into investment decision analysis.

Several pertinent portfolio studies have examined the relationship between eco-efficiency and shareholder value (Derwall et al., 2004a, Guenster et al., 2010) and suggest an environmental and financial relationship through eco-efficiency, whereby eco-efficient companies provide anomalously positive equity returns relative to less eco-efficient firms. However, these studies do not provide a way of implementing such measures, but rather observe the results of improved eco-efficiency.

3.3 Conceptual Frameworks

To integrate environmental issues and firm value by financial analysis a conceptual framework is needed to guide the process (Schaltegger and Synnestvedt, 2002).

A conceptual framework is employed to outline a preferred approach to a systematic analysis of a research question. The framework is built from a set of concepts linked to existing fields of study and relationships and acts like a map that gives coherence to empirical inquiry. Conceptual frameworks take different forms depending upon the research question or problem. Shields and Tajalli (2006) identified several types of conceptual frameworks (working hypotheses, descriptive categories, practical ideal type, models of operations research and formal hypotheses) for the field of public administration as shown in Table 3.1.

The frameworks are linked to particular research purposes (exploration, description, gauging, decision-making and explanation/prediction). When the purpose and framework of a study are clarified, other aspects of empirical research such as choice of methodology (survey, interviews, analysis of existing data, direct observation, focus groups et cetera) and type of statistical technique become apparent.

Table 3.1 Classifying Conceptual Frameworks

Research purpose	Research question	Conceptual framework	Research technique/ methodology	Statistical techniques
Exploration	Anything goes: what, when, where, why, who, how, or any combination	Working hypothesis	Usually qualitative techniques: field research, structured interviews, focus groups, archival record analysis	Any type of statistical analysis possible
Description	What	Descriptive categories	Survey and content analysis	Descriptive statistics: mean, median, mode, frequency distribution, *t*-statistics
Gauging	How close is process/policy to an ideal or standard? How can x be improved?	Practical ideal type	Case study, survey, content analysis, document analysis, structured interviews	Descriptive statistics: mean, median, mode, frequency distribution, *t*- statistics
Decision-making	What is the best decision? Which approach?	Models of operations research	Cost-benefit analysis, linear programming, decision tree, etc.	Quantitative techniques of operations research
Explanation	Why	Formal hypothesis: if x then y	Quantitative, experimental design, survey existing data analysis	*t*-statistics, correlation, chi-square, analysis of variance, regression

Source: (Shields and Tajalli, 2006 p. 318).

The research focus of this study is to examine the short and long-term costs and benefits of voluntary greenhouse gas emissions reductions and identify the best decision. Consequently, as suggested in Table 3.1, this study will utilise an operations research model involving a form of cost-benefit analysis and linear programming. The existing fields of study that will be employed within the conceptual framework include CSR, Environmental Economics incorporating Cost-benefit Analysis, Capital Budgeting and a variation of Linear Programming known as Robust Optimisation.

However, first the issues involved with Climate Change and business are discussed in greater depth to give a more detailed context of the study.

3.4 Climate Change

How exactly does Climate Change impact on a business? To explore this important starting point it is necessary to explore in more detail the phenomenon of Climate Change in order to construct a conceptual framework that may address the many issues it raises.

3.4.1 Climate Change Science

In recent usage, especially in the context of environmental policy, the term 'Climate Change' usually refers to changes in modern climate. The causes of recent Climate Change have been the subject of considerable research in recent decades. This research has focused on changes measured during the time frame of temperature records over the last 150 years when records are most accurate; especially the last 50 years when human civilisation has grown at its fastest rate and measurements of the upper atmosphere have become possible (Solomon et al., 2009). The main cause of recent Climate Change has been ascribed to actions from human activities such as:

- Increasing concentrations in the atmosphere of gases including carbon dioxide and methane;
- Large areas of deforestation; and
- Increasing concentrations of aerosols in the atmosphere (Barnett, 2005).

The Intergovernmental Panel on Climate Change (IPCC, 2013) report concluded that:

> "it is certain that increasing atmospheric burdens of most Well Mixed Green House Gases, especially CO2, resulted in a further increase in their Radiative Forcing from 2005 to 2011" (IPCC, 2013 technical summary p53)
>
> It is extremely likely that human activities caused more than half of the observed increase in global average surface temperature from 1951 to 2010 (IPCC, 2013 technical summary p80)

Whilst there have been dissenting views, the panel represents the broad consensus in the scientific community, defines 'very likely', 'extremely likely', and 'virtually certain' as indicating probabilities greater than 90%, 95%, and 99%, respectively. (IPCC, 2013 Technical Summary p36)

Many scholars suggest Climate Change is one of the more important issues of the 21st century (Garnaut, 2008, Neumayer, 2007, Solomon et al., 2009). The problem of the enhanced greenhouse effect causing Climate Change is a worldwide phenomenon and has far reaching implications for the sustainability of the current patterns of life. The two main gases responsible for Climate Change effects are carbon dioxide (CO_2) and methane (CH_4). In pre-industrial times these gases had concentrations of approximately 280 parts per million (ppm) and 700 parts per billion (ppb) respectively. These gases currently have concentrations of over 400 ppm and 1740 ppb and are projected to increase to over 550 ppm and 2500 ppb by 2100 (IPCC, 2013). These gases have increased primarily due to the rapid increase in the combustion of fossil fuels (coal, oil and gas) since the beginning of the Industrial Revolution (Myhre et al., 1998, Forest et al., 1999, Cowie, 2007).

These concentrations are unprecedented in human history but not in geological history. In the early Jurassic Period over 150 million years ago, a rapid build-up of greenhouse gases led to an average global temperature increase of 5° Celsius. This warming caused the weathering of rocks to increase which locked away more CO_2 which reduced their levels back similar concentrations to pre-industrial times, however, this process appears to have taken 150,000 years (Kopp et al., 2005). Therefore in the time scale of human civilisation Climate Change is considered an irreversible phenomenon.

3.4.2 Climate Change Effects

The effects of Climate Change are uncertain due to the difficulty in modelling and predicting the immensely complex system that is the global climate. However, some effects are certain to occur but it is the extent of which that remains uncertain. For example, global average temperatures are predicted to increase by the end of the century by between 1.5 and 5.8° Celsius(IPCC, 2013). Other effects include:

- Sea level rise between 18cm and 48cm due to thermal expansion if the Greenland ice sheet does not melt. If the ice sheet does melt, then sea level could rise by up to 7 metres;
- Increases severity and occurrence of droughts and floods;
- Desertification;
- Ocean acidification;
- Shutdown of the thermo-haline circulation (the Gulf Stream);
- Biodiversity reduction;
- Deforestation; and
- Stratospheric ozone depletion (Cowie, 2007).

Some of the social and economic issues due to these effects include increased insurance claims, increased maintenance of infrastructure, disrupted agriculture activity, flood defence expenditure, migration away from low lying land (or climate refugees) with corresponding security problems, water scarcity, increased mortality rates from heat stress (though these may be accompanied by decreased mortality rates from cold stress) and the spread of diseases usually associated with tropical areas (Harvell et al., 2002).

When viewed from an economy-wide perspective Climate Change is an increasingly relevant subject with such widely known reports such as the Stern Review (2006) and Garnaut Review (2008). The Stern Review suggests the effects of Climate Change may reduce global national product by 1% and a per capita basis of up to 20% reduction in consumption. The direct effects of natural disasters have led to economic losses due which have been doubling every ten years in the past 30 years and have reached over US$1 trillion since the turn of the century. If current trends continue the figure could reach US$15 billion per annum within the next fifteen years (Stern, 2006).

The Garnaut Review (2008) suggests growth in emissions is expected to have a severe and costly impact on agriculture, infrastructure, biodiversity and ecosystems in Australia which would be profoundly disruptive to society. According to some scholars the most important causes for concern are not the median projections of future Climate Change, but the low probability, high consequence or catastrophic impacts (Webster et al., 2008).

3.4.3 Climate Change and Business

The issues from climate for business stem from the way Climate Change effects society and the environment. While many of the issues such as disrupted economic activity, increased infrastructure maintenance costs and security concerns have effects that are borne by corporations there is little an individual corporation can do to manage those issues aside from setting aside additional funds to self-insure or purchase insurance. The Climate Change issues that a firm may have some influence over stem from the physical and economic issues of Climate Change; however, they are not the same. Climate Change business issues relevant to corporations include:

- Regulation;
- Shareholders;
- Litigation;
- Reputation; and
- Physical impacts (Walsh, 2006, CERES, 2006, Garz and Volk, 2003, Hoffman, 2005).

On an individual level, a company's exposure to such issues depends on a wide range of factors such as emissions intensity, energy source, geographic location and marginal abatement costs. In addition, the impact of these issues and the techniques to measure them are very difficult to determine (Burritt and Saka, 2006, Simon and Proops, 2000). Indeed most Climate Change related issues are exceedingly difficult to quantify in a classical sense as the probabilities are unknowable (Chichilnisky and Heal, 1993). Despite these difficulties these issues will be discussed in more detail below.

Regulation

Climate Change regulatory issues are increasingly coming to the attention of business due to the introduction of regulatory frameworks such as Emissions Trading Schemes (ETS) (Hourcade et al., 2007) or taxes on carbon dioxide emissions (British Columbia Provincial Government, 2011). With the introduction of such schemes many companies are facing the prospect of substantial emissions reductions or non- compliance penalties. In addition, the obligations are not limited to domestic regulations. With the Kyoto protocol expiring in 2012 a more stringent successor may be put in place. However, due to the inconclusive result from the Copenhagen Conference whether a more stringent successor is put in place is very uncertain (Karp and Zhao, 2008). Despite no binding agreement, the Copenhagen Accord which endorses the continuation of the Kyoto Protocol was reached where emissions are to be reduced in an attempt to ensure the average global temperature does not rise more than 2° Celsius above pre-industrial temperatures. The Copenhagen Accord countries representing over 80% of global emissions have engaged with the Accord with individual country's emissions reductions varying from 5% to 45% (UNFCCC, 2009).

Due to the overlapping nature of many jurisdictions as well as the complex nature of ETS and carbon taxes there exists, and will continue to exist, regulatory confusion and uncertainty. There are many examples in the US of regulatory issues and uncertainty with federal efforts to limit greenhouse gas emissions and state Greenhouse Gas Initiatives such as the Regional Greenhouse Gas Initiative in the north eastern states which is consists of a cap and trade system. In addition, California is also introducing regulations to lower emissions from cars with many states set to follow. In addition, the local governments of over 200 cities have signed non-binding agreements to reduce greenhouse gas emissions (RGGI, 2008).

Opportunities from the area of Climate Change regulation exist for companies to make informed efforts to reduce their emissions. Firms which undertake this approach may be better able to meet more regulatory constraints which are expected to tighten in the future. In addition, some firms that anticipate further regulations may be able to trade emissions credits or sell their services (Thomas and Way, 2005, Wilkinson, 2007).

Shareholders

Climate Change issues can significantly impact on shareholder value, particularly in the medium to long-term. Investors in companies may want to understand the emissions exposure of their potential investments and to gain confidence in the ability of companies in which they invest to appropriately manage the issues (Lyster, 2007). As such it would appear shareholders and institutional investors are increasingly examining the Climate Change policies of corporations. Such investors are considering if there is a fiduciary responsibility for corporations to address emissions (Cogan, 2003, Healy and Tapick, 2004). Certain investment funds are already indicating that such policies will impact investment decisions in the long-term. Consequently the possibility exists that if a firm ignores such questions from shareholders then it may face the prospect of their shares being devalued. Such firms may also attract unwanted media attention and possible reputational damage.

In terms of opportunities, a firm that is in a position to provide robust and demonstrable responses to questions on Climate Change policies and associated issues may find their share price enhanced (Kiernan, 2001). Specifically the types of questions shareholders appear to be asking companies regarding Climate Change usually fall within three main categories:

1. To evaluate the financial consequences of Climate Change issues what procedures and policies does the company have?
2. How is the company attempting to maximise shareholder value given the current and expected Climate Change regulations?
3. How many tonnes of greenhouse gas equivalents doe the company emit and what steps are being taking to reduce them? (Lyster, 2007)

Using a cross sectional regression model Garz and Volk (2003) examined the relationship between Climate Change and corporate returns since the Rio Earth Summit Conference in 1992. These results suggest that while Climate Change is not yet factored into the share price, corporations with a high susceptibility to Climate Change issues face the possibility of having their share price reduced.

Historically there has been no expectation on the private sector to have any responsibility for environmental and social issues, including Climate Change. There is a growing trend for institutional and fund managers to use their voting power to foster change rather than using the threat of selling the shares to improve the performance of the companies in their portfolio (Kiernan, 2007). Evidence of this is the creation of programmes such as the International Corporate Governance Network

(ICGN) that have been formed to address such issues. The issue of Climate Change is increasingly the focus of associations of institutional investors. One of the largest of these groups, the Carbon Disclosure Project (CDP), is just such a global organisation. Currently the CDP includes over 220 institutions with US$30 trillion in combined assets (Kiernan, 2007). This adds to the pressure on firms to implement policies which address Climate Change concerns.

Litigation

There would appear to be a growing awareness among society, government and business in particular that Climate Change causes damage through the impacts discussed above. Consequently the possibility exists that the damage from Climate Change may be attributed to companies whose greenhouse gas emissions contribute to Climate Change. This, in turn, may lead to litigation against firms for such activities. Such litigation could be enacted from several areas including:

- Regulatory agencies as they enforce emissions limits through fines or legal proceedings;
- Shareholders as inaction on Climate Change issues may bring about financial losses; and
- Class actions where large groups could file for damages against a particular corporation. Already such cases have been filed and others are being contemplated by citizens of island nations such as Tuvalu and the Maldives. Such cases are extremely complex and involve complicated legal questions concerning standing and assessment of blame. Nevertheless it would appear that the prevalence of such cases is likely to increase. (Bubna-Litic, 2007, Durrant and Maguire, 2006)

Due to these factors the risk of liability relating to Climate Change is an increasingly important issue for business. The appears to be little doubt that the increasing concern about Climate Change will result in tighter regulations and liability issues for corporations (Grossman, 2003).

In addition a significant, if controversial, risk for corporations is the possibility of tortious liability for greenhouse gas emissions. Already cases have been brought before the courts in the US concerning public law actions or challenging development approvals (Lyster et al., 2007). It is this area of tort based legislation that is seen as a potentially major threat to large emitters in the Australian context.

This is due to the fact the law of torts and Climate Change litigation have three common aims: compensation, deterrence and prevention (Thorpe, 2008).

Reputation

Reputation measurement literature divides reputation into three mainstream categories: social expectations, corporate personality and trust (Berens and van Riel, 2004). It is the first category that a firm's reputation may be affected by Climate Change. The social expectations reputation approach is commonly used to differentiate between types of corporate associations and many researchers have studied this phenomenon using group headings of different stakeholders have regarding behaviour of companies in society for example, the Most Admired Companies survey (Berens and van Riel, 2004). Surveys are the most common method of assessing a firm's reputation.

The importance of reputation to a firm's share price is emphasised by studies that suggest approximately 80% of a firm's value cannot be explained by traditional accounting analysis but rather by issues such as reputation and strategic governance factors (Kiernan, 2007).

Climate Change is likely to increase in importance for consumers and shareholders as well as the wider community and therefore the importance of Climate Change reputation is likely to increase. According to a study by the Carbon Trust (2004), Climate Change awareness in the community and among consumers will increase due to political debate, continued extreme weather events, as well as more products being marketed as climate friendly (Kolk and Pinkse, 2007). If this scenario eventuates, some firms may find their reputations suffering if they do not address Climate Change issues. Nevertheless while it is difficult to quantify the effect on reputations a firm may find their share value marked down or lose market share if they gain a reputation as a Climate Change reprobate (Hoffman, 2006).

Physical Impacts

The physical issues associated with Climate Change include the increased severity of natural disasters such as hurricanes as well as health issues. Rising temperatures and extreme weather effects are expected to affect the reproductive cycle and spreading of disease carriers such as mosquitoes which spread malaria and ticks that spread Lyme disease (Harvell et al., 2002). Due to the effects of such natural disasters modelling is required to assist help companies in a Climate Change environment. These include:

- Identifying and evaluating the potential impacts natural hazards may have on their firm;
- Evaluating potential damage to buildings and assets;
- Determining ways to reduce their Climate Change risks; and
- Ascertaining the need for improvements in buildings (Sadler, 2006).

One major factor to appear in most natural disaster catastrophe models has been the effect on coastal development (Hennessy et al., 2006). Natural disaster modelling and the assessment of physical issues necessitate scientific and engineering studies into each potential project (AGO, 2006).

3.5 Voluntary GHG Emissions Reduction Evaluation Conceptual Framework

Having outlined the issues that Climate Change presents for firms in the preceding section, this section will discuss and integrate the fields of study that will be utilised within the conceptual framework to evaluate the costs and benefits of voluntary GHG emissions reductions for large scale, long-lived project selection and how they will be integrated.

Large-scale project selection has been chosen as the subject of this study due to the considerable significance such investments have for a firm in terms of the firm's long-term viability but also for the long-term GHG emissions profile of the firm. Consequently the study will consider the question of short-term costs for long-term benefits concerning voluntary GHG emissions reductions in the case of large -scale, long-lived project selection. A theoretical case study of potential projects will be examined with consideration of emissions within the project selection process. This approach to project selection with a particular emphasis on emissions is theoretically justified through a CSR perspective as outlined above. Accordingly, the concept of CSR and how it relates to the conceptual framework is discussed in the following section. Following the discussion of CSR, the issues of uncertainty and irreversibility and their relevance to the framework will be discussed. These aspects will then be discussed within the context of investment decisions using Capital Budgeting and modelling employing operations research techniques, specifically multiple objective linear programming, to inform the costs and benefits of voluntary emissions reduction. The solutions from the model will then be compared with a 'business as usual' Capital Budgeting model and the results will be further evaluated through the application of studies which link eco-efficiency and firm reputation and value.

3.5.1 Corporate Social Responsibility (CSR)

While no single definition of Corporate Social Responsibility (CSR) has been agreed upon in the literature, it is generally regarded as a concept where organisations consider the interests of the wider society by taking responsibility for the impact of their activities on customers, employees, shareholders, communities and the environment. This obligation goes beyond the minimum statutory requirements to comply with legislation and regulations and considers corporations to actively take steps to improve the lives of employees, their families, communities and the environment (Mackey et al., 2007).

As such CSR is often be considered to be a form of business ethics and guides the way a corporation is administered and influences the decision-making process. Therefore CSR falls within the domain of corporate governance and strategic management (Freeman and Ramakrishna, 2008) and can be viewed as an extension of the responsibilities that come from corporate governance obligations (Li, 2006). Despite the ethical character of CSR, the appropriateness of implementing CSR has been the subject of considerable amount of debate. Proponents of CSR argue there is a strong business case for it and that it ensures the long-term viability of the firm, suggesting that being ethical makes business sense. Critics suggest that CSR distracts from the fundamental role of businesses of being profitable as notably argued by Friedman (1962). Others view CSR as a way for multinationals to avoid government regulation (Anderson and Landau, 2006). It is the business case for CSR that this study examines.

3.5.2 Environmental and Financial Performance

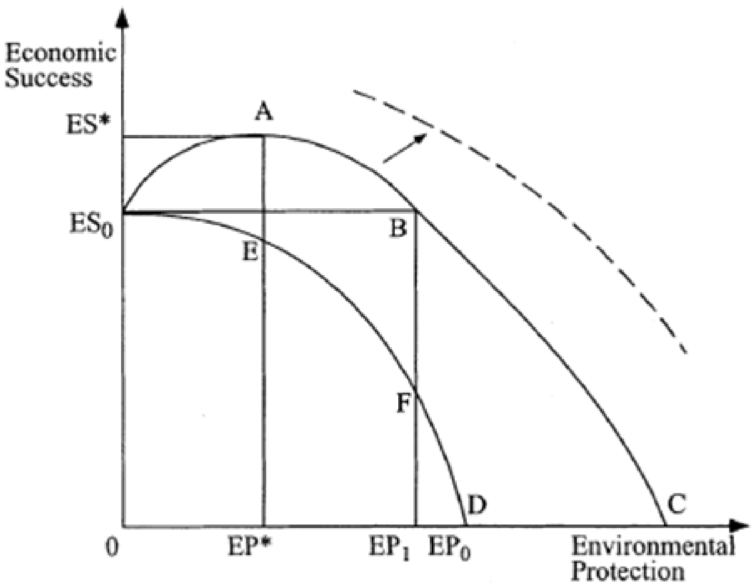
To the extent that socially responsible activities are inconsistent with economic objectives, traditional financial logic suggests they should be avoided (Orlitzy et al., 2003). However, the scholars that argue the business case for CSR suggest the following factors may lead to beneficial outcomes for the firm:

- Improved brand value;
- Increased sales;
- Increased share valuation;
- Improved relationship with suppliers and lenders;
- Increased customer attraction and retention;
- Improved reputation;

- Improved employer attractiveness; and
- Higher employee motivation and retention (Weber, 2009, Orlitzy et al., 2003, Kiernan, 2007, Guenster et al., 2010).

It is suggested the reasoning for the benefits listed above is that competitive advantages can be gained by being better able to balance various stakeholders' interests (Orlitzy et al., 2003). Despite these benefits it seems reasonable to conclude there are a finite number of CSR activities that continue to increase economic performance. After a certain amount the net marginal benefits from CSR activities will begin to decrease and further efforts will represent net costs and as Schaltegger and Synnestvedt (2002) suggest, the relationship between environmental performance and economic benefit is most probably an inverse U shaped curve as shown in Figure 3.1. For example, the benefits listed above must be weighed against any costs such as direct costs, a loss of consumer surplus from firms producing less output as well as shareholders receiving lower dividends (Reinhardt et al., 2008).

Figure 3.1 Possible Relationships between Corporate Environmental Protection and Economic Success



Source: (Schaltegger and Synnestvedt, 2002 p341).

Figure 3.1 illustrates the two main schools of thought regarding the economic success of implementing CSR, in this case, environmental policies. The curve ES_0 to EP_0 diagrammatically represents the view that increasing environmental protection only leads to decreased economic success. The converse view is demonstrated by the curve ES_0, A, B to C. This curve shows that with some environmental protection, economic success actually increases.

Consequently, this study examines the case of voluntary GHG emissions reductions and whether such a policy is on the curve A-C, or curve E-D and thus whether reductions can be justified from both a CSR and financial perspective. In addition to examining whether economic benefits can be gained, this study will examine how various conditions affect the project selection process.

Investment decision studies guided by CSR are rare in the literature. A paper by Weber (2009) is the only one the author is aware of. Weber suggests a range of benefits (as discussed in Chapter 2) that a firm may gain by incorporating CSR criteria into investment decisions but does not specify how they might be measured and is of little use with respect to examining emissions reductions and investments. Therefore a method to evaluate the costs and benefits of emissions reductions is needed. This is developed in the following section which makes use of the intersection of CSR benefits and Climate Change business issues discussed previously.

The approach will address shareholder factors and reputation as well as anticipating regulatory uncertainty in addition to a conventional discounted cash flow measure. Including regulatory uncertainty is justified from a CSR perspective as the regulatory uncertainty stems from environmental uncertainty. By anticipating such environmental regulations it is argued a firm may potentially increase its economic success through the avoidance of stranded assets as explained below.

However two business issues discussed above, litigation and physical impacts are not addressed in this framework. Litigation is not included as numerous studies indicate this issue is limited to the stationary power sector (Powers, 2007, Thorpe, 2008).While it is not possible to incorporate physical impacts on theoretical projects as such an analysis would require specific geographical and engineering information and this study explores the issue from a generalised perspective.

3.5.3 Environmental Cost-Benefit Analysis

The inclusion of environmental issues such as Climate Change into economic analyses usually reduces to a form of cost-benefit analysis where the benefits from policies to reduce environmental impacts are measured against the costs of implementing the policy to indicate the desirability of such measures (Pindyck, 2007). Such an analysis examines the public benefits and costs. The purpose of this study is a variation on this as it aims to evaluate the private benefits that stem from publicly beneficial action of voluntarily reducing GHG emissions.

The cost-benefit analysis for this study will therefore weigh the costs of emissions reductions in large-scale project selection, which may involve reduced revenue, against the benefits of improved reputation and shareholder value, as well as possible real options benefits through increased flexibility.

3.5.4 Uncertainty

In addition to a timeline of decades, the complexity and stochastic processes with respect to climate makes it very difficult for uncertainties to be understood from a strategic management and investment perspective (Clark, 1986, Wheatley, 1999, Weitzman, 2009). Consequently the response to Climate Change regulations is complex and uncertain at many different levels, particularly for multinational firms, due to the many regulatory settings they operate in.

Regulatory settings are uncertain as emissions levels are uncertain. The emissions levels are uncertain as economic growth, energy intensities and amounts of renewable sources of energy all are uncertain as is the most appropriate level of CO_2 concentrations in the atmosphere to maintain current patterns of life. In addition, as described by Weitzman in his Dismal Science Theorem (Weitzman, 2009), the economic impacts are characterised by uncertainty with higher temperatures potentially being beneficial to some cold regions such as Canada where there may be greater food production, but potentially devastating to low lying regions, such as Bangladesh, due to sea level rise. Therefore due to the enormous uncertainties and regional differences in impacts, the regulatory response is highly uncertain and it is not meaningful to assign probability distribution. As a result it may be in a firm’s interests to consider such uncertainty when planning large-scale, long-lived investments. If such uncertainty is not considered into investment evaluation then a firm runs the risk of investing in stranded assets if the regulatory setting becomes unfavourable. Stranded assets are an example of financial irreversibility or sunk costs that cannot be recovered (Reynolds, 2013).

3.5.5 Irreversibility

Two forms of irreversibility exist: financial irreversibility and environmental irreversibility. As described above, financial irreversibility refers to sunk costs (Arrow and Fisher, 1974, Henry, 1974). When investment decisions are considered together with Climate Change both forms of irreversibility are involved. Environmental damages are often irreversible in the sense that once an animal is extinct, that fact cannot be reversed. The same logic applies for Climate Change as to reverse changes in climate would take hundreds to thousands of years, if not longer. From a human time scale perspective, this is essentially irreversible. Environmental irreversibility is a key concept in the regulatory response to Climate Change. Due to this possibility, the regulatory response may be severe. Whether the climate changes sufficiently to represent an irreversible change is uncertain, however, the benefit from preserving a stable climate conducive to current patterns of life is extremely large. Nevertheless, the foregone wage and consumption benefits must also be considered if the investments do not proceed due to this preservation. Therefore, from a business perspective, the consequences of financial irreversibility (stranded assets) must be weighed against the regulatory consequences of environmental irreversibility (increasingly strict regulations).

3.5.6 Uncertainty and Irreversibility

Irreversibilities are only of concern if there is uncertainty (Fuss et al., 2012). If there is no uncertainty then the appropriate decision becomes obvious. Irreversibility will affect current decisions if it would constrain future behaviour under plausible outcomes. Specifically firms face the consequences of potential financial irreversibility due to stranded assets from the uncertainty of regulatory policy which itself stems from the potential environmental irreversibility of Climate Change.

If, however, the environmental impacts turn out to be less problematic and the regulatory setting less severe and emissions restrictions are relaxed, then there exists the potential for delayed investments to be made after all. However, if the reverse is true and the emissions restrictions are tighter, then there would be little that could be done to correct the situation and financial losses would result from the stranded assets. The issues connected with these countervailing forces are captured in the concept of real options.

3.6 Ecology-driven Real Options Analysis

As well as being characterised by uncertainty, the importance of Climate Change as an issue is partially derived from its irreversible nature; the possibility that a new climate state will develop and in human time frames this new state is essentially permanent. However, whether this will happen is uncertain as how much the climate will change is uncertain. This highlights the two aspects of irreversibility, as discussed previously, environmental irreversibility and financial irreversibility, both of which a firm must take into consideration if Climate Change is incorporated into the decision-making process for large-scale investments. If a firm invests in emissions abatement for large-scale emissions reductions or foregoes profitable investments and it eventuates that Climate Change is not as serious as initially thought, nor the regulatory settings so severe, then the firm risks suffering from lost sunk costs or large opportunity costs should it choose to forego an investment to reduce emissions. Conversely, should Climate Change prove to be as substantial a problem as the scientific research suggests, along with its irreversible environmental nature, and a firm does not reduce emissions, then the resultant regulations may lead to stranded assets and resultant financial difficulty.

Therefore it may be in a firm's interests to balance such irreversibilities in the presence of such severe uncertainty when making investment decisions. However, the difficulty in doing so is compounded by the lack of any meaningful probability distributions associated with Climate Change uncertainties (Weitzman, 2009). Nevertheless, an alternate way of considering irreversibility is through its reciprocal: flexibility. Greater flexibility means less irreversibility and vice versa (Graham-Tomasi, 1995). Consequently, when faced with such an uncertain setting businesses may include flexibility as a factor to counterbalance the consequences of the irreversible nature of Climate Change.

Project appraisal methods based solely on Net Present Value (NPV) fail to take irreversibility into account and fail to place a value on flexibility (Whitten et al., 2012). Increasing the amount of flexibility allows firms to respond to future uncertainties. The interaction of uncertainty, irreversibility and flexibility has been incorporated into the concept of 'real options'. This concept is based on financial options but applied to real assets. In the case of real options, investors are 'buying' increased decision-making ability, specifically, the creation, extension or delay of a particular project (Anda et al., 2009). Therefore increased flexibility may have a real option value. Busch and Hoffman (2009) proposed an Ecology driven real options investment framework where the profitability of an investment includes NPV augmented by a real option value. They argue the real option value stems from incorporating flexibility into investment appraisals as a response to ecologically induced uncertainties through analysis of underlying conditions, appraisal of future revenues and the best time to invest. Busch and Hoffman (2009) suggest there are five types of real options that add to the profitability of investments include: option to defer, option to grow, option to extend, option to switch, and an option to abandon. In the current study the real option value of deferral may be significant. When more and better information is expected following an uncertain irreversible decision or uncertainty may be resolved, it may be optimal to bias decisions toward maintaining flexibility (i.e. decreasing irreversibility). More flexibility in this case refers to the ability of a firm to respond to either tighter or looser emissions regulations through their investment decisions in an optimal manner. This is the case as information in the future only has a value if the ability, or option, to use it still exists. This suggests the opportunity cost of an irreversible project should be expanded to include the potential value of information in the future. This concept was developed by Arrow and Fisher (1974) and labelled the Irreversibility effect by Henry (1974).

However, the time required for uncertainty to be resolved controls the period over which hedging policies limit activities which has a significant impact on the cost of policy. For hazards such as Climate Change extreme uncertainty is likely to continue for decades (Roe and Baker, 2007) and thus the optimal timing of deferral is problematic.

Consequently in addition to NPV, it may be illuminating to explore the results from the models in terms of the flexibility and implied option value they involve as well as balancing the two forms of irreversibility; this suggests the results may be viewed in terms of a form of hedging. Real world decision makers often consider hedges to be actions that reduce vulnerability and enhance flexibility if the unexpected occurs. However, such hedges will often be suboptimal for any given set of expectations about the future and hard to find in an analysis designed to produce optimum policies. Consequently firms may seek strategies that are robust against a wide range of potential Climate Change scenarios: either firms will have to make very large reductions in emissions over the course of the coming decades, or they will not. Since firms do not yet know which future will happen then logically they should prepare for both and favour strategies that are flexible over irreversible choices. Such policies should aim is to keep as low as possible the cost of being wrong about future Climate Change and real options capture the value of managerial flexibility in a way that a strictly financial net present value analysis does not (Copeland and Antikarov, 2001, Herath and Park, 2001).

Unfortunately, the calculation of real option value is far from simple due to the lack of probabilities and specified time horizon (Copeland and Antikarov, 2001). The usual practice in real options valuation is to presume the asset is like a European option where there is a specific end date and the option can only be exercised on that day. However, this does not match with real world practice where options are exercise at a point in time deemed most suitable for the firm. Hence real options have greater similarity to American options, which have no specified expiry date and consequently are more difficult to value (Luehrman, 1998).

As a result, it is very difficult to accurately quantify real options (Tyler and Chivaka, 2011). Despite this, due to the significance of Climate Change impacts it would appear important to take into consideration ecology- driven real-options-thinking within the investment planning process, especially when considering short-term costs and long-term interests, even if it is not possible to calculate an exact figure. Therefore the models and results will be evaluated not just in terms of their financial and emissions performance, but how the flexible each solution is and what any real option value implications are for a firm's future.

Given the factors discussed above to assess investment decisions requires a modelling framework which can encompass severe uncertainty and yet not have probability distributions in the calculations as such probability distributions are unavailable. Such a modelling framework is Robust Optimisation .(Hall et al., 2012)

3.7 Robust Optimisation

Robust Optimisation is a modelling framework for decision-making which makes use of different potential yet plausible scenarios which are appropriate for the particular decision problem being investigated. The scenarios, or input data sets, are reliant on the modeller making judgements as to the appropriateness of the data sets. However, no assumptions are made regarding the probabilities of any scenario because in Robust Optimisation it is assumed the probabilities are unknown or unknowable. Consequently all scenarios are regarded as being equally likely to occur. This approach is justified as the process of assigning probabilities emphasizes high probability scenarios as opposed to low probability, yet potentially catastrophic scenarios (Weitzman, 2009). Robust Optimisation prepares the decision maker for unlikely, but still potential, outcomes and therefore enables them to handle such developments should they occur (Greenberg and Morrison, 2008).

Consequently the success of Robust Optimisation as a decision-making tool is dependent upon the scenario planning or data sets. The scenarios typically represent possible future divergent states and a decision solution is found that satisfies the decision criteria decided as relevant for the problem (Ben-Tal et al., 2009). The decision criteria are discussed in the following section.

The use of scenarios to structure the input data uncertainty allows the ability to model the relationship between a few major uncertain factors in the decision environment and the large set of input parameters to the decision model, with many of these parameters being simultaneously affected by one or more of these factors (Kouvelis and Yu, 1997).

Robust Optimisation is often employed due to the recognition that traditional single point estimates or range forecasts have been proven to be inaccurate portrayals of reality and prone to providing suboptimal decisions (Rosenhead, 2001).

The final step in the Robust Optimisation framework is the construction of the decision model. The decision model is described in a following section.

Decision Criteria

Within the Robust Optimisation framework there are three different criteria: Absolute Robustness, Robust Deviation and Relative Robustness. These criteria are appropriate for different circumstances. In a specific decision situation, some or all of the robustness criteria might be applied (Hall et al., 2012).

The Absolute Robust criterion usually leads to decision that are very conservative in nature where the main concern is how to hedge against the worst possible happening. This decision criterion involves a maximin decision. Maximin generates a decision that maximises the minimum outcome, that is, it examines all the optimal solutions in all of the scenarios and selects the solution whose minimum is maximised. Therefore given the highly uncertain regulatory setting this is particularly useful (Rosenhead, 2001).

The Robust Deviation criterion is usually less conservative in the decision solution and has been found to be more in line with attempts to exploit opportunities for improvement. Robust Deviation is a form of mini-max regret. Mini-max regret examines the optimal solutions in all scenarios and assesses the performance of each optimal solution in all other scenarios. The solution which generates the minimal absolute level of regret when compared with all scenarios is the Robust Deviation decision. This selects the solution whose maximum level of regret is minimised (Fabozzi et al., 2007).

The Relative Robustness decision criterion is the calculated in the same way as the Robust Deviation solution. However, all figures are converted to percentages. Hence the Relative Robustness decision selects the solution which minimises the maximum regret percentage.

Robust Deviation and Relative Robustness have a propensity to select solutions where uncertainty is regarded as an opportunity, as opposed to a risk that must be hedged against as with Absolute Robustness. The Robust Deviation and Relative Robustness criteria are useful in settings where either the performance of the optimal single scenario decisions fluctuates across a wide range of values or the performance of a decision across scenarios is highly variable given the highly uncertain regulatory environment this will prove useful (Fabozzi et al., 2007).

Climate Change Regulatory Uncertainty

The input data sets for Climate Change regulatory uncertainty include either emissions reductions or a price on emissions as these are the factors that are subject to regulation. As a consequence, two models will be developed to consider the form of regulatory uncertainty; one for each to evaluate the impact of both. One model will have a range of input data for emissions reductions and the other will have a range of input data for a price on emissions, thereby capturing the regulatory uncertainty.

In addition to emissions reductions and emissions prices, the model will also include a range of input data on cash flows and discount rates.

While research is scarce, some studies suggest projected cash flows vary substantially from reality. Consequently a range of values will also be included in the parameters (Statman and Tyebjee, 1985, Chen and Dyer, 2009).

A final parameter to be included in the evaluation is the discount rate. Discount rates are the source of considerable controversy, especially when environmental impacts are included in an analysis (Pindyck, 2007). As policies to safeguard the environment usually have time horizons much greater than normal investments (often more than 100 years) the question of the discount rate becomes increasingly problematic. For example, $100 at a discount of 2% is worth $14 in one hundred years, whereas $100 at a discount rate of 4% is $2.

However, if the benefits accumulate in the future, then to give them a present-day value a discount rate must be used but the issue is at what rate it should be set. In addition to there being no agreed discount rate for the present, there is no way of knowing the discount rate for the future. Consequently a range of discount rate values will also be included in the input data sets.

Climate Change Reputation and Shareholder Value

The means of exploring the reputation and shareholder value impact of voluntary emissions reductions in project selection will be by utilising the results of Guenster, Bauer et al. (2010). Their results explore the valuation of firms when the firm’s eco-efficiency is taken into account. These results show anomalously positive equity returns relative to less eco-efficient firms and they propose that such results are a direct manifestation of improved environmental reputation.

3.8 Robust Optimisation Decision Model

The Decision model will bring together various techniques in order to address the Climate Change business issues and evaluate the costs and benefits of voluntary emissions reductions when assessing large scale projects. These techniques include Capital Budgeting and multiple objective linear programming.

Capital Budgeting

The decision model will be based upon Capital Budgeting techniques as this is the conventional method of assessing potential investments (Bierman and Smidt, 2007a). Capital Budgeting is an investment planning process used to determine whether a firm's long-term investments are worth pursuing. Therefore Capital Budgeting is concerned with choices among alternative investment opportunities. There are a number of decision criteria within the Capital Budgeting process but there is a general consensus in the literature that NPV is the best means of assessing potential projects (Zimmerman and Yahya-Zadeh, 2011)..

While in theory Capital Budgeting analysis only includes a single goal of maximising NPV or internal rate of return to determine the best investment option, in practice Capital Budgeting decisions often involve multiple goals (Candler and Boehlje, 2001) as well as capital rationing. This study will also incorporate the multiple goals of minimising GHG emissions and maximising NPV within a constrained budget.

Operations Research: Linear Programming

Linear programming is an operations research optimisation technique originally developed during the Second World War to reduce the number of anti-aircraft rounds used to shoot down enemy aircraft (Kirby, 2003). The purpose of linear programming is to arrive at an optimal solution for a particular objective given a set of constraints.

Optimisation problems' key characteristics are decisions, constraints and objectives. It is necessary to incorporate these elements into a mathematical model in order to solve the given problem. It is also necessary to use a mathematical function that accurately describes the objective and constraints of the problem. These functions can be linear or non-linear and sometimes the optimal values of the decision variables must be integers (Ravindran, 2008).

Most linear programming and integer linear programming models involve one objective function. These objective functions are usually either maximise profits or minimise costs. However, it is common for more than one objective to be satisfied in a problem. For example, if a production process creates a toxic pollutant that is dangerous to the environment, a company might want to minimise the toxic by-product while simultaneously maintaining profitability. Increasing profits is likely to create additional toxic waste that is, the desirable outcome of increased profits is associated with the undesirable outcome of increased pollution. Consequently, a decision must be made in terms of a trade-off between profits and pollution. Therefore there exist multiple objectives and solving these problems involves multiple objective linear programming (MOLP); this is the focus for this study (Klimberg, 2006). However, the difficulty for multiple objective linear programming occurs when the various objectives have different units and cannot be directly compared. To solve this problem a new variable is introduced into the model which minimises the percentage variation from the target value for each objective (Ragsdale, 2007).

Multiple Objectives

The objectives in this study are the maximisation of NPV of the forecast cash flows and the minimisation of emissions or emissions costs depending upon the model.

The maximisation of NPV is self-evident as the firm would wish to make as large a profit as possible. The realisation of emissions reductions forms the key question for this study of voluntary emissions reductions.

Comparative Evaluation

In order to fully evaluate the solutions generated by the model, a conventional Capital Budgeting model will also be constructed to establish a baseline to compare the Robust Optimisation solution. In addition to comparing the results for different regulatory settings, the reputation and shareholder value implications will also be examined using the method and results from Guenster, Bauer et al (2010) who link reputation, eco-efficiency and Tobin's *Q*. This will provide a fuller picture for evaluating the costs and benefits of voluntary emissions reductions.

3.9 Conclusion

This chapter outlined the issue of decisions which involve short and long-term costs and benefits. The contemporary example being examined in this study of voluntary emissions reductions was described and the limitations of existing approaches discussed. A new conceptual framework was developed to examine this issue incorporating the Climate Change business impacts of reputation, shareholder expectations and regulatory uncertainty. To integrate these issues the conceptual framework included the factors of uncertainty, irreversibility and flexibility which are the fundamental aspects of real options analysis which is a central aspect for evaluating the business case for voluntary emissions reductions. The modelling approach to be used within the framework of Robust Optimisation was then described. This modelling approach draws on multiple objective linear programming techniques.

Chapter 4 Methodology

This chapter is designed to provide an overview of the methods, models and design of a model to evaluate the short-term costs and long-range benefits of voluntary emissions reductions for large-scale projects. The various research approaches are examined as well as research methodologies involving quantitative and qualitative analysis. Operations research techniques and Capital Budgeting methods are examined as to their suitability for the study in question.

4.1 Research Approach

There are four types of research approaches which differ according to the purpose of the research. These are exploratory, descriptive, analytical and predictive all of which are discussed in this study (Yin, 2014).

4.1.1 Exploratory Research

Exploratory research is employed when there is limited existing knowledge of a particular phenomenon and few previous studies have been undertaken. Exploratory research aims to improve understanding and identify patterns as opposed to testing a particular hypothesis. It usually involves data collection of empirical evidence and may take the form of case studies, observations or historical analysis (Collis and Hussey, 2009). This study has an element of exploratory research as there has been considerable research on the physical risks posed to corporations by climate change and many studies examining the impact of emissions reductions on the economy as a whole but few studies appear to have examined the business case for voluntary emissions reductions.

4.1.2 Descriptive Research

Descriptive research describes the specific and particular characteristics of a phenomenon. This research describes the relevant aspects and issues to whichever perspective is taken or conceptual framework used. This type of research describes who, what, when and where. It often incorporates quantitative statistical techniques (Newing et al., 2011). This study has a descriptive element to it, because it describes a process of examining the business case of a voluntary greenhouse gas emissions reduction strategy.

4.1.3 Analytical Research

Analytical research extends descriptive research in that theories are developed and causal relationships are identified and adds the how element to descriptive research's who, what, when and where (Christensen, 2011). This research also analyses how a voluntary emissions reduction strategy using Capital Budgeting techniques may be constructed and implemented.

4.1.4 Predictive Research

Predictive research extends analytical research by developing the theories are developed and tested (Adams et al., 2014). The predictive element to this study is the forecasting of the economic success of a firm may be affected by voluntary emissions reductions.

4.2 General Research Methodology

There are two main types of research methodologies which are dependent upon the type of research being conducted. They are quantitative and qualitative research. Quantitative research focuses on measuring various phenomena while qualitative research is more subjective and examines perceptions and types of understanding (Ragsdale, 2007).

This research will utilise the quantitative approach. Quantitative methods are used to construct financial models using quantitative data such as cash flows, emission levels and optimal investment decisions (Lempert et al., 2004). Quantitative techniques, including the mathematical models, are incorporated within a CSR framework.

4.2.1 Quantitative Research

Quantitative Research

Quantitative research involves the study of phenomena in which it is possible to arrive at numerical values. Quantitative research has also been categorised as being part of a positivist research paradigm. A positivist approach seeks the facts or basis of various phenomena and is founded on the belief that social sciences should be performed in the same way as natural sciences to explore relationships. These relationships should establish causal links which can generate testable theories (Punch, 2013).

Measurement is fundamental to quantitative studies as it provides the building blocks of further analysis and theory development. As such, quantitative research involves developing mathematical models and or theories to provide a mathematical relationship between the factors being studied. Quantitative research can also be used to verify hypotheses generated through qualitative research through the analysis of numerical data (Bryman and Bell, 2007).

Consequently, quantitative research involves collecting numerical data which can be used to test a hypothesis or generate a theory. Often large amounts of data are used to ensure the sample set is large enough to be statistically reliable. As a consequence statistics is the most commonly applied branch of maths in quantitative research in the social sciences, although operations research techniques are also used (Veal, 2005).

Relationships between variables is frequently studied using linear and non-linear models or by factor analysis. However, quantitative methods often incorporate a qualitative element by being used within a qualitative framework or a qualitative approach may be utilised to comprehend the results of statistical analysis. The application of quantitative methods enables qualitative concepts to be tested and this combination of quantitative and qualitative approaches is frequently described as mixed method research (Bryman and Bell, 2007).

4.3 Modelling Approach to Decision-making

The use of models to aid decision-making is a common technique. Examples of models include three dimensional models in architecture, scaled-down models of bridges or cars and abstract mathematical models which uses mathematical relationships to represent an object or decision problem. Models can aid decision-making by accurately representing the important characteristics of a decision problem in a way that is cheaper and easy to analyse. In addition, models can provide insight and understanding into an object or decision problem that are impossible to test in reality, for example crash test dummies in place of humans (Ragsdale, 2007).

Broadly speaking, there are four categories of models:

- Descriptive models which are defined by a set of mathematical relationships which predict how a system will behave;
- Normative models that form the basis of quantitative decision making following a logical set of arguments;

- Prescriptive models involve systematic analysis of problems with the application of intuition and judgement; these models incorporate uncertainty and preference analysis; and
- Decision models, which is a derived category as they combine concepts underlying normative and prescriptive models (Di Domenica et al., 2007).

This study involves the construction and implications of a decision model from underlying normative arguments from a CSR perspective for voluntary greenhouse emissions reductions.

4.4 Data

This section identifies the source and types of data used in the research. The data used in the model was obtained from a private investment firm for the assessment of potential projects as described in feasibility study documents. These documents provide the financial analysis of the project and emissions data will be calculated from the Department of Climate Change (2008).

4.4.1 Data Sources

The financial data in this research comes from a private investment firm which has collated information on Initial Public Offers (IPOs), feasibility studies and cash flow statements. Emissions in Australia have a particular profile due to the preponderance of electricity sourced from black and brown coal, very few renewable sources of energy, no nuclear power, large distances between capital cities as well as significant emissions from non-electricity generating activities (CSIRO, 2005). Consequently emissions conversions factors have been calculated for the Australian setting and different business sectors by the Australian Bureau of Statistics and the Department of Climate Change based upon the National Greenhouse Accounts Factors (ABS, 2009, Department of Climate Change, 2009a).

4.4.2 Data Types

The types of data used include cash flow statements, including cash inflows from sales, other cash inflows, cash outflows from operating expenses and other cash outflows. Emissions conversions factors will be used in accordance with the type of project to assess the Scope 1 and 2 emissions of each project (IPCC, 2013). Scope 1 and 2 emissions refer to the following:

- Scope 1: All direct GHG emissions; and
- Scope 2: Indirect GHG emissions from consumption of purchased electricity, heat or steam.

Emissions conversion factors are discussed in more detail below.

Emission Conversion Factors

There are several ways to establish the GHG emissions from a project or activity. The direct method measures the emissions directly at the source through continuous monitoring whereas the indirect method involves estimating emissions using historical activity data and the appropriate conversion factors. The use of conversion factors is a much simpler, cheaper and often equally effective technique as direct measurement. The use of conversion factors enables organisations to calculate emissions from a wide range of activities such as energy and water use, waste generation and transport. From the conversion factors it is possible to calculate an emissions quantity in the universally recognised units of carbon dioxide equivalents (CO_2e). As different greenhouse gases have different heating characteristics there is a need to convert them all into a consistent unit. CO_2e convert all the relevant greenhouse gases such as carbon dioxide, methane and nitrous oxides into an equivalent greenhouse potential using carbon dioxide as the base (Solomon et al., 2009).

4.4.3 Financial Modelling and Operations Research

Financial modelling includes developing a theoretical representation (a model) of a financial decision-making situation. This is usually in the form of a mathematical model, such as a linear programming formulation, which is designed to represent the functioning of a financial asset of a business or project (Vladimirou, 2007).

Operations research is also known as management science or decision science. It is a branch of knowledge that uses computers, statistics and mathematics to resolve problems in an optimal way. It involves applying the methods and tools of science and mathematics to management and decision-making. It is the science of making better decisions through the use of mathematical techniques. Management science makes use of mathematical models to represent a decision problem. Although models are unavoidably simplified representations of reality, they are useful if they are valid. Model building has the benefit of being an economical and quick way of analysing difficult problems as problems are easier to investigate and variables quicker and easier to manipulate (Ragsdale, 2007).

Mathematical Models

Mathematical models describe functional relationships between variables. For example, profit is a function of revenue and expenses. There are several types of mathematical models used in business;

these include prescriptive models, predictive models and descriptive models. These models utilise management science techniques in order to prescribe, describe or predict decisions. The characteristics of the different models are described in Table 4.1.

Table 4.1 Types of Mathematical Models

Model characteristics			
Category	**Functional form**	**Values of independent models**	**Management Science techniques**
Prescriptive models	Known, well defined	Known or under decision maker's control	Linear programming, networks, integer programming, Critical Path Method, Goal Programming, Multiple Objective Linear Programming, Economic Order Quantity, non-linear programming
Predictive models	Unknown, ill defined	Known or under decision maker's control	Regression analysis, time series analysis, discriminant analysis
Descriptive models	Known, well defined	Unknown or uncertain	Simulation, queuing, program evaluation and review technique

Source: (Collis and Hussey, 2009).

Prescriptive models utilise independent variables in a functional form with dependent variables that is usually well-defined. Decision-makers are able to modify the independent variables in order to find a solution to the model for a dependent variable. The solution to prescriptive models provides valuable information to the decision maker in order to reach an optimal decision; it is for this reason they are described as prescriptive (Collis and Hussey, 2009).

Predictive models calculate a dependent variable from values given for the independent variables. However, the functional form is often ill-defined. Therefore the strength of these models to predict dependent variable values is dependent upon the validity of the functional form (Punch, 2013).

Descriptive models are employed where the functional form that describes the relationship between the independent and dependent variables is well defined. However, uncertainty exists about the values of both the independent and dependent variables. This form of model describes the performance and relationships of a system and provides greater understanding of the system (Pakes, 2014).

The two financial models developed in this research are prescriptive models. They aim to help management assess the short and long-term costs and benefits of implementing voluntary GHG emissions reductions. The models to be developed in this research will utilise capital budgeting techniques and operations research methods of linear programming which, when solved, provide optimal solutions. The first model will be a conventional capital budgeting model where the only criterion for optimisation is the NPV for the projects within the budgetary constraint. The second model will have two forms: one with an emissions price, the other with emissions reductions. It will incorporate both the capital budgeting cash flow analysis within the budgetary constraint but also emissions linked to each project. The solutions of the two models shall be compared to illustrate the implications and repercussions of voluntary GHG emissions reductions.

The methods and techniques for the models are discussed in more detail in the following sections.

4.5 Capital Budgeting

Capital Budgeting (also known as Project Appraisal) is an investment planning process used to determine whether a firm's long-term investments such as new machinery, replacement machinery, new plants, new products, and research and development projects are worth pursuing. Therefore capital budgeting is concerned with choices among alternative investment opportunities. Given the breadth of applicability of investment alternatives for business decisions, including roads, education and research and development, some scholars view capital budgeting as one of the most important economic activities in both private and public sectors (Kashyap, 2014).

While in theoretical capital budgeting analysis only a single goal of maximising NPV or internal rate of return to determine the best investment option, in practice capital budgeting decisions often involve multiple goals as is the case with this study (Candler and Boehlje, 2001).

4.5.1 Capital Budgeting Assumptions

Several basic assumptions are made with respect to capital budgeting and those that will fund the prospective investments, namely:

- Investors prefer more return to less, *ceteris paribus*; and
- Cash received today is preferred to same amount received in the future (Dayananda et al., 2002).

The final assumption refers to the time value of money. This concept is discussed in more detail in the following section.

Time Value of Money and Risk Considerations

The formula $(1+r)^{-t}$ is universally used to convert future monetary amounts into their present value equivalents. Depending upon the research perspective taken, the discount rate (r) either takes into consideration the pure time value (using a risk-free rate), the risk of the corporation (often, but not always the firm's weighted average cost of capital), the risk of the operating unit, the risk of the specific project or the risk of the specific cash flow component. The time period for the present value calculation is represented by t, with later time periods leading to a lower present value due to its compounding nature (Bierman and Smidt, 2007b).

The concept of the time value of money is based on the choice of receiving a given sum of money now or at a later date, the tendency of most people is to receive the money now. Therefore, it is considered that a dollar received today is more valuable than a dollar received in the future. This concept is reinforced by the existence of positive rates of interest at which money can be invested or borrowed (Dayananda et al., 2002).

Therefore in capital budgeting calculations, expected future cash flows must be adjusted according to which time period the cash flows occur in. In order to perform these calculations a discount rate must be chosen. Often a rate is chosen which contains a pure time element as well as a risk element to give the total discount rate (Froot and Stein, 1996).

The pure time value of money can be estimated from either the interest rate of government bonds or the interest rate on long-term bonds of the firm. Government securities come as close to default free as possible (Zhang, 1997).

However, the determination of the risk adjustment is very difficult and controversial (Heal, 1997). Proponents of incorporating a risk element in the discount rate argue that more risky projects should have higher discount rates to account for their risky nature. Conversely low risk investments should have a risk element that is smaller to represent the lower risk (Bierman and Smidt, 2007a). However, there is a considerable body of research, starting with Bowman (1980), and including Bettis and Mahajan (1985), Fiegenbaum and Thomas (1988), Miller and Bromiley (1990), Sinha (1994), Andersen et al. (2007), Bromiley and Rau (2010) that suggests the opposite. This research suggests it is far from clear how a higher discount rate accurately reflects the risk of a particular project, the nature or timing of the risk. In addition, it is problematic to justify the selection of a particular value for the discount rate to reflect its risk and higher discount rates discriminate against projects with a long life.

High discount rates also place a very low priority on the welfare of future generations, which can also discriminate against projects that improve the environment. Conversely some scholars argue that by adopting very low discount rates this discriminates in favour of climate change policies and against investments that could still benefit society (Stavins, 2001).

Research into the value of discount rates over time suggests people's discount rates decline over time (Frank, 2000). This can have a profound effect on aggregate analysis of the benefits and costs of alternative climate policies (Stavins, 2001). The treatment of discount rates in the model is addressed in Chapter 5.

4.5.2 Capital Budgeting Techniques

Many formal methods are used in capital budgeting, however, the most commonly used measures include:

- Net present value;
- Internal rate of return;
- Payback Period;
- Discounted Payback; and
- Return on Investment (Hall et al., 2012).

These methods use the cash flows from each potential investment. No matter which measure is used, the capital budgeting decision must take into consideration the following factors:

- Alternative investments and future opportunities; and
- Time value of money (Dayananda et al., 2002).

Net Present Value

Net present value (NPV) is normally defined as the sum of present values of a time series of cash inflows and outflows. It is a typical method for using the time value of money to assess large-scale, long-term projects. It measures the surplus or deficit of cash flows, in present value terms, after financing charges have been satisfied.

Cash flows are considered to be the relevant measure of the impact of a decision on the firm and the use of anticipated cash flows is the primary input in the decision to be analysed. In particular, investments should be evaluated using after tax incremental cash flows. Incremental cash flows are regarded as changes the bank account or cash balance, there is a cash flow. This description includes opportunity costs. However, these are often difficult to quantify and are often omitted for that reason (Adams et al., 2010).

The calculation of NPV requires the following steps:

1. Choose an appropriate rate of discount;
2. Compute the present value of the cash proceeds expected from the investment;
3. Compute the present value of the cash outlays required by the investment; and
4. Add the present value equivalents to obtain the investment's NPV (Dayananda et al., 2002).

Mathematically NPV is expressed as the sum of all terms:

$$NPV_i = \sum_{t=1}^{T} \frac{X_t}{(1+r)^t} - X_0$$

where:

t is the time of the cash flow

r is the discount rate

X_t is the net cash flow (the amount of cash, inflow minus outflow) at time *t* (X_0 is the initial investment).

An investment is considered to be worth pursuing if it fulfils two criteria:

- The NPV must be greater than zero; and
- The NPV must be greater than any mutually exclusive alternative available to the firm (Segelod, 1998).

NPV is an indicator of how much value an investment or project adds to the firm. With a particular project, if X_t is a positive value, the project is in the status of discounted cash inflow in the time of *t*. If X_t is a negative value, the project is in the status of discounted cash outflow in the time of *t*. Projects with a positive NPV may be accepted or rejected. This is because there may be an alternative investment with a higher NPV and if a choice must be made between the two investments, it is the option with the higher NPV that should be chosen, thus eliminating a project with a positive NPV. Despite this, Bierman and Smidt (2007a) argue that all projects with a positive NPV should be accepted as theoretically there should be no rationing of capital in a perfect market. This would lead to the project being funded through either debt or equity or a combination of both. However, in practice markets are not perfect and capital rationing scenarios arise frequently and a firm is often forced to choose between projects. Table 4.2 two summarises the consequence of NPVs in various scenarios.

Table 4.2 NPV Investment Scenarios

IF...	IT MEANS...	THEN...
NPV > 0	The investment would add value to the firm.	The project may be accepted.
NPV < 0	The investment would subtract value from the firm.	The project should be rejected.
NPV = 0	The investment would neither gain nor lose value for the firm.	Indifferent in the decision whether to accept or reject the project. This project adds no monetary value. Decision should be based on other criteria, for example, strategic positioning or other factors not explicitly included in the calculation.

Source:(Bierman and Smidt, 2007a).

Therefore one way of viewing the NPV of an investment is the maximum amount a firm could pay for the opportunity of investing in a project without being monetarily worse off. As such payments are not paid in practice; the NPV is an unrealised capital gain from investing in the project and the capital gain will be achieved if the cash flows eventuate as forecasted.

NPV Assumptions

As well as the assumptions with all capital budgeting measures, further assumptions are made in calculating the NPV of a potential investment if no capital constraints exist, these include:

- Cash flows are known;
- Any funds required for potential projects be raised externally or invested externally at discount rate *r*;
- The discount rate *r* is constant through all time periods;
- All costs and benefits can be expressed in terms of cash flows; and
- If more than one source of capital is used, each source remains a constant proportion of the present value of remaining cash flows throughout the life of the asset (Levary and Seitz, 1990).

However, as discussed in the Capital Budgeting section below, the issue of capital rationing will be discussed and incorporated into the proposed model.

Internal Rate of Return

The internal rate of return also utilises present value calculations. The technique involves finding a discount rate that will make the sum of the net present values of the cash flows expected from an investment equal to zero. This is the Internal Rate of Return (IRR) of the investment and it is now possible to simply calculate this value with widely available computer software. However, difficulties in the practice of implementing IRR as a decision criterion include some investments have non-conventional cash flows which alternate between being positive and negative, the IRR may not exist, or there may be more than one IRR (Percoco and Borgonovo, 2012).

Payback Period

The payback period is one of the simplest and most frequently used methods of measuring the value of an investment (Konstantakos et al., 2012). The payback period is defined as the length of time required for the stream of cash proceeds produced by an investment to equal the original cash outlay for the investment. However, while it is widely practised (Graham and Harvey, 2001), it suffers from two theoretical weaknesses: it fails to give any consideration to cash proceeds earned after the payback date and it fails to take into account the differences in the timing of cash flows earned prior to the payback date (Brooks and Mukherjee, 2013).

Discounted Payback Period

The discounted payback period addresses one of the weaknesses of payback period in that it incorporates the time value of money into its calculations. This technique involves calculating the length of time required for the present value of cash flows to change from negative to positive. This calculation gives a break-even life of the asset. If the life of the asset exceeds this break even life, the asset will have a positive present value. This approach is an improvement on payback period as it includes the time value of money; however, it still does not consider the cash flows after the payback period (Remer and Nieto, 1995).

Return on Investment

Return on Investment (ROI) is the ratio of a project's net cash flows divided by the cash outflows of the investment. However, return on investment is not a reliable measure to use in comparing investment alternatives as, like payback period, it also fails to consider the time value of money. This is its main shortcoming, but it also depends on a depreciation accounting assumptions and does not consider effectively the size of the investment (Arrow and Kruz, 2013).

4.5.3 Capital Budgeting Technique in Model

Due to the limitations of techniques such as payback period and return on investment (described above), these techniques were not considered the appropriate approach for the model. In addition, the IRR was also considered inappropriate due to its nature of finding a particular rate as opposed to monetary value. Hence, the NPV is the most appropriate technique to evaluate voluntary emissions reductions and assess the economic success of the firm.

4.5.4 Traditional Capital Budgeting Solutions

Alternative Investments and Future Opportunities

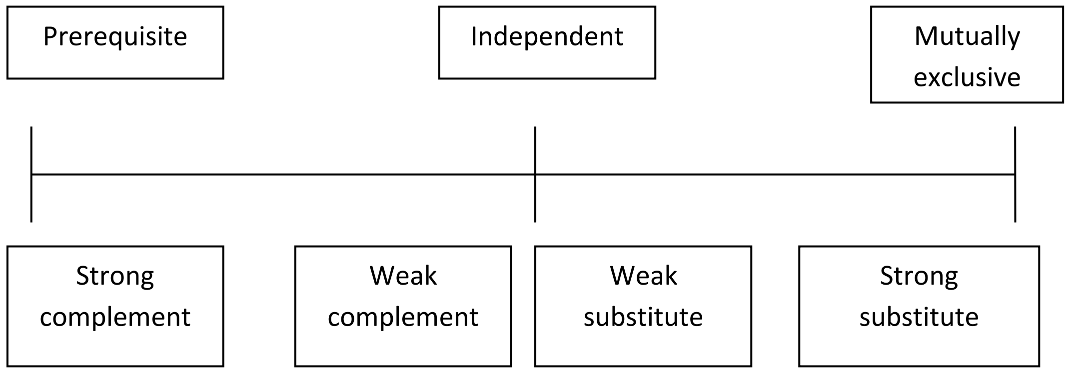
When assessing alternative investments it is vital to be conscious of the potential connection between one or more investment proposals. When one investment is dependent on another proposal, attention must be given to the question of whether decisions about the first investment can or should be made separately from decisions about the second.

For two investments to be independent of one another two conditions must be satisfied:

- It must be possible, in principle, to invest in project A whether or not project B is accepted; and
- The net value from project A must not be affected by whether investment in project B takes place or not.

In practice, investments often fall on a continuum from investment A being a prerequisite for investment B to investment A being mutually exclusive of investment B. This is shown in Figure 4.1. The prospective projects in this study are all mutually exclusive and consequently the benefits from one project are not affected by the acceptance or rejection of another project.

Figure 4.1 Investment Relationships



Source: (Bierman and Smidt, 2007a p46).

4.6 Capital Budgeting under Capital Rationing

When undertaking capital budgeting investigations, situations may occur where the potential sums to be invested are limited. This phenomenon is known as capital rationing (Levary, 1996). The two forms of capital rationing are external and internal capital rationing. External capital rationing is when there is a difference between the market rate of interest at which the firm can borrow money (that is, when a firm obtains capital from the market by issuing a security) and the market rate at which it can lend (that is, the use of funds to purchase any type of security). Internal capital rationing occurs when management decides to limit the total amount invested or the kind of investment the firm undertakes (Brüggen and Luft, 2011).

4.6.1 External Capital Rationing

If capital markets were such that a firm could lend or borrow as much money as it wished at the going rate of interest, this rate of interest would be the same for both the borrowing and lending transactions. The goal of profit maximisation would then require the firm to accept all independent investments whose present values were positive. With such capital markets, the choice of investments would not be dependent on the amount of funds available to the firm, as by borrowing each firm could finance investments that had positive NPVs. In practice, this theoretical situation never occurs. There will always be some divergence between the rates of interest at which the firm and lend (invest) and the rates at which it can borrow funds. The size of the difference will vary due to underwriting costs and other transaction costs (Thakor, 1990).

4.6.2 Internal Capital Rationing

There are two types of internal capital rationing: where the firm sets a cut-off rate for investments that is higher than the firm's cost of money and where a firm decides to limit the total amount of funds committed to internal investments in a given year. There are various reasons management may set a ceiling for the funds to be invested; being unwilling to take on extra debt or going to the market to obtain extra funds so as to prevent possible outside control, or dilution of earnings per share (Stein, 1997).

Whatever the reasons, capital rationing is a common phenomenon and this situation is the one assumed to be the case for the model proposed.

4.7 Operations Research (Management Science) and Optimisation

Management Science techniques such as linear programming, networks, Critical Path Method, Goal Programming, Multiple Objective Linear Programming, Economic Order Quantity, Non-Linear programming and regression analysis are used to analyse and solve complex decision-making problems which require an optimal solution. Some of these techniques are discussed in more detail below (Hillier and Lieberman, 2005).

Optimisation problems have the key characteristics of decisions, constraints and objectives which must be incorporated into the model for it to be effective. It is necessary to incorporate these elements into a mathematical model in order to solve the problem. It is also necessary to use a mathematical function that accurately describes the objective and constraints of the problem. These functions can be linear or non-linear and sometimes the optimal values of the decision variables must be integers (Ravindran, 2008).

The importance of optimisation as a field of mathematics stems from the broad applicability of its techniques and the recent development of effective algorithms. Optimisation is either the maximisation or minimisation of a particular objective, for example, profits or expenses. The objective is represented mathematically by an objective function which includes the decision variables. The optimal value for the objective function is limited by whatever constraints apply to a given problem, for example, total number of staff available (Bazaraa et al., 2011).

An optimisation problem may require integers for the decision variables (for example, it is not possible to have 0.34 of a person) and such problems are called integer or discrete optimisation problems. However, if there are no such limitations on the decision variable then it is considered to be a continuous optimisation problem.

4.7.1 Some Optimisation Techniques

Linear Programming

The use of linear programming as the methodology to assist in the analysis of capital budgeting problems has been in use since the suggestion by Weingartner (1963) and Baumol and Quandt (1965) among others.

Linear programming derives its name from the objective and constraint functions which are linear. The objective function sets out the variable which is to be optimised, for example, profits or costs. The constraint functions set out the limits for the objective function, this may include a limited number of parts or number of hours staff can work. Consequently a linear programming model takes the general form of:

MAX (or MIN): $c_1X_1 + c_2X_2 + ... + c_nX_n$

subject to:

$$\begin{aligned} & a_{11}X_1 + a_{12}X_2 + ... + a_{1n}X_n \leq b_1 \\ & a_{k1}X_1 + a_{k2}X_2 + ... + a_{kn}X_n \leq b_k \\ & a_{m1}X_1 + a_{m2}X_2 + ... + a_{mn}X_n = b_m \\ & X_n \geq 0 \end{aligned}$$

The last constraint is the non-negativity constraint.

Linear Programming is commonly used to solve Internal Capital Rationing problems where the objective is to maximise the NPV and the constraints consist of a limited budget (Weingartner, 1963).

Linear Programming Models built with spread sheet programs such as Microsoft Excel use the Solver Add-In to find solutions to the problems. The Solver Add-In uses the Simplex Method which operates by identifying any feasible solution or extreme point of the feasible region. It then moves to the adjacent extreme point if this improves the value of the objective function. This process continues until no further improvements in the objective function are longer possible (Nash and Sofer, 1996).

Integer Linear Programming

When some or all of the decision variables in a linear programming problem are restricted to assuming only integer values, the resulting problem is referred to as an Integer Linear Programming (ILP) problem. This is often the case in many business situations, for example, when scheduling workers for a shift it is not possible to allocate 0.375 of a worker. The restriction to integer values is known as an integrality condition. A further restriction is the binary condition, where the integer solutions are restricted to either 0 or 1 (Schrijver, 1998).

Integer models come in two forms: pure integer programs and mixed integer programs. Mixed integer programs have some values which must be integers and others can be continuous.

Integer problems with many variables can be very difficult to solve. in contrast to continuous programs, for an integer program it can be hard to prove that a particular solution is the optimal one (Ragsdale, 2007).

4.7.2 Goal Programming

Goal Programming (GP) (also called Linear Goal Programming) and is categorised as a special case of Linear Programming. GP originated as a means of resolving infeasible LP problems with multiple objectives. GP is considered a multi- criteria decision-making method and is used to solve multi-variable, constrained resource and similar problems with multiple goals (Künzi, 2008).

Usually linear programming models and capital budgeting problems assume any constraints are hard constraints. A hard constraint is a constraint that can never be broken, for example budgetary constraints. However, not all constraints are hard constraints and often these, known as soft constraints, may be infringed slightly. GP incorporates soft constraints in that the constraint represents a desired target as opposed to a binding constraint, before the objective function, or set of objective functions with variable weightings, can be maximised or minimised (Kosmidou and Zopounidis, 2004).

GP models have an objective function, constraints (goal constraints) and non- negativity requirements. The GP objective function is commonly expressed in minimisation form such as (Schniederjans, 1984):

$$\min Z = \sum_{i=1}^{T} w_{kl} P_k (d_i^- + d_i^+)$$

$$\textit{for} \quad k = 1,....K; l = 1,...L$$

Where *i* is the goal constraint index, *k* is the priority rank index and *l* is the index of the deviation variables within priority rank. In the objective function, *Z* is the summation of all deviations, the w_{kl} are optional mathematical weights used to differentiate deviation variables within the k^{th} priority level. The P_k rankings are called pre-emptive priorities because they establish an ordinal priority ranking where ($P_1 > P_2 > P_3 > .....P_K$) that orders the systematic optimisation of the deviation variables. However, it is possible to solve a goal programming model without the pre-emptive priorities and only assigning weights to each goal (Candler and Boehlje, 2001).

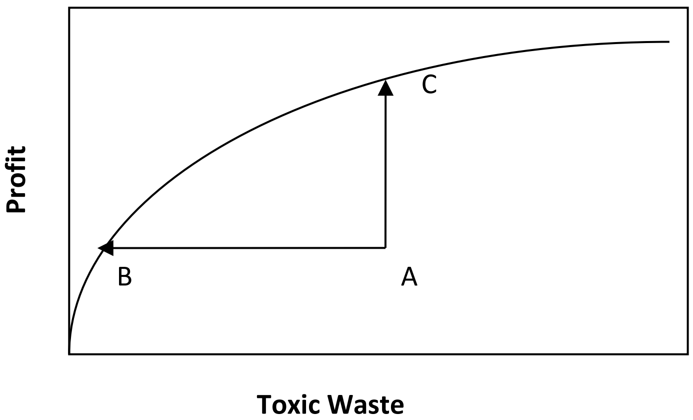
Unlike standard linear programming, different GP solutions cannot be compared on the basis of their optimal objective function values. Changing the weights of the various objective functions from iteration to iteration and then comparing their values is not appropriate as they measure different things. The objective function(s) of a goal programming problem allows the exploration of possible solutions and consequently it is the solutions that are produced that are compared, not the results for the objective functions themselves. In addition, one or more goals may be viewed as being very much more important than the other goals and consequently such a large weight is attached to that goal that deviations from that goal do not occur. This is another form of pre-emptive goal programming as certain goals pre-empt others in order of their importance. If the target values of these goals can be achieved, then the use of pre-emptive weighting effectively makes these goals hard constraints and thereby eliminates the need for additional pre-emptive priority rankings. It is also possible to place hard constraints on how much deviation occurs from a goal and also the use of another type of objective function, the Minimax regret objective can be advantageous to minimise the maximum deviation from any goal (Mukherjee and Bera, 1995).

4.7.3 Multiple Objective Linear Programming

Unlike Goal Programming, Multiple Objective Linear Programming (MOLP) has multiple objective functions. Most linear programming and integer linear programming models involve one objective function; these objective functions usually either maximise profits or minimise costs. However, if a production process creates a toxic pollutant that is dangerous to the environment, a company might want to minimise the toxic by-product. Increasing profits is likely to create additional toxic waste, that is, the desirable outcome of increased profits is associated with the undesirable outcome of increased pollution. Consequently a decision must be made in terms of a trade-off between profits and pollution. Therefore, there exist multiple objectives and solving these problems involves MOLP (Klimberg, 2006).

Within MOLP there exist dominated and non-dominated solutions. Accepting a solution that involves a solution at point A (seeFigure 4.2) is undesirable. There are two alternatives that are desirable. Point B provides the same profit but with less waste, while point C provides more profit for the same waste. Thus, both points B and C are desirable to A, that is, points B and C dominate A. In addition, all of the points along the curve from point B to point C dominate A. In MOLP a decision alternative is dominated if there is another alternative that produces a better value for one objective without worsening the other value. Therefore the preference is for decision alternatives which are non-dominated (An, 2008).

Figure 4.2 Trade-offs Between Objectives and Decision Solution Alternatives(Ragsdale, 2007)



Source: (Ragsdale, 2007).

MOLP problems can be viewed as special types of goal programming problems where target values must be determined for each objective, this contrasts with GP where specific goals are predetermined (Ragsdale, 2007).

4.7.4 Uncertainty

Uncertainty is considered to be a lack of information about the factors that describe the system that is being modelled (Lontzek and Narita, 2009). In traditional linear programming optimisation approaches a small uncertainty is simply ignored and the nominal optimal solution is recommended in the hope the uncertainties will not affect the feasibility or optimality of the solution. However, this is not the case for the problem being investigated where the input values may vary to a large degree.

Normally the data of real world linear optimisation problems is not known exactly. The most common reasons for this include:

- Some of data entries (such as future demand and returns) do not exist when the problem is solved. Thus this data is subject to prediction errors;
- Some of the data cannot be measured exactly, this data is subject to measurement errors; and
- Some of the decision variables cannot be implemented exactly as computed. This data is subject to implementation errors. The contribution of a particular decision variable x_j, to the left hand side of constraint i is the product $a_{ij}x_j$.

For this study, the type of uncertainty being modelled is the first listed. The uncertain regulatory framework and hence the input data is not known at the time the model is solved.

While recent optimisation algorithms and software developments allow modellers to handle a wide variety of very complex optimisation problems, the optimal solutions produced can be very sensitive to small fluctuation in the problem inputs. However data is rarely certain or accurate, consequently a number of optimisation methods have been suggested for treating parameter uncertainty. The most common methods to address uncertainty are best case/worst ca se modelling, ‘what if’ analysis, sensitivity analysis, Monte Carlo simulation, stochastic programming and Robust Optimisation. These are discussed in more detail below (Ragsdale, 2007, Kouwenberg, 2001).

Best Case/Worst Case

If the value of a particular variable is unknown, one technique for managing this uncertainty is to use the most optimistic (best case) or pessimistic (worst case) values that are possible for the uncertain variables. However, this approach is entirely subjective. Nevertheless, the appeal of this technique is that it is easy and quick (Hall et al., 2012).

What if Analysis

What if Analysis is similar to Best Case/Worst Case analysis in that a decision maker can change the value of uncertain variables to determine the effect this has on the final model outcome or objective function. Various values may be entered and thus provide some insight into how the variables affect the performance measure in question; be it costs or profit. However, this type of analysis has 3 major flaws:

- As the values used are based on the decision maker's judgement they are likely to be biased;
- A very large number of scenarios must be generated to provide a reasonable insight into the performance measure and model; and
- There is not enough objectivity to the analysis and therefore it lacks credibility (Ragsdale, 2007).

Sensitivity Analysis

Sensitivity analysis is a technique to determine how the uncertain variables in a model affect the performance measures or model output. This is done by systematically changing the values of the variables to determine the effects of the change. The difference between sensitivity analysis and What If Analysis is the more systematic nature of the former (Saltelli and Annoni, 2010).

In addition, it is possible to study the effects of changing several coefficients or variables simultaneously using the Simplex Method (Wendell, 1985). This technique provides information about:

- The range of values the objective function coefficients can take without the optimal solution being affected;
- The impact on the optimal solution of increases and decreases in the constraints;
- The impact on the optimal solution value by forcing changes to the values of variables from their optimal value; and
- The impact that changes in constraint coefficients have on the optimal solution (Winston and Venkataramanan, 2003).

However, this simplex method technique is not available for multiple objective linear programming models where the optimal solution involves minimising the percentage deviations from the various goals (Winston and Venkataramanan, 2003). It is also an *ex post* technique and does not include uncertainty in the calculations to reach the solution, consequently a completely different solution may have been reached if the uncertainty is incorporated into the formulation of the solution.

Monte Carlo Simulation

Monte Carlo Simulation is a technique that describes the characteristics of the performance measure of a model when the values of the variables are uncertain. The purpose of Monte Carlo simulation is to describe the distribution of the possible output values of the model. This technique is an automated, random and more rigorous version of What If Analysis. The assigning of values to the variables is automated by a random number generator and these values are then used to calculate the output value. This process is undertaken repeatedly and the number of iterations is determined by the modeller. This process will produce an array of results which can then be used to calculate a probability distribution of outcome values with associated mean and variance. Therefore this technique provides greater insight into the effects of uncertainty on the model and performance measure (Kosmidou and Zopounidis, 2004).

However, if data about the probability distribution is unavailable then judgement is required to select the type of probability distribution and which single point measure is most appropriate (Law and Kelton, 1991)**.** Another disadvantage of simulation is that direct optimisation is generally not possible. It is necessary to use some search procedure in conjunction with the stochastic simulation model to find better settings of the decision variables (Hardaker et al., 2004a) and this approach is problematic when applied to linear programming as a single figure is required, usually the mean or median, which ignores the possibility of low probability, high impact scenarios.

Stochastic Programming

Stochastic programming models utilise probability distributions in their formulation and produces an optimal solution using values for the variables from within the probability distribution. Often Stochastic Programming models consist of linear programming models with two states. The first stage involves a decision after which a random event takes place which affects the outcome from the first stage decision. The second stage involves a recourse decision taken in light of the random event which has taken place (Heitsch and Römisch, 2011).

Solving a Stochastic Programming model generates an optimal solution for a first stage and group of recourse decisions that explicitly which indicate which action should be taken following the resolution of the random event (Kouwenberg, 2001).

For example a two stage stochastic linear program with recourse is usually represented mathematically as follows:

$$\text{Max}_x \quad \begin{aligned} & a^T x + E[\max_{y(\omega)} c(\omega)^T y(\omega)] \\ & Ax = b \\ & B(\omega)x + C(\omega)y(\omega) = d(\omega) \\ & x \geq 0, y \geq 0 \end{aligned}$$

Usually in stochastic programming vector *x* represents first stage decisions and vector *y (ω)* represented second stage or recourse decisions following a random event *ω*. As with conventional linear programming deterministic constraints are represented by *A* and *b* for the first stage decision, while stochastic constraints for the second stage decision are represented by *B(ω)*, *C(ω)* and *d(ω)* which links them to the first stage decision. The objective function for the deterministic first stage is represented by $a^T x$, while the second stage objective function takes into consideration all the possible outcomes of the random event *ω* and is represented by the term $c(\omega)^T y(\omega)$ (Hardaker et al., 2004b).

However, in order to effectively model a problem with Stochastic Programming it is necessary for the uncertainty to have a known probabilistic distribution (Bertsimas et al., 2010). In addition, stochastic programming is a two stage approach and not applicable when a single decision is required as to proceed with an investment or not. Consequently stochastic programming is not ideally suited to this study.

Robust Optimisation

Robust Optimisation methods have emerged in recent years as a computationally attractive alternative to stochastic programming methods. Robust Optimisation treats uncertainty as deterministic but does not limit parameter values to point estimates which Monte Carlo Simulation requires. Robust Optimisation requires problems to remain feasible for any values of the uncertain parameters within the pre-specified uncertainty sets. Therefore the main idea behind Robust Optimisation is to allow for multiple possible values of the uncertain parameters to be taken into consideration during the optimisation procedure and construct a solution that is optimal for any realisation of the uncertainty in a given set (Bertsimas et al., 2010). As such Robust Optimisation is not a problem class (for example, Linear Programming or Quadratic Programming), but rather modelling techniques for addressing data uncertainty.

Robust Optimisation is not an *ex post* tool like sensitivity analysis, which is a typically applied post optimisation tool for quantifying changes for small variations in the underlying problem data. With Robust Optimisation the goal is to compute solutions with *a priori* feasibility when the problem parameters vary within the prescribed uncertainty set (Kuhn et al., 2011).

The degree of robustness required for the problem determines the range of the uncertainty set. Robust Optimisation models are especially applicable in the following situations:

- Estimation is required for the values of some parameters;
- The constraints may have uncertain values which must be satisfied nonetheless;
- The optimal solution of the objective function is especially susceptible to small changes; and
- Low probability but high magnitude risks may lead to catastrophic results.

There are several definitions of Robust Optimisation. However, there are two main classes of Robust Optimisation: constraint robustness (model robustness) and objective robustness (solution robustness).

Constraint robustness is a common approach in engineering when all possible values of uncertain inputs require a solution that stays feasible for any of those values. This is represented mathematically by

$$\begin{aligned} &\min_x f(x) \\ &G(x, p) \in K, \forall p \in U \end{aligned}$$

When uncertain parameters are included in the objective function the type of modelling is considered to be objective robustness. The design of this form of robust solution aims for the solution to be close to the optimal for all possible values of the uncertain parameters. Consequently, an objective robust solution may be obtained by solving:

$$\min_{x \in S} \max_{p \in U} f(x, p)$$

Where *S* is the feasible set, *f* is the objective function which is dependent upon the uncertain parameters *p*. Objective robustness has been demonstrated to be a special case of constraint robustness (Greenberg and Morrison, 2008).

Given the features of Robust Optimisation where solutions are obtained that are good for all eventualities, the lack of requirement for probability distributions, the incorporation of low probability, high impact events, makes the Robust Optimisation modelling framework suitable for this study.

4.8 Conclusion

This chapter has examined the task of applying operations research techniques and capital budgeting methods for this study. A number of operations research techniques were explored to investigate the research problem and the most appropriate techniques of multiple objective linear programming within a Robust Optimisation framework were justified according to the specific aspects of this study.

Chapter 5 Model

5.1 Introduction

This chapter will describe a Conventional NPV Model with Capital Rationing for assessing potential projects and then develop two multiple objective emissions models to assess the same projects and also incorporate uncertainty in the selection process. The Conventional NPV Model with Capital Rationing will provide a 'business as usual' point of reference for the Emissions Models. Comparison of the models will enable analysis and implications of the Emissions Models to be evaluated.

In this chapter the Capital Budgeting and Robust Optimisation techniques used are described in more detail to evaluate voluntary GHG emissions reductions for large-scale investment decisions.

The broad outline of the model formulation in this study consists of:

- Computer simulation and optimisation MOLP examining cash flows and GHG; and
- Decision Criteria to maximise the minimum outcome or minimise the maximum regret within a Robust Optimisation framework.

Traditionally there have been three main categories of models which incorporate environmental factors. These include:

- Optimisation methods;
- Complete conversion problems modelled as optimal stopping problems; and
- Stochastic programming models.

Of these, this study will use a form of multi-criteria optimisation modelling known as Robust Optimisation which has been developed in recent years to better suit the particular issues of the problems being examined.

5.2 Theoretical Development of Robust Optimisation

The modelling paradigm called Robust Optimisation emerged from dissatisfaction with limitations of the three classical models: the Mean Risk Model, Stochastic Programming and the Chance Constrained Model which do not quite capture major effects of relatively small variations in input data (Greenberg and Morrison, 2008).

Gupta and Rosenhead (1968) first introduced the notion of robustness optimisation with the intention of providing greater flexibility in terms of recourse actions becoming available. They favour flexibility in what recourse actions are subsequently available. Given two policies x_1 and x_2, with x_1 preferred on the basis of expected return, they considered the relative flexibility of how many and what recourses are available in each case. When compared to the traditional Mean Risk, Recourse and Chance Constrained Models this approach does not require variances as required in the Mean Risk Model, nor precisely defined cost structures as required in the recourse model and does not require probability distributions were which Chance Constrained models require. Consequently, their mode-enabled decision to be based on qualitative information to gain the most recourse alternatives (Wang et al., 2012).

However, a second view of robustness was developed to examine the degree to which a solution is sensitive to the underlying assumptions (to the data values as well as functional relations). This has evolved into a collection of Robust Optimisation models (Fabozzi et al., 2007).

A major problem with dynamic and Stochastic Programming models is that in practice it is often difficult, if not impossible, to obtain detailed information about the probability distributions of the uncertainties in the model. This is especially the case when environmental factors such as Climate Change and concomitant regulations are incorporated into the model. Consequently, Robust Optimisation was developed to address the same type of problems as Stochastic Programming, but without the need for assumptions on the probability distributions of the uncertain parameters and still remain computationally tractable (Fabozzi et al., 2007) and for situations where it is not possible to model recourse actions.

Robust Optimisation deals with making optimisation models robust with respect to constraint violations by solving so-called robust counterparts of these problems for appropriately defined uncertainty sets for the uncertain parameters. These robust counterparts can be worst case formulations of the original problem in terms of deviations of the parameters from their nominal values (Ben-Tal et al., 2013).

In Robust Optimisation the modeller makes the problem well defined by assuming that the uncertain parameters vary in a particular set defined by the knowledge of the particular decision problem (Fabozzi et al., 2007). This framework is described in more detail below.

5.3 Robust Optimisation Framework

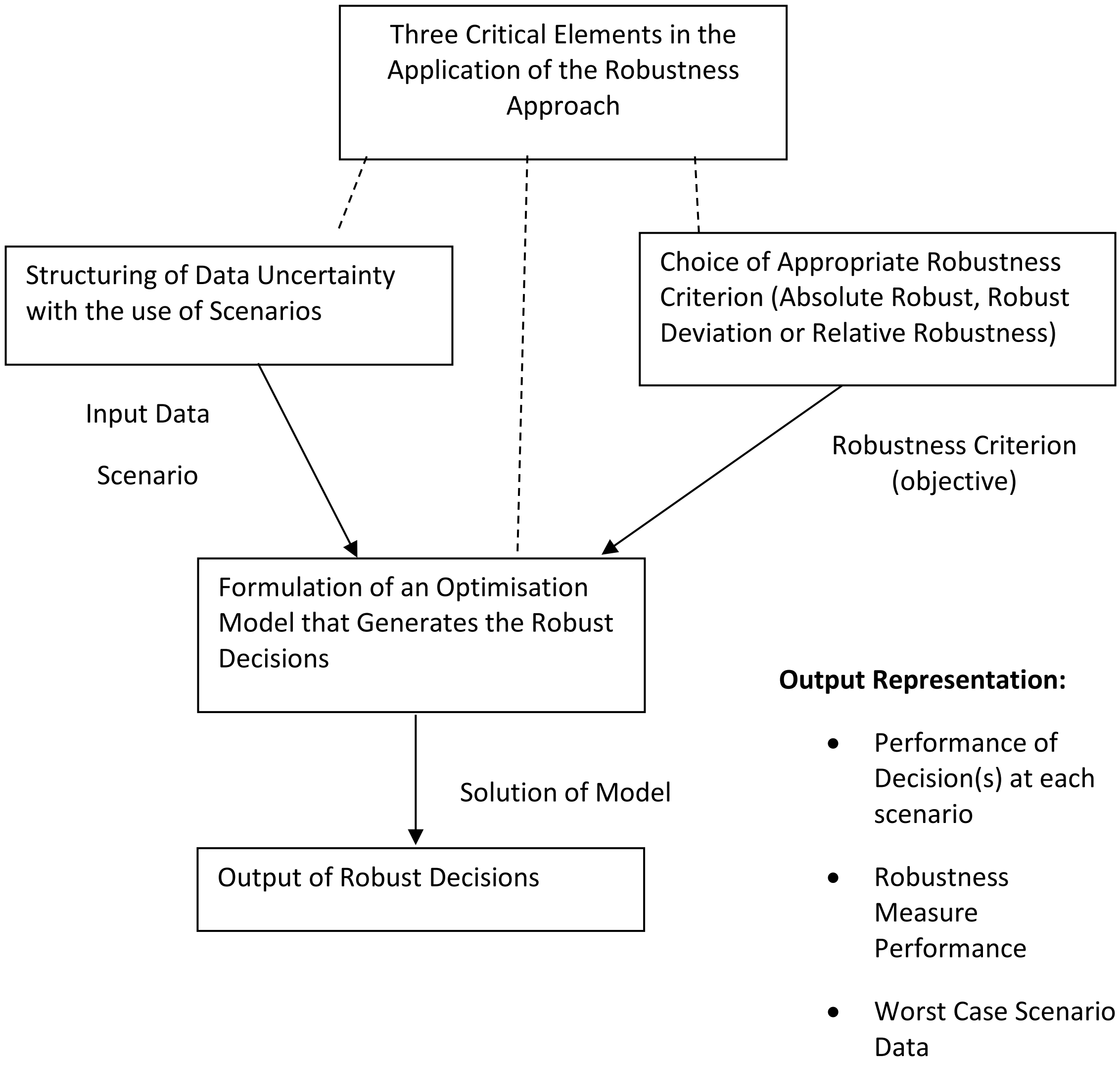
The Robust Optimisation approach to decision-making first identifies potentially realisable input data sets, or scenarios, that are suitable for the decision model. This is done without assigning probabilities to the various instances and then proceeds to find the decision that achieves a good outcome even in the worst case input data sets the solution performs well, or in other words, it performs well in all scenarios.

There are three critical elements in the application of the robustness approach to decision-making which include:

- Use of a Scenario Planning approach to structure data uncertainty for the decision situation;
- Choice of appropriate Robustness Criterion (or criteria) for the decision situation; and
- The formal development of a Decision Model known as Robust Optimisation.

This is shown in Figure 5.1.

Figure 5.1 Robust Optimisation Framework



Source: (Kouvelis and Yu, 1997 p12).

5.3.1 Robust Optimisation, Uncertainty and Scenario Planning

While Stochastic Programming accounts for uncertainty through a recourse decision and probability distributions, many instances require 'here and now' decisions which must be taken without any possibility of recourse, knowledge or probability distributions and are properly addressed through Robust Optimisation (Ben-Tal et al., 2009).

Uncertainty in such problems could be due to at least three different factors:

- Ignorance, such as not knowing the impacts of increased greenhouse gases in the atmosphere;

- Measurement errors or incomplete data; and
- Future events.

Using probabilistic measures, such as averages, leads to the replacement of the uncertain parameters with their expected values which can lead to less than optimal decision as:

- The parameters may be correlated; and
- The functions may not be linear.

Consequently, using expected values cannot account for worst case scenarios or provide a decision that will perform well in all scenarios. Therefore optimisation techniques that must account for potentially catastrophic consequences are best modelled using the robustness approach.

5.3.2 A Scenario Planning Approach to Structuring Uncertainty

The key to structuring data uncertainty in Robust Optimisation is Scenario Planning. In most applications, scenarios represent several contrasting possible future states and which are generated by using the decision-maker's own model of the system and its realities. In 'pure' scenario development, and according to the robustness approach, no probabilities are attached to the various outcomes because to do so would mean attaching probabilities to an unknown. Also, assigning probabilities emphasizes high probability scenarios as opposed to low probability, yet potentially catastrophic, scenarios. Robust Optimisation prepares the decision-maker for unlikely, but still potentially realisable, outcomes and therefore enables them to handle such developments should they occur (Gregory et al., 2011).

The use of scenarios to structure the input data uncertainty allows the ability to describe the relationship between a few major uncertain factors in the decision environment and the large set of input parameters to the decision model, with many of these parameters being simultaneously affected by one or more of these factors (Kouvelis and Yu, 1997).

Robust Optimisation and scenario planning were developed as alternatives to traditional single point estimates or range forecasts since these have been proved to be generally inaccurate prone to provide suboptimal decisions (Greenberg and Morrison, 2008).

Compared with other classical decision-making approaches (such as deterministic or stochastic optimisation) that depends entirely on forecasted input data and which attempt to separate the decision-maker from framing the uncertainty of the decision; Robust Optimisation forces the decision-maker to participate in the generation and evaluation of all scenarios, thus placing more responsibility on the decision-maker (Ben-Tal et al., 2009).

5.4 Robust Optimisation Decisions

Two Robust Optimisation decision criteria will be utilised in the models developed in this study. These are the Absolute Robust decision and the Robust Deviation decision.

The general formulation of the Robust Optimisation approach follows Kouvelis and Yu (1997) and is as follows: Let *S* be the set of all potential input data scenarios over a certain planning horizon. Let *X* be the set of decision variables and *D* the set of input data. *D* represents the case of the input data that corresponds to scenario *s*. Whereas F_s indicates the set of all feasible decisions when scenario *s* is realised and the quality of the decision is appraised using the function $f(X, D_s)$ (Kouvelis and Yu, 1997). Consequently the optimal single scenario decision X_s^* for the input data instance D_s is the solution to a deterministic optimisation model and it satisfies the following:

$$z^s = f\left(X_s^*, D^s\right) = \min_{X \in F_s} f(X, D^s)$$

5.4.1 Constraint Robustness and Objective Robustness

Constraint Robustness refers to situations where the uncertainty is in the constraints and solutions are sought that remain feasible for all possible values of the input data set. This approach is often used with multi-stage problems where the uncertain outcomes of earlier stages impact upon the optimal decision of the later stage. With constraint robustness the decision variables must satisfy particular constraints, despite the outcome of the uncertain parameters of the problem. Therefore the solution must be constraint robust with respect to the uncertainties of the problem.

Objective Robustness refers to solutions that will remain close to optimal for all possible realisations of the uncertain problem parameters. As solutions for objective robustness problems can be difficult to achieve (this is especially the case where the uncertainty sets are large), another goal is to obtain solutions where the result is maximised in the worst case data input set. The result in the worst case data input set is the value of the objective function which leads to the worst result.

Both Constraint Robustness and Objective Robustness models have a worst case scenario orientation. That is, these attempt to optimise the behaviour of the solutions under the most adverse conditions. In accordance with Kouvelis and Yu (1997), solutions that optimise worst case behaviour under uncertainty are called Absolute Robust solutions. While such conservatism is necessary in some optimisation settings it may not be in others. Absolute robustness is not always consistent with a decision theoretic approach and with common utility functions. An alternative is to seek robustness in a relative sense to other possible scenario realisations which is Robust Deviation.

5.4.2 Choice of Robustness Criteria

Within the Robust Optimisation framework there are three different robustness criteria: Absolute Robustness, Robust Deviation and Relative Robustness. These criteria are appropriate for different circumstances. In a specific decision situation, some or all of the robustness criteria might be applied. The Absolute Robust criterion has a tendency to incline towards decisions that are very conservative in nature where the main aim is to attempt to hedge against the worst possible outcome (Kouvelis and Yu, 1997).

The Robust Deviation and Relative Robustness criteria are considered less conservative in their decision choice and more in tune with logic that endeavours to take advantage of opportunities for enhancement. In their construction Robust Deviation and Relative Robustness are predisposed towards regarding uncertainty as an opportunity compared to a risk that must be hedged against. Robust Deviation measures the deviation from optimality and therefore is regarded as a way of benchmarking in decision-making. The deviation from optimality is a pointer of how much the organisational performance could be improved if the uncertainty could be totally or partially resolved and can be regarded as a form of pricing future information (Rosenhead, 2001).

The Relative Robustness criterion is best applied in situations where either the results of the optimal single scenario decisions vary across a wide range of values or the outcome of a decision across scenarios is extremely variable. These robustness criteria are described in more detail below.

5.4.3 Absolute Robust Decision

As per Kouvelis and Yu (1997), the absolute robust decision X_A is considered to be the decision that minimises the maximum total cost (or maximises the minimum value) among all feasible decisions over all scenarios. Using the same notation as above:

$$z_A = \max_{s \in S} f\left(X_A, D^s\right) = \min_{X \in \cap_{s \in S} F_S} \max_{s \in S} f(X, D^s)$$

($X \in \cap_{s \in S} F$ that is, solutions that are feasible across every scenario that all solutions are feasible for)

Absolute Robust decisions are based on the anticipation that the worst case scenario may eventuate. One motivation of such a criterion is the need to take account of potentially catastrophic situations.

However, the focus on an absolute measure or worst case performance through the Absolute Robust decision is not consistent with the risk tolerances of many decision-makers. Instead it may be preferred to measure the worst case in a manner relative to the best possible solution under each scenario discussed below. This leads to the notion of Relative Robustness. However, relative robust formulations can also be significantly more difficult than the standard absolute robust formulations. Often the optimal value function and has an optimisation problem embedded within it, these can lead to three level optimisation problems as opposed to two level optimisation problems in absolute robust formulations. Hence, robust deviation will be utilised as this provides a percentage value which is more illustrative than the absolute values used in relative robustness.

5.4.4 Robust Deviation Decision

The Robust Deviation decision X_D is classified as the decision that produces the minimal deviation from optimality in the worst case scenario among all feasible decisions over all potential input data scenarios, that is:

$$z_D = \max_{s \in S}\left(f\left(X_D, D^s\right) - f\left(X_s^*, D^s\right)\right) = \min_{X \in \cap_{s \in S} F_S} \max_{s \in S}\left(f\left(X, D^s\right) - f\left(X_s^*, D^s\right)\right)$$

($X \in \cap_{s \in S} F$ i.e. solutions that are feasible across every scenario that all solutions are feasible for)

The performance of the decision in each scenario is evaluated against the best possible decision for that scenario, and the performance of all decisions in terms of deviation from the optimal performance in the scenario is documented for all scenarios. The decision which produces the smallest deviation from the optimal one is the solution, i.e. minimax regret.

5.5 Uncertainty Sets

In Robust Optimisation the description of the uncertainty of the parameters is formalised via uncertainty sets. Uncertainty sets may be formed by differences of opinion on future values of particular parameters, alternative estimates of parameters generated by statistical techniques from historical data and/or Bayesian techniques (Bertsimas et al., 2010).

Common types of uncertainty sets in Robust Optimisation models include the following:

- Uncertainty sets representing a finite number of scenarios generated for the possible values of the parameters:

  $\mathcal{U} = f$

- Uncertainty sets representing the convex hull of a finite number of scenarios generated for the possible values of the parameters (sometimes called polytopic uncertainty sets):

  $\mathcal{U} = \text{conv}(p_1, p_2, \ldots.., p_k)$

- Uncertainty sets representing an interval description for each uncertain parameter:

  $\mathcal{U} = (p_l \leq p \leq u)$

- Ellipsoidal uncertainty sets:

  $\mathcal{U} = (p: p = p_0 + M_u, |u| \leq 1)$

The shape and size of the uncertainty set can significantly affect the robust solutions generated. In this study the uncertainty set shall be represented by a finite number of scenarios and will be described in more detail in the following section.

5.5.1 Emissions Reduction Model Uncertainty Set Scenarios

The uncertainty set for the proposed models is a finite number of scenarios for the particular parameter variables. The scenarios developed for the models have three variables: emissions costs, discount rates and cash flows. The cash flow of an investment depends on which scenario is realised in the future, but the current investment needed and available budget are known and fixed.

Scenario Data Values

The choice of values for the variables is based upon various expert technical inputs. The emissions costs are based on the McLennan, Magasanik and Associates' *Report to Department of Climate Change: Benefits and Costs of Expanded Renewable Energy Target* (2009) which itself is based on modelling of emissions trading undertaken for the Federal Treasury. The report outlines a carbon price trajectory from \$20/tCO_2e in 2010 to \$34/tCO_2e in 2020, \$51/tCO_2e in 2030 to \$114/tCO_2e in 2050. For the proposed emissions reduction models with a price on emissions there are four values but only three scenarios are modelled in this study. The \$20/tCO_2e, \$51/tCO_2e and \$114/tCO_2e values will be used to provide a broad cross-section of potential scenarios. Given the model assesses potential long-lived projects, such a range of values is appropriate.

Another model based on emissions reductions, as opposed to a price on emissions, will also be constructed. The values of emissions reductions will be 10%, 50% and 90%. There is little agreement in the literature for the level of emissions reductions required to ensure a stable climate system. Some scholars argue for a 90% reduction by 2050 (Weaver et al., 2007), while others argue, due to the large costs of reducing emissions and uncertain benefits, minimal reductions should be implemented and uncertainties resolved before greater efforts are made. As a result the input set for uncertain emissions reductions will be 10%, 50% and 90%.

While the input values for the emissions costs have been considered acceptable for modelling purposes for the Australian Government, the choice of discount rate is more problematic. Quiggin (1997) discusses the issue in depth and drawing upon the Optimal Growth Theory of Ramsey (1928) suggests a possible range of discount rates from 0% to 10% with the most plausible values being in the range from 3% to 5%, whereas Schillizzi (2003) examined rates from 1.1% to 8%. This study will use the greater range, as suggested by Quiggin, from 0% to 10% with a middle scenario of 5%.

The projected cash flow for each project is assumed to be the medium scenario with figures both 25% below and 25% above representing the low and high scenarios for the cash flows. As Kaplan and Ruback (1994) and Berkman et al. (2000) show, cash flows are routinely inaccurate.

To summarise, the three variables: emissions cost, discount rate and cash flows, will each have a low, medium and high scenario as shown in Table 5.1 and for the emissions quantity model in Table 5.2.

Table 5.1 Variables and Scenario Input Data Values for Emissions Cost Models

Variable	Low scenario input data values	Medium scenario input data values	High scenario input data values
Emissions cost	$20/t$CO_2$e	$51/t$CO_2$e	$114/t$CO_2$e
Discount rate	0%	5%	10%
Cash flows	0.75 of projected	As projected	1.25 of projected

Table 5.2 Variables and Scenario Input Data Values for Emissions Quantity Models

Variable	Low scenario input data values	Medium scenario input data values	High scenario input data values
Emissions quantity	10% reduction	50% reduction	90% reduction
Discount rate	0%	5%	10%
Cash flows	0.75 of projected	As projected	1.25 of projected

Due to the use of three variables, when combined, this results in the creation of 27 specific scenarios and 11 potential projects as listed in Table 5.3.

Table 5.3 List of Specific Scenarios

Scenario	Emissions variable	Discount rate	Cash flow
1	L	L	L
2	L	L	M
3	L	L	H
4	L	M	L
5	L	M	M
6	L	M	H
7	L	H	L
8	L	H	M
9	L	H	H
10	M	L	L
11	M	L	M
12	M	L	H
13	M	M	L
14	M	M	M
15	M	M	H
16	M	H	L
17	M	H	M
18	M	H	H
19	H	L	L
20	H	L	M
21	H	L	H
22	H	M	L
23	H	M	M
24	H	M	H
25	H	H	L
26	H	H	M
27	H	H	H

The 27 scenarios will be used in the proposed emissions reduction models in this study order to identify the optimal solution given these scenarios and the potential projects. These will be described in the following section.

5.6 Model Formulation

Three models will be developed. The first model is the deterministic Conventional NPV Capital Rationing model with no reference to emissions. The other two models will be Robust Optimisation models; and Emissions Cost Model and an Emissions Quantity Model. The Emissions Cost Model will incorporate a price on emissions in the calculations and have 2 decision criteria; namely an Absolute Robust Decision Criterion and a Robust Deviation Decision Criterion. The Emissions Quantity Model will be based on physical emissions reductions and also have 2 decision criteria; also an Absolute Robust Decision Criterion and a Robust Deviation Decision Criterion.

The models will have two distinct components: the expected value of cash flows or NPV which are assumed to be uncertain and the cost of emissions, or emissions reductions, which are also assumed to be uncertain.

5.6.1 A Conventional Binary Internal Capital Rationing NPV Optimisation Model

The Conventional NPV model developed here assesses a range of projects and selects the optimal set of projects to maximise the total NPV when constrained by a finite budget. That is, Capital Rationing. Projects can either be accepted or rejected. If a project is selected it is assigned the number 1 and 0 if it is rejected. The structure of this model is similar to that developed by Weingartner (1963).

Assumptions

As described in the chapter 4, several assumptions are made with respect to the process of Capital Budgeting and the funding of prospective investments:

- It is assumed investors prefer more return to less, *ceteris paribus*;
- Cash received today is preferred to receiving the same amount in the future. This justifies the use of a discount rate to assess future cash flows; and
- The projects are indivisible, that is, they cannot be partially funded but rather fully funded or not at all.

Capital Rationing

Capital Rationing refers to the fact that prospective projects are limited by a finite budget. As described in chapter 4, Capital Rationing may occur due to internal or external factors. For the sake of this model in this study, the causes of capital rationing are not examined but rather a budget is set in place within the firm and must not be exceeded. Hence, it is an internal Capital Rationing model.

In a Capital Rationing problem a decision-maker is presented with several potential projects or investment alternatives and must determine which projects or investments to choose. The projects or investments typically require different amounts of various resources and generate different cash flows at different times for the company. Therefore the objective of maximising NPV subject to budgetary constraints forms the basis of the investment decision.

Integer (Binary) Linear Programming

It is assumed the projects in question are indivisible. This means that a given project must be either accepted or rejected. This imposes another constraint on the objective function; the decision variable must be an integer, more specifically the decision variable can only take the numbers 0 or 1, thus making the model a binary model.

Conventional NPV Model

$$\text{Maximise } Z = \sum x_i NPV_i$$

where:

$$NPV_i = \sum_{t=1}^{T} \frac{n_{it}}{(1+r)^t} - I_i$$

$x_i \in \{0,1\}$ i.e. select or not select project *i*

$i = 1, \ldots\ldots N$

$t = 1, \ldots\ldots T$

subject to:

$$\sum_{i=1}^{N} I_i x_i \leq b$$

where:

r is the discount rate

n_{it} are the cash inflows for project i in period t

I_i is the investment required for project i

b is the total availability of budget

t is the time period

This model will be solved to determine the optimal investment suite to maximise the sum of the NPVs, given the budgetary constraint. As this approach is the usual procedure for assessing potential projects, the results from this model will provide a 'business as usual' point of reference for the implications of the other proposed models.

5.7 Emissions Models

The Emissions Cost Model and Emissions Quantity models are discussed and the two Emissions Model Decision Criteria are developed in this section.

5.7.1 Emissions Cost Model

The Emissions Costs Models comprise an Emissions Cost Absolute Robust Decision Criterion and an Emissions Cost Model Robust Deviation Decision Criterion which are developed below. These two models assume a cost is imposed on greenhouse gas emissions which must be incorporated into the assessment of potential projects.

Emissions Cost Model Absolute Robust Decision Criterion

The maxi-min concept of the absolute robust decision is applied to hedge against the worst case scenario. There is considerable evidence in the literature that in cases where decisions must be made where there is significant uncertainty of the input data for the decision model, both deterministic optimisation and stochastic optimisation models do not adequately characterise the intentions of the decision-maker. In such cases a robustness approach that hedges against the worst case scenario appears to be most appropriate.

For the following models, S is the set of all potential scenarios over the particular planning period. X is the set of decision variables and D the set of input data. Therefore, D_s represents the data that corresponds to scenario *s*. F_s describes the set of all feasible decisions when scenario *s* is realised and the optimal decision is evaluated using the function *f(X, Ds)* (Kouvelis and Yu, 1997). Then the optimal single scenario decision X_s^* for the input data instance *Ds* is the solution to a deterministic optimisation problem and it satisfies:

$$z^s = f\left(X_s^*, D^s\right) = \max_{X \in F_s} f(X, D^s)$$

The absolute robust decision is given by:

$$z_A = \min_{s \in S} f\left(X_A, D^s\right) = \max_{X \in \cap_{s \in S} F_s} \min_{s \in S} f(X, D^s)$$

($X \in \cap_{s \in S} F$ i.e. solutions that are feasible across every scenario that all solutions are feasible for)

This is a conservative model and anticipates the worst will happen. The value (or return) of an investment depends on what scenario is realised in the future, but the current investment needed and available budget are known and fixed. The value of the investments depends directly upon which scenario is realised in the future. Therefore it is desirable to select a set of projects within a limited budget so that the lowest return over all possible future scenarios is a maximum (Yu, 1996).

The specific formulation is as follows.

Solve z_A such that:

$$z_A = \max_{X \in \cap_{s \in S} F_s} \min_{s \in S} \sum_{i=1}^{n} x_i \left(v_i^s - ec_i^s\right)$$

$$v_i^s = \sum_{t=1}^{T} \frac{n_{it}^s}{(1 + r^s)^t} - I_i$$

subject to:

$$\sum_{i=1}^{N} I_i x_i \leq b$$

$x_i \in \{0,1\}$ that is, select or not select project *i*

$s \in S$

$i = 1, \ldots\ldots N$

$t = 1, \ldots\ldots T$

where:

v_i^s is the NPV of project *i* under scenario $s \in S$

s is the specific scenario instance

S is the total set of scenarios

N is the total set of projects to select from

r^s is the discount rate in scenario *s*

n_{it}^s are the cash inflows for project *i* in period *t* for scenario *s*

ec_i^s are the emissions costs for project *i* for scenario *s*

I_i is the investment required for project *i*

b is the total availability of budget

t is the time period

Emissions Cost Model Robust Deviation Decision Criterion

As explained previously, the Robust Deviation Decision (X_D) is defined as the one that produces the minimal worst case deviation from the optimal decision among all feasible decisions over all realisable input data scenarios.

The Robust Deviation Decision Criterion compares the performance of the decision in each scenario against the optimal decision for that particular scenario. The deviation of the performance of the decision in that scenario from the optimal decision is recorded for all scenarios. Then the robust deviation decision is the one which minimises the maximum deviation from the optimal solution for all scenarios. This is a form of minimising the maximum regret. This is useful for the comparison of the decision as firms whose performance is judged relative to their competitors will want to make decisions that avoid falling behind their competitors under all scenarios rather than protecting themselves against the worst case scenario. In such cases robust deviation is useful. The general formula for robust deviation is given below.

$$z_D = \max_{X \in \cap_{s \in S} F_s} \min_{s \in S} \left(f\left(X, D^s\right) - f\left(X_s^*, D^s\right) \right)$$

The specific formulation for the proposed model in this study is:

$$z_D = \max_{X \in \cap_{s\in S} F_s} \min_{s\in S} \left(\left(\sum_{i=1}^{n} \left(v_i^s - ec_i^s \right) x_i \right) - \left(\max_{x \in F_s} \sum_{i=1}^{n} \left(v_i^s - ec_i^s \right) x_i \right) \right)$$

$$v_i^s = \sum_{t=1}^{T} \frac{n_{it}^s}{(1+r^s)^t} - I_i$$

subject to:

$$\sum_{i=1}^{N} I_i x_i \le b$$

$x_i \in \{0,1\}$ i.e. select or not select project *i*

$s \in S$

$i = 1, \ldots\ldots N$

$t = 1, \ldots\ldots T$

where:

v_i^s is the NPV of project *i* under scenario $s \in S$

s is the specific scenario instance

S is the total set of scenarios

N is the total set of projects to select from

r^s is the discount rate in scenario *s*

n_{it}^s are the cash inflows for project *i* in period t for scenario *s*

eq_i^s is the emissions quantity for project *i* in scenario *s*

I_i is the investment required for project *i*

b is the total availability of budget

t is the time period

5.7.2 Eco-efficiency Adjustment

The reputation and shareholder implications of the different decision criteria are considered through the adjustment of the NPV result based on the research findings of Guenster, Bauer et al. (2010) linking eco-efficiency and Tobin's *Q*. Guenster, Bauer et al. refer to this as an eco-efficiency dividend.

In order to calculate the potential benefits of investments with increased eco-efficiency several assumptions are necessary in order to make the calculations. The market valuation of the most eco-efficient firms relative to the least eco-efficient firms is estimated to be up to 7% higher ceteris paribus. In order to incorporate this conclusion into the model, it is assumed the projects selected represent all a firm's projects and using Rappaport's valuation model where a firm's valuation is equal to the NPV of all future cash flows, the total NPV of the selected projects is readjusted with an increase of 7%.

$$ShareholderValue = \sum_{i=1}^{n} \frac{FCF_n}{(1+i)^n} - InitialCost$$

5.7.3 Emissions Quantity Model

The emissions quantity model is a pure regulation model, in which quantity reductions are imposed on existing firms by government edict without any reference to market effects. Such a potential scheme is a form of cap system without the trade aspect as is being suggested in the United States through the Environmental Protection Agency and Clean Air Act (Burtraw et al., 2011). Whilst such a scheme is not favoured in the literature as it is deemed less efficient a pure regulatory model is possible where all firms must reduce emissions by a certain percentage per year and has the potential to be effective if less efficient in theory.

The emissions variable is incorporated into the model in the form of the physical quantity of emissions. As the units are incompatible between NPV and emissions, i.e. dollars and tonnes of CO_2e, a multiple objective model will therefore be utilised within the Robust Optimisation framework. The Emissions Quantity Based Model comprises an Emissions Quantity Model Absolute Robust Decision Criterion and an Emissions Quantity Model Robust Deviation Decision Criterion.

As with the Emissions Cost Model, the Emissions Quantity Model has three parameters each with three input values which in turns leads to 27 scenarios, as shown in Table 5.3. The specific input data values for the Emissions Quantity models are shown in Table 5.2.

The Emissions Quantity Model also has 2 decision criteria: the Absolute Robust Decision Criterion and the Robust Deviation Decision Criterion. However, unlike the Emissions Cost Model, the physical quantity of emissions are used in the model construction and as this requires physical units, that is, tonnes of CO_2e, a Multiple Objective Linear Programming (MOLP) model and the Robust Optimisation methodology are used to take into account the uncertainty of the input data and determine both the Absolute Robust and Robust Deviation decisions.

The Emissions Quantity Model must be formulated in a different way to the Emissions Cost Model due to the different units of the objectives. This model includes the 2 competing goals of maximisation of NPV and the minimisation of physical emissions as opposed to maximising NPV after the incorporation of emissions costs. Due to the multiple objectives with incompatible units, such a model requires the utilisation of MOLP. MOLP models are special types of GP models in which target values must be set for each objective. Consequently there are two objectives:

maximise NPV:

$$\sum_{i=1}^{n} x_i v_i^s$$

where:

$$v_i^s = \sum_{t=1}^{T} \frac{n_{it}^s}{(1+r^s)^t} - I_i$$

and minimise emissions:

$$\sum_{i=1}^{n} x_i eq_i^s$$

where:

$x_i \in \{0,1\}$ that is, select or not select project *i*

v_i^s is the NPV of project *i* under scenario $s \in S$

s is the specific scenario instance

S is the total set of scenarios

N is the total set of projects to select from

r^s is the discount rate in scenario

n_{it}^s are the cash inflows for project *i* in period t for scenario *s*

eq_i^s is the emissions quantity for project *i* in scenario *s*

I_i is the investment required for project *i*

b is the total availability of budget

t is the time period

However, as the objectives are in conflict with one another, it is not possible to optimise both at the same time and some slack in the constraints will occur in order to reach a solution that takes into consideration both objectives. Consequently, if each objective had a target then it is possible to consider them as follows:

Goal 1: the NPV should be g_1

Goal 2: the emissions quantity should be g_2

Consequently this Robust Optimisation model has three steps in its solution. First, the target values must be generated. In order to ascertain the goal values, g_1 and g_2, the two linear programming problems will be solved independently optimising each objective.

While solving for the maximisation of NPV to obtain a target value is straightforward, this is not the case for emissions. Minimising emissions will always generate a solution where no projects are selected and the emissions are equal to zero. Consequently, the conventional NPV model solution will be used to generate an emissions quantity based on ABS emissions intensities as they relate to revenue. From these figures three emissions scenario targets will be generated as 0.1, 0.5 and 0.9 of the conventional NPV Model's emissions quantity.

Subsequently it is possible to minimise the sum of the percentage deviations from the respective targets, that is:

minimise:

$$\min : w_1\left(\frac{g_1-\left(\sum_{i=1}^{n} x_i v_i^s\right)}{g_1}\right)+w_2\left(\frac{\left(\sum_{i=1}^{n} x_i eq_i^s\right)-g_2}{g_2}\right)$$

However, it can be shown that this is a linear combination of the decision variables and the solutions will be restricted to the corner points of the feasible region (no matter what weights are used), while non-corner point solutions, which provide a greater range of possible solutions, are excluded. Therefore the introduction of a mini-max variable objective function, *Q*, is required to provide this flexibility (Ragsdale, 2007). Consequently the second stage is to solve for *Q* subject to additional constraints as described below:

MIN: Q

subject to:

$$w_1\left(\frac{g_1-\left(\sum_{i=1}^{n} x_i v_i^s\right)}{g_1}\right)\leq Q$$

$$w_2\left(\frac{\left(\sum_{i=1}^{n} x_i eq_i^s\right)-g_2}{g_2}\right)\leq Q$$

This objective allows the exploration of non-corner point solutions of the feasible region with the two objectives having equal weights and is Pareto optimal, that is, given any solution generated there are no other feasible solution allows an increase in any objective without decreasing the other objective (Ragsdale, 2007).

The third stage of the model differs between the Absolute Robust Decision Criterion and the Robust Deviation Decision Criterion.

Emissions Quantity Absolute Robust Model

The third stage of the model for the Absolute Robust Decision Criterion is the utilization of the minimization of *Q* and its corresponding total NPV from the selected projects for each scenario to calculate the Absolute Robust (maxi-min) solution.

As per the previous models, *S* is the set of all potentially realisable scenarios over the specified planning period. *X* is the set of decision variables and *D* the set of input data. Consequently, D_s represents the data that corresponds to scenario *s*. F_s is the set of all feasible decisions when scenario *s* occurs and the optimal decision is evaluated using the function $f(X, D_s)$ (Kouvelis and Yu, 1997). Then the optimal single scenario decision X_s^* for the input data instance *Ds* is the solution to a deterministic optimisation problem and it satisfies:

$$z^s = f\left(X_s^*, D^s\right) = \max_{X \in F_s} f(X, D^s)$$

The absolute robust decision is given by:

$$z_A = \min_{s \in S} f\left(X_A, D^s\right) = \max_{X \in \cap_{s \in S} F_S} \min_{s \in S} f(X, D^s)$$

($X \in \cap_{s \in S} F$ i.e. solutions that are feasible across every scenario that all solutions are feasible for)

In this study the solution for each of the individual twenty-seven scenarios is tested in the other twenty-six scenarios in order to obtain the solution which has the maximum minimum for all twenty-seven scenarios, that is:

solve z_A such that:

$$z_A = \max_{X \in \cap_{s \in S} F_S} \min_{s \in S} \sum_{i=1}^{n} x_i v_i^s$$

MIN: Q

subject to:

$$\left(\frac{g_1^s - \left(\sum_{i=1}^{n} x_i v_i^s\right)}{g_1^s} \right) \leq Q$$

$$\left(\frac{\left(\sum_{i=1}^{n} x_i e q_i^s\right) - g_2^s}{g_2^s} \right) \leq Q$$

$$v_i^s = \sum_{t=1}^{T} \frac{n_{it}^s}{(1 + r^s)^t} - I_i$$

$$\sum_{i=1}^{N} I_i x_i \leq b$$

$x_i \in \{0,1\}$ that is, select or not select project *i*

$s \in S$

$i = 1,......N$

$t = 1,......T$

where:

v_i^s is the NPV of project *i* under scenario $s \in S$

s is the specific scenario instance

S is the total set of Scenarios

N is the total set of projects to select from

r^s is the discount rate in scenario *s*

n_{it}^s are the cash inflows for project *i* in period *t* for scenario *s*

eq_i^s is the emissions quantity for project *i* in scenario *s*

I_i is the investment required for project *i*

b is the total availability of budget

t is the time period

g_1^s is the NPV goal for scenario *s*

g_2^s is the emissions quantity goal for scenario *s*

Emissions Reduction Model Robust Deviation Decision Criterion

As explained previously, the Robust Deviation decision (X_D) is defined as the one that produces the minimal worst case deviation from the optimal decision among all feasible decisions over all realisable input data scenarios.

The Robust Deviation model compares the performance of the decision in each scenario against the best decision for that scenario and the deviation from the optimal decision for each scenario for the decision is the solution of the model. This is a form of minimising the maximum regret.

$$z_D = \max_{X \in \cap_{s \in S} F_S} \min_{s \in S} \left(f\left(X, D^s\right) - f\left(X_s^*, D^s\right) \right)$$

However, as described above for the Emissions Quantity Model Absolute Robust Decision Criterion, the incompatible units and goals for NPV and emissions require the formulation of a multiple objective linear programming model. The same formulation is used as for the Emissions Quantity Absolute Robust Model with the introduction of a mini-max variable objective function *Q* in order to generate non corner point solutions.

The specific formulation for the proposed model is:

$$z_D = \max_{X \in \cap_{s \in S} F_s} \min_{s \in S} \left(\left(\sum_{i=1}^{n} x_i v_i^s \right) - \left(\max_{x \in F_s} \sum_{i=1}^{n} x_i v_i^s \right) \right)$$

given

MIN: Q

subject to:

$$\left(\frac{g_1^s - \left(\sum_{i=1}^{n} x_i v_i^s \right)}{g_1^s} \right) \leq Q$$

$$\left(\frac{\left(\sum_{i=1}^{n} x_i eq_i^s \right) - g_2^s}{g_2^s} \right) \leq Q$$

$$v_i^s = \sum_{t=1}^{T} \frac{n_{it}^s}{(1 + r^s)^t} - I_i$$

$$\sum_{i=1}^{N} I_i x_i \leq b$$

$x_i \in \{0,1\}$ i.e. select or not select project i

$s \in S$

$i = 1, \ldots\ldots N$

$t = 1, \ldots\ldots T$

where:

v_i^s is the NPV of project *i* under scenario $s \in S$

s is the specific scenario instance

S is the total set of scenarios

N is the total set of projects to select from

r^s is the discount rate in scenario *s*

n_{it}^s are the cash inflows for project *i* in period *t* for scenario *s*

eq_i^s is the emissions quantity for project *i* in scenario *s*

I_i is the investment required for project *i*

b is the total availability of budget

t is the time period

g_1^s is the NPV goal for scenario *s*

g_2^s is the emissions quantity goal for scenario *s*

5.7.4 Eco-efficiency Adjustment

As with the Emissions Costs Model, the NPV results from the Emissions Quantity model will be adjusted to take into consideration the reputation and shareholder implications of the different decision criteria. This adjustment will be based on the research findings of Guenster, Bauer et al. (2010) linking eco-efficiency and Tobin's *Q*. Guenster, Bauer et al. refer to this as an eco-efficiency dividend.

In order to calculate the potential benefits of investments with increased eco-efficiency several assumptions are necessary in order to make the calculations. The market valuation of the most eco-efficient firms relative to the least eco-efficient firms is 7% higher ceteris paribus. In order to incorporate this conclusion into the model, it is assumed the projects selected represent all a firm's projects and using Rappaport's valuation model where a firm's valuation is equal to the NPV of all future cash flows, the total NPV of the selected projects is readjusted with an increase of 7%.

$$ShareholderValue = \sum_{i=1}^{n} \frac{FCF_n}{(1+i)^n} - InitialCost$$

5.8 Conclusion

This chapter has described the method and techniques for developing the Conventional NPV model as well as two Robust Optimisation models: an Emissions Cost Model and an Emissions Quantity model each with two decision criteria. The Emissions Cost and Emissions Quantity models incorporate emissions factors into their formulation and scenarios to account for the uncertainty in the input data. The decision criteria include an Absolute Robust Decision Criterion and a Robust Deviation Decision Criterion which provide different emphases so as to provide the decision-maker with different possible solutions when examining potential decisions.

Chapter 6 Results

6.1 Introduction

This chapter describes the results of the three models described in the previous chapter. These models include the conventional NPV model and two Robust Optimisation models, each with two decision criteria: the Emissions Cost Model with Absolute Robust Deviation Decision and Robust Deviation Decision criteria and the Emissions Quantity Model with Absolute Robust Decision and Robust Deviation Decision criteria.

6.2 Potential Investments

The potential suite of investments in this study consisted of eleven projects in varying size and industry sector. The potential investments and their characteristics are listed in Table 6.1. The data for these potential projects was obtained from an investment firm under the proviso the information remained unidentified, hence the projects have been assigned a number and an industry sector only. The capital expenditure figure is the initial capital expenditure, the cash flow figure is the undiscounted projected cash flow over the life of the project (can we say something further about the life or term of the project) and emissions intensity is expressed as tonnes of CO_2e emissions per $million of revenue. The total capital expenditure required to fund all the projects is just under $15 billion.

Table 6.1 Key Characteristics of Potential Projects

Project	Industry sector	ABS industry code	Capital expenditure ($mil)	Undiscounted cash inflow projections ($mil)	Emissions intensity (t CO_2e/$mil revenue) #
1	Soap	2,505	1952.8	15034.7	279
2	Ceramics	2,602	66.8	3188.5	1675
3	Iron & steel	2,701	74.3	6120.4	1568
4	Basic chemicals	2,502	42.6	1523.0	1288
5	Alumina	2,702	275.7	1920.2	1649
6	Other food	2,108	2281.5	14004.3	284
7	Pulp & paper	2,303	4042.0	68587.6	1133
8	Grains	102	323.4	2568.1	523
9	Cotton	0107*	4866.0	27869.1	494
10	Saw mill products	2,301	555.7	7705.2	254
11	Sugar cane	0107*	452.5	10360.7	1054

* Industry data has been disaggregated.

Source: (Department of Climate Change, 2008).

6.2.1 Assumptions

Various assumptions are made in the calculations of the results. First, it is assumed that all the capital expenditure is undertaken in the first period and that once a project begins it is not possible to scale it back or alter it. That is, the project is either fully accepted or rejected in the first period. It is also assumed that the energy source mix for electricity generation remains constant for the duration of the project. This assumption is likely to be incorrect but the model is still instructive as the energy mix will apply equally to all sectors though the levels of Scope 1 (direct) emissions and Scope 2 (indirect, that is, emissions from electricity use) vary between sectors. The analysis of potential changes in the mix of electricity production is beyond the scope of this study. Some projects may be able to alter the energy mix, to reduce emissions, and others may not. This aspect is not considered, however, this does not invalidate the study's findings. The budget is assumed to be $9 billion.

6.2.2 Sectoral Representation, Scale and Emissions Intensities

The projects included in this study vary in capital expenditure from $42.6 million to $4,866.0 million or a factor of over 100 and the undiscounted cash flow projections vary from $1,523.0 million to $68,587.6 million which represents a factor of over 45. In addition, the emissions intensity varies between 279 tonnes CO_2e/$million revenue to 1,649 tonnes CO_2e/$million revenue or a factor of over 6. Consequently a wide range of sectors, scale of projects and emissions intensities are represented in the data.

6.2.3 Creation of the Uncertainty Range in the Data Set

The uncertainty range in the data set for the model is determined by three parameters: the emissions cost or emissions quantity depending on the model, the discount rate and the level of cash flow related to the base case projection. The three opening values for emissions cost shown are each indexed at 5% per annum. As described in the previous chapter, each variable had 3 levels: high, medium and low. These variables are listed in tables 6.2 and 6.3.

Three values for 3 variables lead to 27 potential scenarios. For the robust optimisation approach all 27 scenarios must be solved individually to produce an optimal solution for that particular scenario. In addition, the conventional NPV model, which assumed medium cash flows and medium discount rate with no consideration of emissions costs or emissions reductions, was solved and provided the reference ‘business as usual’ figure for the emissions models. Therefore 28 separate scenarios were solved, and these are summarised in Table 6.4.

The basic input for the analysis of the economic cost model is the calculation, for each project and for each scenario, of the level of emissions cost and the NPV of the net cash flows for that project/scenario pair. Thus, for each such pair, Table 6.5 shows the total emissions cost, at the relevant emissions cost rate, and the net cash flow NPV, for those emissions costs and the relevant discount rate. These estimates are the building blocks of the subsequent analysis.

Table 6.2 Emissions Cost Model Variables and Scenario Input Data Values

Variable	Low scenario input data values	Medium scenario input data values	High scenario input data values
Emissions Cost	\$20/tCO_2e	\$51/tCO_2e	\$114/tCO_2e
Discount rate	0%	5%	10%
Cash Flows	0.75 of projected	As projected	1.25 of projected

Table 6.3 Emissions Quantity Model Variables and Scenario Input Data Values

Variable	Low scenario input data values	Medium scenario input data values	High scenario input data values
Emissions Quantity Reduction	10% of Business As Usual (BAU)	50% of BAU	90% of BAU
Discount rate	0%	5%	10%
Cash Flows	0.75 of projected	As projected	1.25 of projected

Table 6.4 List of Specific Scenarios

Scenario	Emissions factor	Discount rate	Cash flow
1	L	L	L
2	L	L	M
3	L	L	H
4	L	M	L
5	L	M	M
6	L	M	H
7	L	H	L
8	L	H	M
9	L	H	H
10	M	L	L
11	M	L	M
12	M	L	H
13	M	M	L
14	M	M	M
15	M	M	H
16	M	H	L
17	M	H	M
18	M	H	H
19	H	L	L
20	H	L	M
21	H	L	H
22	H	M	L
23	H	M	M
24	H	M	H
25	H	H	L
26	H	H	M
27	H	H	H
NPV	N/A	M	M

Table 6.5 Emissions Cost Model Input Data for all Projects: Emissions Cost and NPV of Net Cash Flow

Scenario	Variables			Input Data Project 1		Input Data Project 2		Input Data Project 3		Input Data Project 4		Input Data Project 5	
	Emissions cost ($/t)	Disc rate	Cash flow	Emissions cost ($m)	NPV ($m)	Emissions cost ($m)	NPV ($m)	Emissions cost ($m)	NPV ($m)	Emissions cost ($m)	NPV ($m)	Emissions cost ($m)	NPV ($m)
1	$20	0%	0.75	$935	$9,323	$801	$2,325	$1,436	$4,516	$480	$1,164	$480	$1,164
2	$20	0%	1	$1,246	$13,082	$1,068	$3,122	$1,914	$6,046	$640	$1,644	$640	$1,644
3	$20	0%	1.25	$1,558	$16,841	$1,335	$3,919	$2,393	$7,576	$801	$2,124	$801	$2,124
4	$20	5%	0.75	$240	$2,492	$305	$1,008	$548	$1,944	$181	$480	$181	$480
5	$20	5%	1	$320	$3,655	$407	$1,356	$731	$2,603	$241	$686	$241	$686
6	$20	5%	1.25	$399	$4,818	$509	$1,704	$914	$3,263	$302	$891	$302	$891
7	$20	10%	0.75	$78	$746	$138	$526	$245	$990	$80	$235	$80	$235
8	$20	10%	1	$104	$1,221	$184	$709	$327	$1,327	$107	$340	$107	$340
9	$20	10%	1.25	$130	$1,695	$230	$892	$408	$1,663	$134	$445	$134	$445
10	$51	0%	0.75	$2,384	$9,323	$2,042	$2,325	$3,661	$4,516	$1,225	$1,164	$1,225	$1,164
11	$51	0%	1	$3,178	$13,082	$2,723	$3,122	$4,881	$6,046	$1,633	$1,644	$1,633	$1,644
12	$51	0%	1.25	$3,973	$16,841	$3,404	$3,919	$6,102	$7,576	$2,042	$2,124	$2,042	$2,124
13	$51	5%	0.75	$611	$2,492	$778	$1,008	$1,398	$1,944	$461	$480	$461	$480
14	$51	5%	1	$815	$3,655	$1,038	$1,356	$1,865	$2,603	$615	$686	$615	$686
15	$51	5%	1.25	$1,019	$4,818	$1,297	$1,704	$2,331	$3,263	$769	$891	$769	$891
16	$51	10%	0.75	$199	$746	$352	$526	$625	$990	$205	$235	$205	$235
17	$51	10%	1	$265	$1,221	$469	$709	$833	$1,327	$273	$340	$273	$340
18	$51	10%	1.25	$331	$1,695	$586	$892	$1,041	$1,663	$341	$445	$341	$445
19	$114	0%	0.75	$5,328	$9,323	$4,565	$2,325	$8,183	$4,516	$2,738	$1,164	$2,738	$1,164
20	$114	0%	1	$7,105	$13,082	$6,086	$3,122	$10,911	$6,046	$3,651	$1,644	$3,651	$1,644
21	$114	0%	1.25	$8,881	$16,841	$7,608	$3,919	$13,639	$7,576	$4,563	$2,124	$4,563	$2,124
22	$114	5%	0.75	$1,366	$2,492	$1,740	$1,008	$3,126	$1,944	$1,031	$480	$1,031	$480
23	$114	5%	1	$1,822	$3,655	$2,319	$1,356	$4,168	$2,603	$1,375	$686	$1,375	$686
24	$114	5%	1.25	$2,277	$4,818	$2,899	$1,704	$5,210	$3,263	$1,719	$891	$1,719	$891
25	$114	10%	0.75	$444	$746	$786	$526	$1,397	$990	$458	$235	$458	$235
26	$114	10%	1	$592	$1,221	$1,048	$709	$1,862	$1,327	$610	$340	$610	$340
27	$114	10%	1.25	$740	$1,695	$1,310	$892	$2,328	$1,663	$763	$445	$763	$445

Input Data Project 6		Input Data Project 7		Input Data Project 8		Input Data Project 9		Input Data Project 10		Input Data Project 11	
Emissions cost ($m)	**NPV ($m)**	**Emissions cost ($m)**	**NPV ($m)**	**Emissions cost ($m)**	**NPV ($m)**	**Emissions cost ($m)**	**NPV ($m)**	**Emissions cost ($m)**	**NPV ($m)**	**Emissions cost ($m)**	**NPV ($m)**
$1,657	$8,222	$27,418	$47,399	$628	$1,603	$1,678	$16,036	$564	$5,223	$2,197	$7,318
$2,209	$11,723	$36,557	$64,546	$837	$2,245	$2,238	$23,003	$752	$7,150	$2,929	$9,908
$2,762	$15,224	$45,696	$81,692	$1,047	$2,887	$2,797	$29,970	$940	$9,076	$3,662	$12,498
$227	$539	$4,441	$10,312	$77	$25	$787	$7,873	$112	$1,453	$624	$2,398
$303	$1,130	$5,921	$14,263	$102	$89	$1,049	$11,495	$149	$2,013	$832	$3,258
$379	$1,721	$7,401	$18,214	$128	$153	$1,311	$15,117	$186	$2,573	$1,040	$4,118
$41	-$563	$1,086	$3,467	$9	-$99	$421	$4,392	$34	$615	$217	$978
$55	-$436	$1,447	$4,896	$11	-$94	$561	$6,543	$45	$867	$290	$1,334
$69	-$308	$1,809	$6,324	$14	-$89	$701	$8,695	$57	$1,119	$362	$1,690
$4,225	$8,222	$69,915	$47,399	$1,602	$1,603	$4,279	$16,036	$1,439	$5,223	$5,602	$7,318
$5,634	$11,723	$93,220	$64,546	$2,136	$2,245	$5,706	$23,003	$1,918	$7,150	$7,470	$9,908
$7,042	$15,224	$116,524	$81,692	$2,670	$2,887	$7,132	$29,970	$2,398	$9,076	$9,337	$12,498
$580	$539	$11,323	$10,312	$196	$25	$2,006	$7,873	$285	$1,453	$1,591	$2,398
$773	$1,130	$15,098	$14,263	$261	$89	$2,675	$11,495	$380	$2,013	$2,122	$3,258
$966	$1,721	$18,872	$18,214	$326	$153	$3,343	$15,117	$475	$2,573	$2,652	$4,118
$106	-$563	$2,768	$3,467	$22	-$99	$1,073	$4,392	$87	$615	$554	$978
$141	-$436	$3,691	$4,896	$29	-$94	$1,430	$6,543	$116	$867	$738	$1,334
$176	-$308	$4,614	$6,324	$37	-$89	$1,788	$8,695	$145	$1,119	$923	$1,690
$9,445	$8,222	$156,280	$47,399	$3,580	$1,603	$9,566	$16,036	$3,216	$5,223	$12,523	$7,318
$12,593	$11,723	$208,373	$64,546	$4,774	$2,245	$12,755	$23,003	$4,288	$7,150	$16,698	$9,908
$15,741	$15,224	$3,580	$81,692	$5,967	$2,887	$15,943	$29,970	$5,360	$9,076	$20,872	$12,498
$1,295	$539	$25,311	$10,312	$437	$25	$4,484	$7,873	$637	$1,453	$3,557	$2,398
$1,727	$1,130	$33,748	$14,263	$583	$89	$5,979	$11,495	$850	$2,013	$4,742	$3,258
$2,159	$1,721	$42,185	$18,214	$729	$153	$7,474	$15,117	$1,062	$2,573	$5,928	$4,118
$236	-$563	$6,188	$3,467	$49	-$99	$2,397	$4,392	$194	$615	$1,238	$978
$315	-$436	$8,250	$4,896	$65	-$94	$3,197	$6,543	$259	$867	$1,651	$1,334
$394	-$308	$10,313	$6,324	$82	-$89	$3,996	$8,695	$324	$1,119	$2,063	$1,690

6.3 Conventional NPV Model

The Conventional NPV model decision did not take into consideration emissions costs or emissions reductions and assumed a medium discount rate and medium cash flow. The results of the Conventional NPV model are shown in Table 6.6. Table 6.6 shows the construction of linear programming model with the NPV and Capex listed for each project 1 to 11. The 1 or 0 below the NPV value represents the selection or non-selection of each project in the optimal solution, with the objective is to maximise total NPV within the budgetary constraint. The set of projects identified as optimal by this decision criterion are shown in Table 6.6, and consist of a group that will subsequently be referred to as optimal investment Suite 1.

Table 6.6 Conventional NPV Optimal Solution

		Medium cash flow		**5% discount rate**		**No emissions cost**						
	Projects											
	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
NPV ($m)	3655	1356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258	total
Select?	1	1	1	1	1	0	1	1	0	1	1	
Total ($m)	$3,655	$1,356	$2,603	$1,007	$686	$0	$14,263	$89	$0	$2,013	$3,258	$28,929
Capex ($m)	-$1,953	-$67	-$74	-$43	-$276	-$2,281	-$4,042	-$323	-$4,866	-$556	-$452	
	-$1,953	-$67	-$74	-$43	-$276	$0	-$4,042	-$323	$0	-$556	-$452	-$7,786
Budget	-9000											
	Max											
Obj Fn	x1+x2+x3+x4+x5+x6+x7+x8+x9+x10+x11											
s.t.	xi must be binary											
	∑xi less than budget											

6.4 Emissions Cost Model

The Emissions Cost Model incorporates a price on carbon emissions for the proposed projects. The emissions are based on the emissions intensity data from the Department of Climate Change (Department of Climate Change, 2008)as described above. The Emissions Cost Model, developed as described in Chapter 5, is based on Robust Optimisation techniques and consists of an Absolute Robust Model and a Robust Deviation Model.

6.4.1 Emissions Cost Model Project Values

The NPV values used for the calculation of the optimal solution for each scenario are those specified in Table 6.6 and the Project Values and Scenario Matrix for the Emissions Quantity Model is shown in Table 6.7. This table shows how each project performs in each scenario. These values for each project in each scenario are used to determine the optimal solution for each scenario.

6.4.2 Emissions Cost Model Optimal Solutions

The 27 different scenarios for the Emissions Cost Model were solved individually to obtain the optimal solution for each particular scenario. For each scenario, with the specific values of the emission price, the discount rate and the cash flow variable appropriate for that scenario, the solution consists of the set of projects which provides the maximum NPV. These solutions are shown in Appendix A (p256) and the optimal investments decisions for the 27 scenarios are summarised in Table 6.8. As can be seen in Table 6.8, **Error! Reference source not found.**there are six different optimal solutions across the 27 separate scenarios – these are referred to as investment suites 1-6. Suites 1 and 3 contain 9 of the eleven projects and suites 2 and 4 contain 8 projects, while suites 5 and 6 consist of only 4 of the eleven projects.

Table 6.7 Project Value and Scenario Matrix

	Projects and value ($million)										
Scenarios	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	$8,388	$1,524	$3,080	$929	$684	$6,565	$19,981	$975	$14,358	$4,659	$5,121
2	$11,835	$2,054	$4,132	$1,252	$1,004	$9,513	$27,989	$1,407	$20,765	$6,397	$6,979
3	$15,283	$2,584	$5,183	$1,576	$1,324	$12,462	$35,997	$1,840	$27,173	$8,136	$8,837
4	$2,252	$703	$1,396	$635	$299	$312	$5,872	-$52	$7,086	$1,341	$1,774
5	$3,335	$949	$1,872	$857	$445	$827	$8,343	-$13	$10,446	$1,864	$2,426
6	$4,418	$1,195	$2,349	$1,079	$590	$1,342	$10,813	$25	$13,806	$2,387	$3,078
7	$668	$388	$745	$459	$155	-$605	$2,382	-$107	$3,971	$581	$761
8	$1,117	$525	$1,000	$619	$233	-$491	$3,448	-$105	$5,982	$822	$1,044
9	$1,565	$662	$1,255	$779	$311	-$377	$4,515	-$104	$7,994	$1,062	$1,328
10	$6,939	$282	$855	$663	-$61	$3,996	-$22,516	$1	$11,756	$3,785	$1,716
11	$9,904	$399	$1,165	$899	$11	$6,089	-$28,674	$109	$17,297	$5,231	$2,438
12	$12,868	$515	$1,475	$1,134	$83	$8,182	-$34,832	$217	$22,838	$6,678	$3,161
13	$1,880	$230	$546	$462	$19	-$40	-$1,011	-$171	$5,867	$1,168	$807
14	$2,840	$318	$739	$625	$71	$357	-$835	-$172	$8,820	$1,633	$1,137
15	$3,799	$407	$932	$789	$122	$755	-$658	-$173	$11,774	$2,098	$1,466
16	$547	$175	$366	$338	$31	-$669	$699	-$121	$3,319	$528	$425
17	$956	$240	$494	$458	$67	-$577	$1,205	-$123	$5,113	$751	$596
18	$1,364	$306	$622	$578	$104	-$485	$1,710	-$126	$6,907	$974	$766
19	$3,995	-$2,240	-$3,667	$124	-$1,574	-$1,223	-$108,881	-$1,978	$6,470	$2,008	-$5,205
20	$5,977	-$2,965	-$4,865	$180	-$2,006	-$870	-$143,828	-$2,529	$10,249	$2,862	-$6,789
21	$7,960	-$3,689	-$6,063	$236	-$2,439	-$518	$78,112	-$3,080	$14,027	$3,716	-$8,373
22	$1,125	-$732	-$1,182	$109	-$551	-$756	-$14,999	-$413	$3,389	$815	-$1,158
23	$1,833	-$964	-$1,564	$155	-$689	-$597	-$19,485	-$494	$5,516	$1,163	-$1,484
24	$2,541	-$1,196	-$1,947	$201	-$828	-$438	-$23,971	-$576	$7,643	$1,510	-$1,810
25	$302	-$260	-$406	$94	-$222	-$800	-$2,721	-$148	$1,995	$421	-$260
26	$628	-$339	-$535	$133	-$270	-$751	-$3,355	-$159	$3,347	$608	-$317
27	$955	-$419	-$665	$171	-$318	-$702	-$3,989	-$171	$4,699	$795	-$374
NPV	$8,388	$1,524	$3,080	$929	$684	$6,565	$19,981	$975	$14,358	$4,659	$5,121

Table 6.8 Optimal Solutions Project Selection Summary for 27 Scenarios (for details see Appendix A)

	Projects select? 1/0											Optimal investment suite
Scenario	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
1	1	1	1	1	1	0	1	1	0	1	1	Suite 1
2	1	1	1	1	1	0	1	1	0	1	1	Suite 1
3	1	1	1	1	1	0	1	1	0	1	1	Suite 1
4	1	1	1	1	1	0	0	0	1	1	1	Suite 2
5	1	1	1	1	1	0	0	0	1	1	1	Suite 2
6	1	1	1	1	1	0	0	1	1	1	1	Suite 3
7	1	1	1	1	1	0	0	0	1	1	1	Suite 2
8	1	1	1	1	1	0	0	0	1	1	1	Suite 2
9	1	1	1	1	1	0	0	0	1	1	1	Suite 2
10	1	1	1	1	0	0	0	1	1	1	1	Suite 4
11	1	1	1	1	1	0	0	1	1	1	1	Suite 3
12	1	1	1	1	1	0	0	1	1	1	1	Suite 3
13	1	1	1	1	1	0	0	0	1	1	1	Suite 2
14	1	1	1	1	1	0	0	0	1	1	1	Suite 2
15	1	1	1	1	1	0	0	0	1	1	1	Suite 2
16	1	1	1	1	1	0	0	0	1	1	1	Suite 2
17	1	1	1	1	1	0	0	0	1	1	1	Suite 2
18	1	1	1	1	1	0	0	0	1	1	1	Suite 2
19	1	0	0	1	0	0	0	0	1	1	0	Suite 5
20	1	0	0	1	0	0	0	0	1	1	0	Suite 5
21	1	0	0	1	0	0	1	0	0	1	0	Suite 6
22	1	0	0	1	0	0	0	0	1	1	0	Suite 5
23	1	0	0	1	0	0	0	0	1	1	0	Suite 5
24	1	0	0	1	0	0	0	0	1	1	0	Suite 5
25	1	0	0	1	0	0	0	0	1	1	0	Suite 5
26	1	0	0	1	0	0	0	0	1	1	0	Suite 5
27	1	0	0	1	0	0	0	0	1	1	0	Suite 5
NPV	1	1	1	1	1	0	1	1	0	1	1	Suite 1

6.4.3 Emissions Cost Model Absolute Robust Decision Criterion

In order to calculate the Absolute Robust and Robust Deviation decisions, the performance of each solution set must be compared every other solution set for all the scenarios. This is shown in Table 6.9. The investment suite which constitutes, from Table 6.8, the solution for say scenario 1 is tested in all other scenarios, and the NPV of scenario 1 in all other scenarios is shown in the 'x1' column in Table 6.9. Similar results are provided for all other scenarios 2-27 in columns x2-x27. At the bottom of each column the minimum and maximum NPV values for that solution across all scenarios are shown.

The Absolute Robust Decision Criterion is found by maximising the minimum outcome. As shown in Table 6.9, the minimum outcomes vary between –$153,963 and $2,811 million. Therefore, the maximum minimal outcome is $2,811 million which is found in optimal policy sets 19, 20, 22 to 27 which select an identical suite of projects, that is, Optimal Investment Suite 5.

Therefore the Absolute Robust solution is found by selecting the following projects: 1, 4, 9 and 10. This solution involves capital expenditure of $7,417 million, with slack in the budget of $1,583 million, and an NPV varying between $2,811 million to $52,167 million depending upon which scenario eventuates. Its key characteristic here is that it generates the highest minimum NPV across all scenarios.

Table 6.9 Maximin Table: Optimal Solutions in other Scenarios (NPV, $million)

Scenario	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15
1	45341	45341	45341	38743	38743	39717	38743	38743	38743	39033	39717	39717	38743	38743	38743
2	63050	63050	63050	54419	54419	55826	54419	54419	54419	54822	55826	55826	54419	54419	54419
3	80759	80759	80759	70096	70096	71935	70096	70096	70096	70612	71935	71935	70096	70096	70096
4	14220	14220	14220	15487	15487	15435	15487	15487	15487	15135	15435	15435	15487	15487	15487
5	20077	20077	20077	22194	22194	22180	22194	22194	22194	21736	22180	22180	22194	22194	22194
6	25933	25933	25933	28901	28901	28926	28901	28901	28901	28336	28926	28926	28901	28901	28901
7	6032	6032	6032	7729	7729	7622	7729	7729	7729	7467	7622	7622	7729	7729	7729
8	8703	8703	8703	11342	11342	11237	11342	11342	11342	11004	11237	11237	11342	11342	11342
9	11373	11373	11373	14955	14955	14852	14955	14955	14955	14541	14852	14852	14955	14955	14955
10	-8335	-8335	-8335	25936	25936	25937	25936	25936	25936	25998	25937	25937	25936	25936	25936
11	-8518	-8518	-8518	37344	37344	37453	37344	37344	37344	37442	37453	37453	37344	37344	37344
12	-8701	-8701	-8701	48752	48752	48969	48752	48752	48752	48886	48969	48969	48752	48752	48752
13	3929	3929	3929	10978	10978	10807	10978	10978	10978	10788	10807	10807	10978	10978	10978
14	6355	6355	6355	16182	16182	16010	16182	16182	16182	15939	16010	16010	16182	16182	16182
15	8782	8782	8782	21386	21386	21213	21386	21386	21386	21091	21213	21213	21386	21386	21386
16	2988	2988	2988	5729	5729	5608	5729	5729	5729	5578	5608	5608	5729	5729	5729
17	4643	4643	4643	8675	8675	8552	8675	8675	8675	8485	8552	8552	8675	8675	8675
18	6299	6299	6299	11621	11621	11495	11621	11621	11621	11392	11495	11495	11621	11621	11621
19	-117418	-117418	-117418	-90	-90	-2067	-90	-90	-90	-494	-2067	-2067	-90	-90	-90
20	-153963	-153963	-153963	2643	2643	114	2643	2643	2643	2120	114	114	2643	2643	2643
21	66379	66379	66379	5375	5375	2294	5375	5375	5375	4733	2294	2294	5375	5375	5375
22	-16985	-16985	-16985	1815	1815	1402	1815	1815	1815	1953	1402	1402	1815	1815	1815
23	-21531	-21531	-21531	3965	3965	3470	3965	3965	3965	4160	3470	3470	3965	3965	3965
24	-26076	-26076	-26076	6115	6115	5539	6115	6115	6115	6366	5539	5539	6115	6115	6115
25	-3200	-3200	-3200	1663	1663	1515	1663	1663	1663	1738	1515	1515	1663	1663	1663
26	-3607	-3607	-3607	3254	3254	3095	3254	3254	3254	3365	3095	3095	3254	3254	3254
27	-4013	-4013	-4013	4845	4845	4674	4845	4845	4845	4992	4674	4674	4845	4845	4845
min	-153963	-153963	-153963	-90	-90	-2067	-90	-90	-90	-494	-2067	-2067	-90	-90	-90
Max	80759	80759	80759	70096	70096	71935	70096	70096	70096	70612	71935	71935	70096	70096	70096

x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	NPV	Max	
38743	38743	38743	28334	28334	33957	28334	28334	28334	28334	28334	28334	45341	45341	
54419	54419	54419	40251	40251	47474	40251	40251	40251	40251	40251	40251	63050	63050	
70096	70096	70096	52167	52167	60991	52167	52167	52167	52167	52167	52167	80759	80759	
15487	15487	15487	11314	11314	10100	11314	11314	11314	11314	11314	11314	14220	15487	
22194	22194	22194	16502	16502	14398	16502	16502	16502	16502	16502	16502	20077	22194	
28901	28901	28901	21689	21689	18697	21689	21689	21689	21689	21689	21689	25933	28926	
7729	7729	7729	5679	5679	4090	5679	5679	5679	5679	5679	5679	6032	7729	
11342	11342	11342	8540	8540	6005	8540	8540	8540	8540	8540	8540	8703	11342	
14955	14955	14955	11400	11400	7921	11400	11400	11400	11400	11400	11400	11373	14955	
25936	25936	25936	23144	23144	-11129	23144	23144	23144	23144	23144	23144	-8335	25998	
37344	37344	37344	33331	33331	-12640	33331	33331	33331	33331	33331	33331	-8518	37453	
48752	48752	48752	43518	43518	-14152	43518	43518	43518	43518	43518	43518	-8701	48969	
10978	10978	10978	9376	9376	2498	9376	9376	9376	9376	9376	9376	3929	10978	
16182	16182	16182	13918	13918	4263	13918	13918	13918	13918	13918	13918	6355	16182	
21386	21386	21386	18459	18459	6028	18459	18459	18459	18459	18459	18459	8782	21386	
5729	5729	5729	4733	4733	2113	4733	4733	4733	4733	4733	4733	2988	5729	
8675	8675	8675	7279	7279	3370	7279	7279	7279	7279	7279	7279	4643	8675	
11621	11621	11621	9824	9824	4627	9824	9824	9824	9824	9824	9824	6299	11621	
-90	-90	-90	12597	12597	-102755	12597	12597	12597	12597	12597	12597	-117418	12597	
2643	2643	2643	19268	19268	-134808	19268	19268	19268	19268	19268	19268	-153963	19268	
5375	5375	5375	25939	25939	90024	25939	25939	25939	25939	25939	25939	66379	90024	
1815	1815	1815	5438	5438	-12950	5438	5438	5438	5438	5438	5438	-16985	5438	
3965	3965	3965	8666	8666	-16335	8666	8666	8666	8666	8666	8666	-21531	8666	
6115	6115	6115	11895	11895	-19719	11895	11895	11895	11895	11895	11895	-26076	11895	
1663	1663	1663	2811	2811	-1904	2811	2811	2811	2811	2811	2811	-3200	2811	
3254	3254	3254	4716	4716	-1986	4716	4716	4716	4716	4716	4716	-3607	4716	
4845	4845	4845	6620	6620	-2068	6620	6620	6620	6620	6620	6620	-4013	6620	
														Maximin
-90	-90	-90	2811	2811	-134808	2811	2811	2811	2811	2811	2811	-153963		2811
70096	70096	70096	52167	52167	90024	52167	52167	52167	52167	52167	52167	80759		

6.4.4 Emissions Cost Model Robust Deviation Decision Criterion Solution

The Robust Deviation decision is one of minimizing the maximum regret, in this case financial regret. As discussed in Chapter 5, regret is defined as the opportunity loss to the decision-maker if alternative A_i is chosen and scenario S_j occurs. Regret is the payoff difference between the best possible outcome under S_j and the actual outcome from choosing A_i. To minimise the maximum regret a Regret/Opportunity Loss Table is constructed (Table 6.10). This table calculates the value for each scenario as well as the maximum and minimum in each scenario for all policy choices.

Table 6.10 is calculated from Table 6.9 by determining the difference between the maximum outcome for a given scenario (the right hand column of Table 6.9) and the NPV value for the other policy settings in that scenario (that is, the x1-x27 values for a given scenario). Having determined the potential value of regret for each policy setting and each scenario, then the policy with the minimal difference between the maximum and minimum (that is, the lowest level of regret) is selected.

From Table 6.10 it can be seen that the Robust Deviation decision produces a mini-max regret figure of $64,085 million from the optimal policy set from scenarios 19, 20, 22 to 27. That is, Optimal Investment Suite 5. The levels of regret vary from the minimum of $64,085 million for Optimal Investment Suite 5 to a maximum of $173,231 million for Optimal Investment Suite 1. This means that, by choosing that particular investment suite, the firm may potentially have a regret of $173,231 million of value, whereas by choosing Optimal Investment Suite 5 the maximum opportunity loss is $64,085 million. The conventional NPV solution coincides with Optimal Investment Suite 1. Therefore, the potential regret of the Conventional NPV solution is $173,231 million.

It should be noted the Robust Deviation Decision Criterion produces the same decision as the Absolute Robust Solution.

Table 6.10 Regret/Opportunity Loss Table ($million)

	Extent of NPV regret for the optimal solution for any given scenario, relative to the maximum NPV for each scenario ($million)														
Scenario	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14	x15
1	0	0	0	6,598	6,598	5,624	6,598	6,598	6,598	6,308	5,624	5,624	6,598	6,598	6,598
2	0	0	0	8,631	8,631	7,223	8,631	8,631	8,631	8,227	7,223	7,223	8,631	8,631	8,631
3	0	0	0	10,663	10,663	8,823	10,663	10,663	10,663	10,147	8,823	8,823	10,663	10,663	10,663
4	1,267	1,267	1,267	0	0	52	0	0	0	351	52	52	0	0	0
5	2,117	2,117	2,117	0	0	13	0	0	0	458	13	13	0	0	0
6	2,992	2,992	2,992	25	25	0	25	25	25	590	0	0	25	25	25
7	1,697	1,697	1,697	0	0	107	0	0	0	262	107	107	0	0	0
8	2,640	2,640	2,640	0	0	105	0	0	0	339	105	105	0	0	0
9	3,583	3,583	3,583	0	0	104	0	0	0	415	104	104	0	0	0
10	34,333	34,333	34,333	61	61	61	61	61	61	0	61	61	61	61	61
11	45,971	45,971	45,971	109	109	0	109	109	109	11	0	0	109	109	109
12	57,670	57,670	57,670	217	217	0	217	217	217	83	0	0	217	217	217
13	7,049	7,049	7,049	0	0	171	0	0	0	190	171	171	0	0	0
14	9,827	9,827	9,827	0	0	172	0	0	0	243	172	172	0	0	0
15	12,605	12,605	12,605	0	0	173	0	0	0	295	173	173	0	0	0
16	2,741	2,741	2,741	0	0	121	0	0	0	151	121	121	0	0	0
17	4,032	4,032	4,032	0	0	123	0	0	0	190	123	123	0	0	0
18	5,323	5,323	5,323	0	0	126	0	0	0	230	126	126	0	0	0
19	130,015	130,015	130,015	12,686	12,686	14,664	12,686	12,686	12,686	13,090	14,664	14,664	12,686	12,686	12,686
20	173,231	173,231	173,231	16,625	16,625	19,154	16,625	16,625	16,625	17,148	19,154	19,154	16,625	16,625	16,625
21	23,645	23,645	23,645	84,649	84,649	87,730	84,649	84,649	84,649	85,291	87,730	87,730	84,649	84,649	84,649
22	22,423	22,423	22,423	3,623	3,623	4,036	3,623	3,623	3,623	3,485	4,036	4,036	3,623	3,623	3,623
23	30,197	30,197	30,197	4,702	4,702	5,196	4,702	4,702	4,702	4,507	5,196	5,196	4,702	4,702	4,702
24	37,971	37,971	37,971	5,780	5,780	6,357	5,780	5,780	5,780	5,529	6,357	6,357	5,780	5,780	5,780
25	6,011	6,011	6,011	1,148	1,148	1,296	1,148	1,148	1,148	1,074	1,296	1,296	1,148	1,148	1,148
26	8,322	8,322	8,322	1,461	1,461	1,621	1,461	1,461	1,461	1,351	1,621	1,621	1,461	1,461	1,461
27	10,634	10,634	10,634	1,775	1,775	1,946	1,775	1,775	1,775	1,628	1,946	1,946	1,775	1,775	1,775
Max	173,231	173,231	173,231	84,649	84,649	87,730	84,649	84,649	84,649	85,291	87,730	87,730	84,649	84,649	84,649

x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	
6,598	6,598	6,598	17,007	17,007	11,384	17,007	17,007	17,007	17,007	17,007	17,007	
8,631	8,631	8,631	22,799	22,799	15,576	22,799	22,799	22,799	22,799	22,799	22,799	
10,663	10,663	10,663	28,591	28,591	19,768	28,591	28,591	28,591	28,591	28,591	28,591	
0	0	0	4,172	4,172	5,387	4,172	4,172	4,172	4,172	4,172	4,172	
0	0	0	5,692	5,692	7,795	5,692	5,692	5,692	5,692	5,692	5,692	
25	25	25	7,236	7,236	10,229	7,236	7,236	7,236	7,236	7,236	7,236	
0	0	0	2,050	2,050	3,640	2,050	2,050	2,050	2,050	2,050	2,050	
0	0	0	2,803	2,803	5,337	2,803	2,803	2,803	2,803	2,803	2,803	
0	0	0	3,555	3,555	7,034	3,555	3,555	3,555	3,555	3,555	3,555	
61	61	61	2,854	2,854	37,126	2,854	2,854	2,854	2,854	2,854	2,854	
109	109	109	4,122	4,122	50,093	4,122	4,122	4,122	4,122	4,122	4,122	
217	217	217	5,451	5,451	63,121	5,451	5,451	5,451	5,451	5,451	5,451	
0	0	0	1,602	1,602	8,480	1,602	1,602	1,602	1,602	1,602	1,602	
0	0	0	2,264	2,264	11,919	2,264	2,264	2,264	2,264	2,264	2,264	
0	0	0	2,927	2,927	15,358	2,927	2,927	2,927	2,927	2,927	2,927	
0	0	0	995	995	3,616	995	995	995	995	995	995	
0	0	0	1,396	1,396	5,305	1,396	1,396	1,396	1,396	1,396	1,396	
0	0	0	1,798	1,798	6,994	1,798	1,798	1,798	1,798	1,798	1,798	
12,686	12,686	12,686	0	0	115,351	0	0	0	0	0	0	
16,625	16,625	16,625	0	0	154,076	0	0	0	0	0	0	
84,649	84,649	84,649	64,085	64,085	0	64,085	64,085	64,085	64,085	64,085	64,085	
3,623	3,623	3,623	0	0	18,388	0	0	0	0	0	0	
4,702	4,702	4,702	0	0	25,001	0	0	0	0	0	0	
5,780	5,780	5,780	0	0	31,614	0	0	0	0	0	0	
1,148	1,148	1,148	0	0	4,715	0	0	0	0	0	0	
1,461	1,461	1,461	0	0	6,701	0	0	0	0	0	0	
1,775	1,775	1,775	0	0	8,688	0	0	0	0	0	0	**Minimax Regret**
84,649	**84,649**	**84,649**	**64,085**	**64,085**	**154,076**	**64,085**	**64,085**	**64,085**	**64,085**	**64,085**	**64,085**	**64,085**

6.4.5 Influence of Variables on Optimal Solution

Given the limited number of solutions for 27 different scenarios, it is worth examining which factors play the dominant role in the solution of the model. The three variables in the model have influence over the project selection to varying degrees. The variables and optimal investment suites are summarised Table 6.11. The investment suites which choose the same projects are highlighted in the same colour. Therefore the optimal investment suite for scenarios 1, 2 and 3 are the same and hence they have the same colour, as are the optimal investment suites for scenarios 6, 11 and 12.

Table 6.11 Variables and Optimal Investment Suites

				Projects select 1/0										
Scen.	Emis. cost	Disc. rate	Cash flow	1	2	3	4	5	6	7	8	9	10	11
1	L	L	L	1	1	1	1	1	0	1	1	0	1	1
2	L	L	M	1	1	1	1	1	0	1	1	0	1	1
3	L	L	H	1	1	1	1	1	0	1	1	0	1	1
4	L	M	L	1	1	1	1	1	0	0	0	1	1	1
5	L	M	M	1	1	1	1	1	0	0	0	1	1	1
6	L	M	H	1	1	1	1	1	0	0	1	1	1	1
7	L	H	L	1	1	1	1	1	0	0	0	1	1	1
8	L	H	M	1	1	1	1	1	0	0	0	1	1	1
9	L	H	H	1	1	1	1	1	0	0	0	1	1	1
10	M	L	L	1	1	1	1	0	0	0	1	1	1	1
11	M	L	M	1	1	1	1	1	0	0	1	1	1	1
12	M	L	H	1	1	1	1	1	0	0	1	1	1	1
13	M	M	L	1	1	1	1	1	0	0	0	1	1	1
14	M	M	M	1	1	1	1	1	0	0	0	1	1	1
15	M	M	H	1	1	1	1	1	0	0	0	1	1	1
16	M	H	L	1	1	1	1	1	0	0	0	1	1	1
17	M	H	M	1	1	1	1	1	0	0	0	1	1	1
18	M	H	H	1	1	1	1	1	0	0	0	1	1	1
19	H	L	L	1	0	0	1	0	0	0	0	1	1	0
20	H	L	M	1	0	0	1	0	0	0	0	1	1	0
21	H	L	H	1	0	0	1	0	0	1	0	0	1	0
22	H	M	L	1	0	0	1	0	0	0	0	1	1	0
23	H	M	M	1	0	0	1	0	0	0	0	1	1	0
24	H	M	H	1	0	0	1	0	0	0	0	1	1	0
25	H	H	L	1	0	0	1	0	0	0	0	1	1	0
26	H	H	M	1	0	0	1	0	0	0	0	1	1	0
27	H	H	H	1	0	0	1	0	0	0	0	1	1	0
NPV	N/A	M	M	1	1	1	1	1	0	1	1	0	1	1

- Optimal Investment Suite 1
- Optimal Investment Suite 2
- Optimal Investment Suite 3
- Optimal Investment Suite 4
- Optimal Investment Suite 5
- Optimal Investment Suite 6

As described above and can be seen from Table 6.11, there are six different investment suites. While a precise interpretation of the relative importance of the three variables in determining preferred outcomes cannot be given, the table does suggest that the emission cost variable is particularly important. In all of the high emissions cost scenarios investment suites containing only four projects (suites 5 and 6) are chosen, and indeed suite 5 is chosen in eight of these nine scenarios. While the projects chosen are not confined to the lowest emissions projects, the three most energy intensive projects (projects 2, 3 and 5) are all excluded. This issue is analysed further below.

6.4.6 Emissions Cost Model Solutions: GHG Emissions and NPV

The model proposed is concerned with throwing light on methods for evaluating the business case for voluntarily reducing emissions in a business environment characterised by uncertain Climate Change regulations, among others. The Emissions Cost model examines the impact a price-based instrument has on reducing emissions while simultaneously maximising NPV.

The emissions generated by the investments are a direct function of the revenue, consequently the figures vary depending on the undiscounted cash flows and not the discount rate or emissions cost. The total emissions generated by each optimal solution in their respective scenarios are found in Table 6.12, and are shown diagrammatically in Figure 6.1. As before, the optimal solutions that select the same projects are highlighted with the same colour, that is, all green solutions select the same set of projects; all blue solutions select the same set of projects and so on. As Table 6.12 shows, depending upon the scenario, the emissions vary between a low figure of 135,496,517 tonnes of CO_2e in Scenario 24 to 554,354,174 tonnes of CO_2e in Scenario 6. This represents over four times as many emissions in one scenario as in the other. This compares with the NPV performance, where the lowest stands at $2,811 million in Scenario 24 and the highest is at $90,024 million in Scenario 21. This represents over 32 times the NPV.

Figure 6.1 Optimal Solutions Emissions and NPV

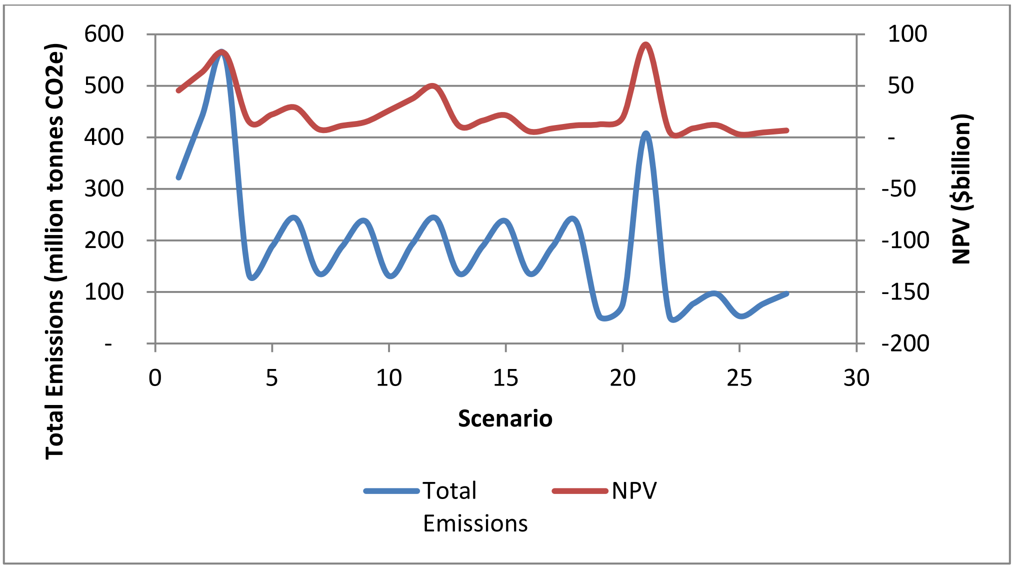


Table 6.12 Emissions Cost Model Total Emissions in each Scenario

				Projects Select 1/0												
Scen.	**Emis. cost**	**Disc. rate**	**Cash flow**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Emissions (tonnes CO_2e)**	**NPV ($ million)**
1	L	L	L	1	1	1	1	1	0	1	1	0	1	1	321,973,241	45,341
2	L	L	M	1	1	1	1	1	0	1	1	0	1	1	440,343,041	63,050
3	L	L	H	1	1	1	1	1	0	1	1	0	1	1	554,354,174	80,759
4	L	M	L	1	1	1	1	1	0	0	0	1	1	1	135,496,517	15,487
5	L	M	M	1	1	1	1	1	0	0	0	1	1	1	188,580,810	22,194
6	L	M	H	1	1	1	1	1	0	0	1	1	1	1	243,345,382	28,926
7	L	H	L	1	1	1	1	1	0	0	0	1	1	1	135,496,517	7,729
8	L	H	M	1	1	1	1	1	0	0	0	1	1	1	188,580,810	11,342
9	L	H	H	1	1	1	1	1	0	0	0	1	1	1	237,306,435	14,955
10	M	L	L	1	1	1	1	0	0	0	1	1	1	1	131,168,881	25,998
11	M	L	M	1	1	1	1	1	0	0	1	1	1	1	193,276,657	37,453
12	M	L	H	1	1	1	1	1	0	0	1	1	1	1	243,345,382	48,969
13	M	M	L	1	1	1	1	1	0	0	0	1	1	1	135,496,517	10,978
14	M	M	M	1	1	1	1	1	0	0	0	1	1	1	188,580,810	16,182
15	M	M	H	1	1	1	1	1	0	0	0	1	1	1	237,306,435	21,386
16	M	H	L	1	1	1	1	1	0	0	0	1	1	1	135,496,517	5,729
17	M	H	M	1	1	1	1	1	0	0	0	1	1	1	188,580,810	8,675
18	M	H	H	1	1	1	1	1	0	0	0	1	1	1	237,306,435	11,621
19	H	L	L	1	0	0	1	0	0	0	0	1	1	0	53,063,720	12,597
20	H	L	M	1	0	0	1	0	0	0	0	1	1	0	77,123,808	19,268
21	H	L	H	1	0	0	1	0	0	1	0	0	1	0	407,834,021	90,024
22	H	M	L	1	0	0	1	0	0	0	0	1	1	0	53,063,720	5,438
23	H	M	M	1	0	0	1	0	0	0	0	1	1	0	77,123,808	8,666
24	H	M	H	1	0	0	1	0	0	0	0	1	1	0	96,825,229	11,895
25	H	H	L	1	0	0	1	0	0	0	0	1	1	0	53,063,720	2,811
26	H	H	M	1	0	0	1	0	0	0	0	1	1	0	77,123,808	4,716
27	H	H	H	1	0	0	1	0	0	0	0	1	1	0	96,825,229	6,620

Optimal Investment Suite 1
Optimal Investment Suite 2
Optimal Investment Suite 3
Optimal Investment Suite 4
Optimal Investment Suite 5
Optimal Investment Suite 6

Table 6.12 also highlights the Investment Suite which is optimal for each scenario, and Table 6.13 provides the emissions cost and NPV levels for each Investment Suite in each scenario. These two values for each of the six Investment Suites are also presented diagrammatically in figures 6.2-6.7. The 'saw-tooth' pattern that is evident in the NPV data reflects the impact of the cash flow variability assumptions and the way the scenarios are arranged, as the cash flow assumptions go from low-medium- high- low, etc. across the scenarios.

Table 6.13 NPV and Emissions Cost Model Optimal Investment Suites in all Scenarios

	Optimal Invest Suite 1		Optimal Invest Suite 2		Optimal Invest Suite 3		Optimal Invest Suite 4		Optimal Invest Suite 5		Optimal Invest Suite 6	
Scen.	Total emissions (tonnes CO_2e)	NPV ($ million)	Total emissions (tonnes CO_2e)	NPV ($ million)	Total emissions (tonnes CO_2e)	NPV ($ million)	Total emissions (tonnes CO_2e)	NPV ($ million)	Total emissions (tonnes CO_2e)	NPV ($ million)	Total emissions (tonnes CO_2e)	NPV ($ million)
1	321,973,241	45,341	135,496,517	38,743	138,849,264	39,717	131,168,881	39,033	53,063,720	28,334	236,187,697	33,957
2	440,343,041	63,050	188,580,810	54,419	193,276,657	55,826	182,429,894	54,822	77,123,808	40,251	324,190,193	47,474
3	554,354,174	80,759	237,306,435	70,096	243,345,382	71,935	229,332,241	70,612	96,825,229	52,167	407,834,021	60,991
4	321,973,241	14,220	135,496,517	15,487	138,849,264	15,435	131,168,881	15,135	53,063,720	11,314	236,187,697	10,100
5	440,343,041	20,077	188,580,810	22,194	193,276,657	22,180	182,429,894	21,736	77,123,808	16,502	324,190,193	14,398
6	554,354,174	25,933	237,306,435	28,901	243,345,382	28,926	229,332,241	28,336	96,825,229	21,689	407,834,021	18,697
7	321,973,241	6,032	135,496,517	7,729	138,849,264	7,622	131,168,881	7,467	53,063,720	5,679	236,187,697	4,090
8	440,343,041	8,703	188,580,810	11,342	193,276,657	11,237	182,429,894	11,004	77,123,808	8,540	324,190,193	6,005
9	554,354,174	11,373	237,306,435	14,955	243,345,382	14,852	229,332,241	14,541	96,825,229	11,400	407,834,021	7,921
10	321,973,241	–8,335	135,496,517	25,936	138,849,264	25,937	131,168,881	25,998	53,063,720	23,144	236,187,697	–11,129
11	440,343,041	–8,518	188,580,810	37,344	193,276,657	37,453	182,429,894	37,442	77,123,808	33,331	324,190,193	–12,640
12	554,354,174	–8,701	237,306,435	48,752	243,345,382	48,969	229,332,241	48,886	96,825,229	43,518	407,834,021	–14,152
13	321,973,241	3,929	135,496,517	10,978	138,849,264	10,807	131,168,881	10,788	53,063,720	9,376	236,187,697	2,498
14	440,343,041	6,355	188,580,810	16,182	193,276,657	16,010	182,429,894	15,939	77,123,808	13,918	324,190,193	4,263
15	554,354,174	8,782	237,306,435	21,386	243,345,382	21,213	229,332,241	21,091	96,825,229	18,459	407,834,021	6,028
16	321,973,241	2,988	135,496,517	5,729	138,849,264	5,608	131,168,881	5,578	53,063,720	4,733	236,187,697	2,113
17	440,343,041	4,643	188,580,810	8,675	193,276,657	8,552	182,429,894	8,485	77,123,808	7,279	324,190,193	3,370
18	554,354,174	6,299	237,306,435	11,621	243,345,382	11,495	229,332,241	11,392	96,825,229	9,824	407,834,021	4,627
19	321,973,241	–117,418	135,496,517	–90	138,849,264	–2,067	131,168,881	–494	53,063,720	12,597	236,187,697	–102,755
20	440,343,041	–153,963	188,580,810	2,643	193,276,657	114	182,429,894	2,120	77,123,808	19,268	324,190,193	–134,808
21	554,354,174	66,379	237,306,435	5,375	243,345,382	2,294	229,332,241	4,733	96,825,229	25,939	407,834,021	90,024
22	321,973,241	–16,985	135,496,517	1,815	138,849,264	1,402	131,168,881	1,953	53,063,720	5,438	236,187,697	–12,950
23	440,343,041	–21,531	188,580,810	3,965	193,276,657	3,470	182,429,894	4,160	77,123,808	8,666	324,190,193	–16,335
24	554,354,174	–26,076	237,306,435	6,115	243,345,382	5,539	229,332,241	6,366	96,825,229	11,895	407,834,021	–19,719
25	321,973,241	–3,200	135,496,517	1,663	138,849,264	1,515	131,168,881	1,738	53,063,720	2,811	236,187,697	–1,904
26	440,343,041	–3,607	188,580,810	3,254	193,276,657	3,095	182,429,894	3,365	77,123,808	4,716	324,190,193	–1,986
27	554,354,174	–4,013	237,306,435	4,845	243,345,382	4,674	229,332,241	4,992	96,825,229	6,620	407,834,021	–2,068

A central theme of this thesis has been that, in the face of pervasive uncertainty, an understanding of the performance of the different solutions in all the scenarios is vital for good decision-making. Such knowledge can inform the decision-maker about the ramifications of different solutions, and is especially relevant when the emissions and NPV performance varies so markedly across scenarios, as shown in Table 6.13 and figures 6.1 to 6.7.

The Absolute Robust and Robust Deviation Criteria solution is the Optimal Investment Suite 5. The NPV and emissions performance of Suite 5 is shown in **Error! Reference source not found.**Table 6.13 and Figure 6.6. For all scenarios Suite 5 returns a positive NPV, whereas several other suites return large negative NPVs (in excess of $100 billion for a maximum investment of $9 billion). Suite 5 also generates consistently low emissions, with total emissions less than 100 tonnes of CO_2e for all 27 scenarios, whereas some Investment Suites have emissions over 400 tonnes of CO_2e for many scenarios.

It is particularly instructive to Suite 5, the robust optimisation solution, with Suite 1, that generated by the conventional NPV approach (see Table 6.14). While Suite 1 performs better than Suite 5 in NPV terms in a few scenarios with low emissions cost, low discount rates and low cash flow variability, it performs much worse in higher risk scenarios, especially those with a high emissions cost. It returns negative NPVs in 11 of the 27 scenarios (Table 6.13), two of which are over $100 billion. It also remains a very high emissions scenario, with average emissions across the 27 scenarios 25 times those of Suite 1. This high emissions character is one of the key reasons why it performs poorly in higher emissions contexts.

Figure 6.2 NPV and Emissions Optimal Investment Suite 1 in all Scenarios

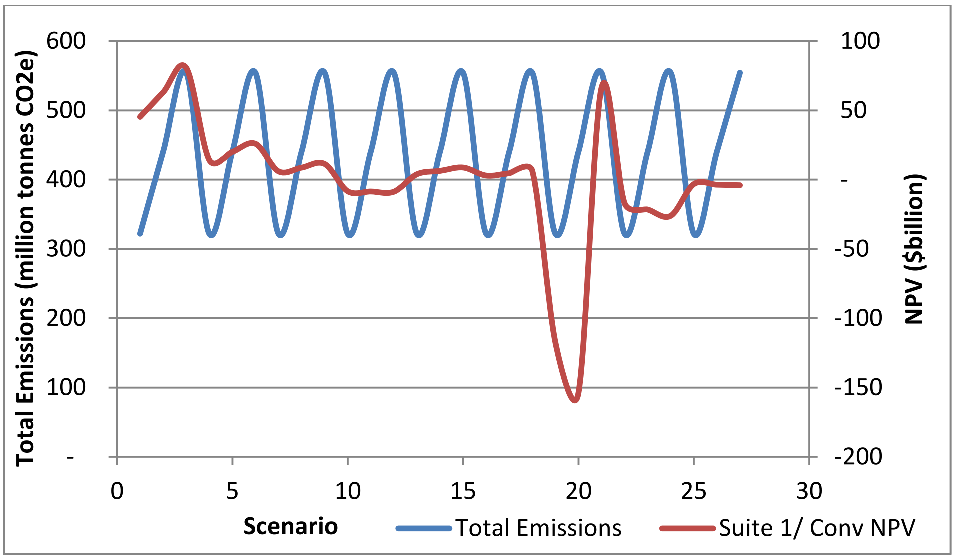


Figure 6.3 NPV and Emissions Optimal Investment Suite 2 in all Scenarios

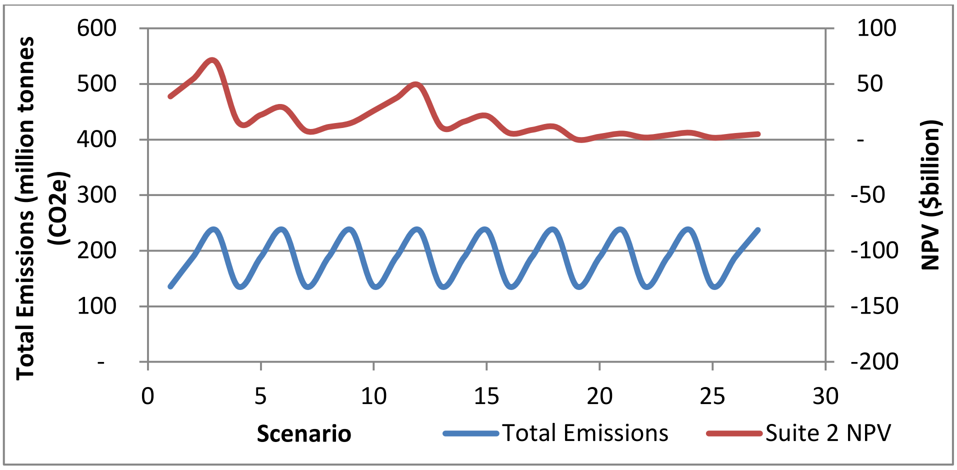


Figure 6.4 NPV and Emissions Optimal Investment Suite 3 in all Scenarios

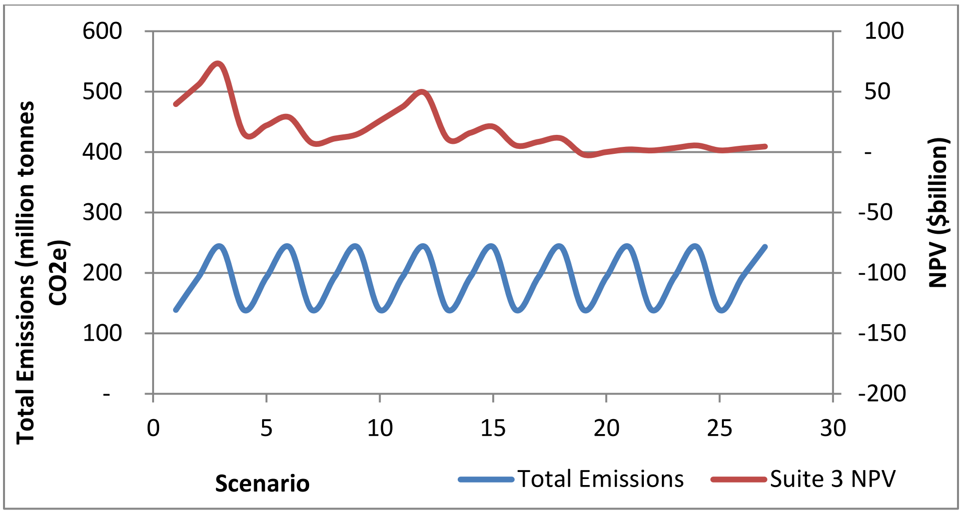


Figure 6.5 NPV and Emissions Optimal Investment Suite 4 in all Scenarios

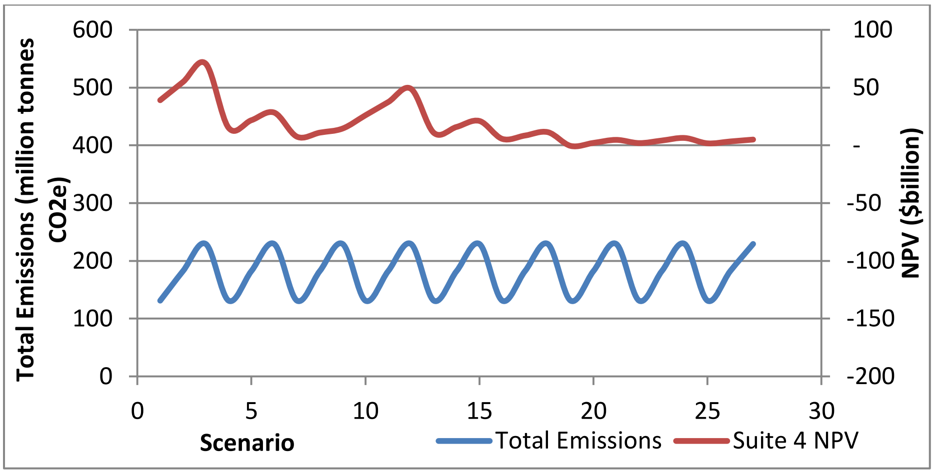


Figure 6.6 NPV and Emissions Optimal Investment Suite 5 in all Scenarios

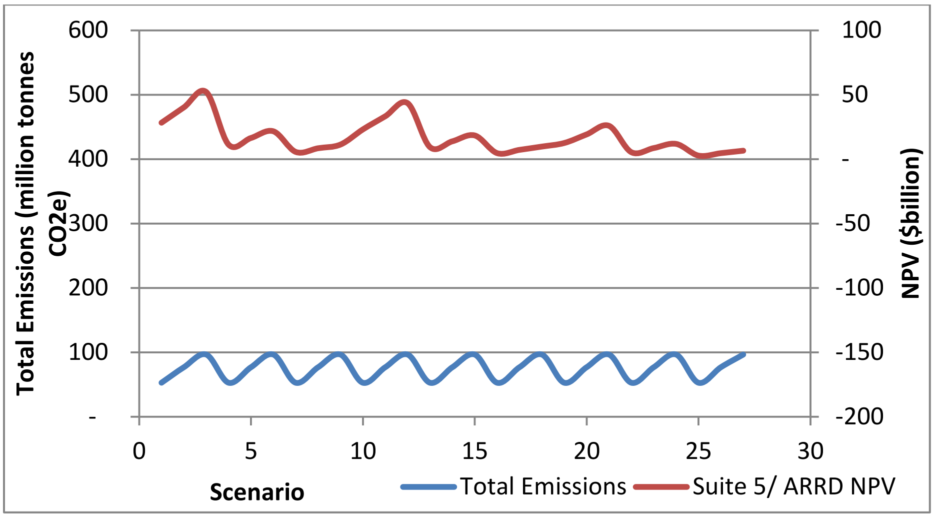


Figure 6.7 NPV and Emissions Optimal Investment Suite 6 in all Scenarios

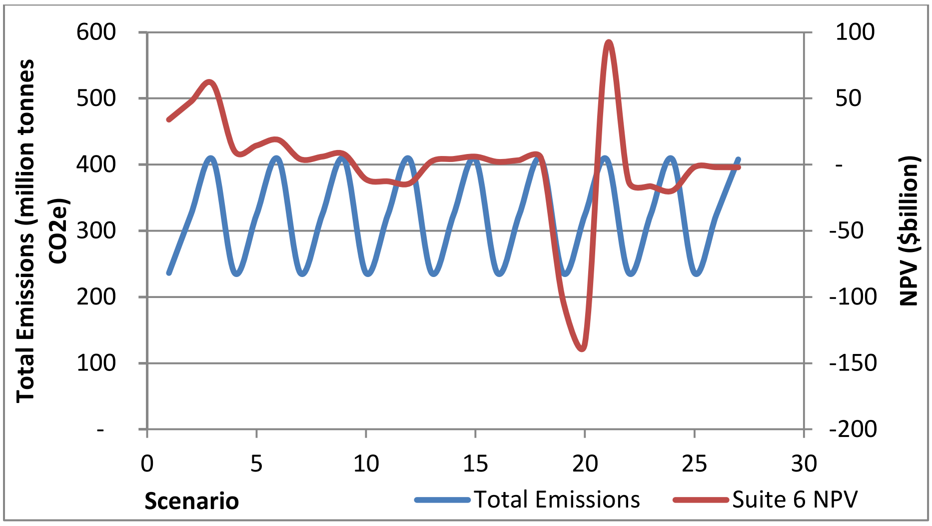
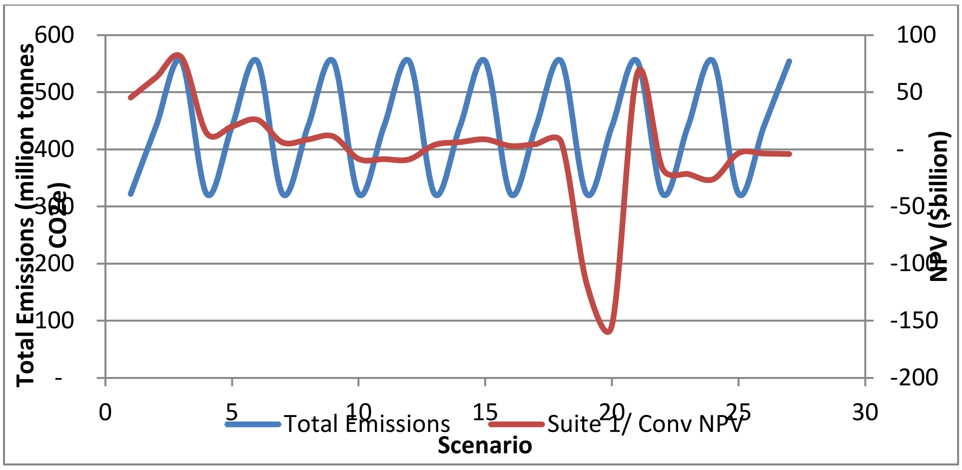


Table 6.14 NPV and Emissions Conventional NPV Solution in all Scenarios

Scen.	Total emissions (tonnes CO_2e)	NPV ($ million)
1	321,973,241	33,957
2	440,343,041	47,474
3	554,354,174	60,991
4	321,973,241	10,100
5	440,343,041	14,398
6	554,354,174	18,697
7	321,973,241	4,090
8	440,343,041	6,005
9	554,354,174	7,921
10	321,973,241	−11,129
11	440,343,041	−12,640
12	554,354,174	−14,152
13	321,973,241	2,498
14	440,343,041	4,263
15	554,354,174	6,028
16	321,973,241	2,113
17	440,343,041	3,370
18	554,354,174	4,627
19	321,973,241	−102,755
20	440,343,041	−134,808
21	554,354,174	90,024
22	321,973,241	−12,950
23	440,343,041	−16,335
24	554,354,174	−19,719
25	321,973,241	−1,904
26	440,343,041	−1,986
27	554,354,174	−2,068

Figure 6.8 NPV and Emissions Conventional NPV solution in all Scenarios



6.4.7 Emissions Cost Model Eco-Efficiency Implications

The concept of corporate eco-efficiency is defined as creating more value with fewer environmental resources resulting in less environmental impact, for example, less pollution (Schaltegger et al., 2003). In this study a simplified eco-efficiency measure is defined as NPV divided by emissions. Guenster, Bauer et al. (2010) report that eco-efficient companies provide anomalously positive equity returns relative to their less eco-efficient peers. Generally the evidence is uniform and points to a positive and significant relationship between environmental management policies and Tobin's *Q*.

Guenster, Bauer et al. (2010) use Innovest Strategic Value Advisors' eco-efficiency ratings which reflect environmental performance in five fundamental areas, one of which pertains to energy intensity and energy efficiency, and this factor has broadly similar ratings to the overall eco-efficiency ratings.

This correlation enables the use of Guenster, Bauer et al.'s (2010) results in the consideration of the market valuation of a firm. Their results show that the gain in market valuation from receiving a high eco-efficiency score ranges between 0 to 7% depending upon the relative eco-efficiency scores.

If this result is accepted, it is possible to use Rappaport's (1986) model of shareholder value being the discounted net current value of a company's future free cash flows as shown in, or in the case of this study the net present value as shown below.

Rappaport's Shareholder Value

$$ShareholderValue = \sum_{i=1}^{n} \frac{FCF_n}{(1+i)^n} - IC$$

where:

FCF = free cash flow

I = discount rate

IC = investment capital

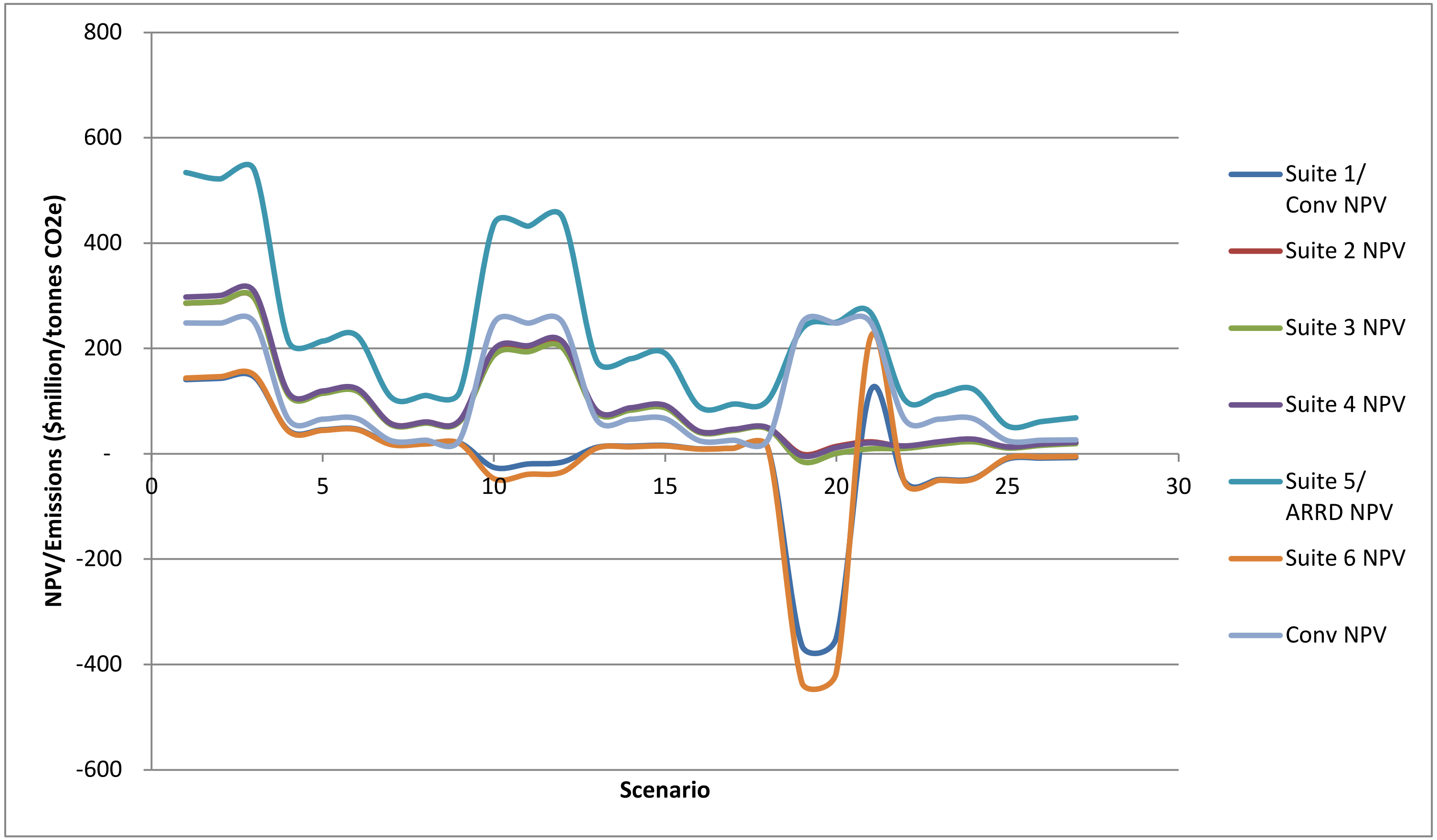
Combining this shareholder value model and Guenster et al.'s market valuation increase, the NPV of the most eco–efficient optimal investment suite, the Absolute Robust model, can be re-evaluated by up to 7%.

The results of the simplified eco-efficiency are shown in Table 6.15, with the negative results showing that the NPV for that solution is negative and hence this produces a negative eco-efficiency value. As shown in these results it is difficult to pinpoint the performance of the different solutions as the relative eco-efficiency performance varies depending upon which scenario eventuates. However, Optimal Investment Suite 5 clearly outperforms all other Optimal Investment Suites in terms of Eco-Efficiency. The Conventional NPV figures do not include any emissions price and hence appear inflated when compared to the inclusion of an emissions price. As Suite 1 selects the same projects as the Conventional NPV solution, this suite represents the value of the Conventional NPV eco-efficiency solution with an emissions cost which is negative in some scenarios. The relative performance of the various Optimal Investment Suites is shown diagrammatically in Figure6.9. The eco-efficiency performance of Suite 5 varies but is better than the Conventional NPV case (Suite 1) by a factor of between 2 to 4. According to Guenster et al. (2010) such relative performances represent the difference between the higher and lower firms and hence the more efficient suite would expect to receive an upward market valuation.

Table 6.15 Eco-Efficiency of Optimal Investment Suites in all Scenarios

	NPV/Emissions ($/tonne of CO_2e)						
Scen.	**Conv. NPV**	**Suite 1**	**Suite 2**	**Suite 3**	**Suite 4**	**Suite 5**	**Suite 6**
1	248	144	286	286	297.6	534.0	143.8
2	248	146	289	289	300.5	521.9	146.4
3	250	149	295	296	307.9	538.8	149.5
4	65	45	114	111	115.4	213.2	42.8
5	66	47	118	115	119.1	214.0	44.4
6	67	48	122	119	123.6	224.0	45.8
7	25	19	57	55	56.9	107.0	17.3
8	26	20	60	58	60.3	110.7	18.5
9	26	21	63	61	63.4	117.7	19.4
10	248	–26	191	187	198.2	436.2	–47.1
11	248	–20	198	194	205.2	432.2	–39.0
12	250	–16	205	201	213.2	449.4	–34.7
13	65	12	81	78	82.2	176.7	10.6
14	66	15	86	83	87.4	180.5	13.1
15	67	16	90	87	92.0	190.6	14.8
16	25	9	42	40	42.5	89.2	8.9
17	26	11	46	44	46.5	94.4	10.4
18	26	12	49	47	49.7	101.5	11.3
19	248	–373	–1	–15	–3.8	237.4	–435.1
20	248	–357	14	1	11.6	249.8	–415.8
21	250	122	23	9	20.6	267.9	220.7
22	65	–54	13	10	14.9	102.5	–54.8
23	66	–50	21	18	22.8	112.4	–50.4
24	67	–48	26	23	27.8	122.9	–48.4
25	25	–10	12	11	13.2	53.0	–8.1
26	26	–8	17	16	18.4	61.1	–6.1
27	26	–7	20	19	21.8	68.4	–5.1
Max	**250**	**149**	**295**	**296**	**308**	**539**	**221**
Min	**25**	**–373**	**–1**	**–15**	**-4**	**53**	**–435**

Figure 6.9 Eco-efficiency of Emissions Cost Model Optimal Investment Suites in all Scenarios (\$/tonne of CO_2e)



6.5 Emissions Quantity Model

The Emissions Quantity Model incorporates emissions into the decision model through physical emissions, as opposed to a price on GHG emissions as used in the Emissions Cost Model. This necessitated the construction of a multiple objective model due to the incompatible units between cash flows; measured in dollars and GHG emissions; measured in kilograms. Due to the multiple objective nature of the model, a new objective function was introduced which minimises the deviation from the different goals. As with the Emissions Cost model, the Emissions Quantity model allocates emissions to proposed projects based on emissions intensity data from the Department of Climate Change (Department of Climate Change, 2008) as described above. Two Emissions Quantities Decision Criteria have been developed as described in Chapter 5. These are based on Robust Optimisation techniques and consist of an Absolute Robust Decision Criterion and a Robust Deviation Decision Criterion.

The quantity model is a pure regulation model, in which quantity reductions are imposed on existing firms, by government order, without any market effects, in the sense of any price associated with emissions being imposed. It is a cap system, without the cap and trade, as is being suggested in the United States through the Environmental Protection Agency and Clean Air Act (Burtraw et al., 2011). Whilst such a scheme may be a less likely approach to be implemented in the current economic environment, where there is a strong sense of the importance of prices in generating the most efficient reduction in emissions. However, a pure regulatory model is possible where all firms must reduce emissions by a certain percentage per year and could be quite effective if less efficient in theory.

Hence the emissions cost and emissions quantity models refer to different government emissions reductions strategies, a price based one such as emissions trading or a quantity one based on regulation, and each provides an appropriate tool to deal with the strategy that the firm has to deal with. From this point of view the cost model is likely to be more relevant, as the price based strategy is more likely, but the quantity model would provide an approach to use if a pure quantity strategy was implemented.

6.5.1 Emissions Quantity Model Project Values

The NPV values used for the calculation of the optimal solution for each scenario are those specified in Table 6.5 but without the emissions cost being incorporated into the calculations. The Project Values and Scenario Matrix for the Emissions Quantity Model is shown in Table 6.16.

Table 6.16 Emissions Quantity Project Value Scenario Matrix

	Projects and value (in dollars)										
Scenarios	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	9,323	2,325	4,516	1,100	1,164	8,222	47,399	1,603	16,036	5,223	7,318
2	13,082	3,122	6,046	1,480	1,644	11,723	64,546	2,245	23,003	7,150	9,908
3	16,841	3,919	7,576	1,861	2,124	15,224	81,692	2,887	29,970	9,076	12,498
4	2,492	1,008	1,944	748	480	539	10,312	25	7,873	1,453	2,398
5	3,655	1,356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258
6	4,818	1,704	3,263	1,266	891	1,721	18,214	153	15,117	2,573	4,118
7	746	526	990	536	235	–563	3,467	–99	4,392	615	978
8	1,221	709	1,327	722	340	–436	4,896	–94	6,543	867	1,334
9	1,695	892	1,663	908	445	–308	6,324	–89	8,695	1,119	1,690
10	9,323	2,325	4,516	1,100	1,164	8,222	47,399	1,603	16,036	5,223	7,318
11	13,082	3,122	6,046	1,480	1,644	11,723	64,546	2,245	23,003	7,150	9,908
12	16,841	3,919	7,576	1,861	2,124	15,224	81,692	2,887	29,970	9,076	12,498
13	2,492	1,008	1,944	748	480	539	10,312	25	7,873	1,453	2,398
14	3,655	1,356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258
15	4,818	1,704	3,263	1,266	891	1,721	18,214	153	15,117	2,573	4,118
16	746	526	990	536	235	–563	3,467	–99	4,392	615	978
17	1,221	709	1,327	722	340	–436	4,896	–94	6,543	867	1,334
18	1,695	892	1,663	908	445	–308	6,324	–89	8,695	1,119	1,690
19	9,323	2,325	4,516	1,100	1,164	8,222	47,399	1,603	16,036	5,223	7,318
20	13,082	3,122	6,046	1,480	1,644	11,723	64,546	2,245	23,003	7,150	9,908
21	16,841	3,919	7,576	1,861	2,124	15,224	81,692	2,887	29,970	9,076	12,498
22	2,492	1,008	1,944	748	480	539	10,312	25	7,873	1,453	2,398
23	3,655	1,356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258
24	4,818	1,704	3,263	1,266	891	1,721	18,214	153	15,117	2,573	4,118
25	746	526	990	536	235	–563	3,467	–99	4,392	615	978
26	1,221	709	1,327	722	340	–436	4,896	–94	6,543	867	1,334
27	1,695	892	1,663	908	445	–308	6,324	–89	8,695	1,119	1,690

6.5.2 Emissions Quantity Model Optimal Solutions

The 27 different scenarios for the Emissions Quantity Model were solved individually to obtain the optimal solution for that particular scenario. These solutions are shown in Appendix B (p260) and the optimal investments decisions for the 27 scenarios are summarised in Table 6.17. As can be seen in, for the 27 separate scenarios there are 11 different optimal solutions which differ markedly from the Emissions Cost Model which had 6 different optimal solutions.

Table 6.17 Emissions Quantity Model Optimal Solution Project Selection Summary

	Projects select? 1/0											**Optimal investment suite**
Scenario	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	
1	1	1	1	0	0	1	1	0	0	1	0	Suite 1
2	1	1	1	0	0	1	1	0	0	1	0	Suite 1
3	1	1	1	0	0	1	1	0	0	1	0	Suite 1
4	0	0	1	0	0	0	1	0	1	0	0	Suite 2
5	0	0	1	0	0	0	1	0	1	0	0	Suite 2
6	0	0	1	0	0	0	1	0	1	0	0	Suite 2
7	1	1	1	1	0	0	0	0	1	1	1	Suite 3
8	1	1	1	1	0	0	0	0	1	1	1	Suite 3
9	1	1	1	1	0	0	0	0	1	1	1	Suite 3
10	0	0	0	0	0	0	1	1	0	0	0	Suite 4
11	0	0	0	0	0	0	1	1	0	0	0	Suite 4
12	0	0	0	0	0	0	1	1	0	0	0	Suite 4
13	1	1	1	1	1	0	0	1	1	1	1	Suite 5
14	1	1	1	1	1	0	0	1	1	1	1	Suite 5
15	1	1	1	1	1	0	0	1	1	1	1	Suite 5
16	1	0	1	1	0	0	0	0	1	1	0	Suite 6
17	1	1	0	1	1	0	0	0	1	1	0	Suite 7
18	1	1	0	1	1	0	0	0	1	1	0	Suite 7
19	1	0	0	0	0	0	0	1	1	1	0	Suite 8
20	1	0	0	0	0	0	0	0	1	1	0	Suite 9
21	1	0	0	0	0	0	0	0	1	1	0	Suite 9
22	1	0	0	0	0	0	0	0	1	1	0	Suite 9
23	1	0	0	0	0	0	0	0	1	0	0	Suite 10
24	1	0	0	0	0	0	0	0	1	0	0	Suite 10
25	1	0	0	1	0	0	0	0	0	1	0	Suite 11
26	1	0	0	1	0	0	0	0	0	1	0	Suite 11
27	1	0	0	1	0	0	0	0	0	1	0	Suite 11
NPV	1	1	1	1	1	0	1	1	0	1	1	

In order to calculate the Absolute Robust and Robust Deviation Decision Criteria, the performance of each solution set must be compared with every other solution set for all the scenarios. However, unlike the Emissions Cost model which compares the monetary value of each project in each scenario, the Emissions Quantity Model is constructed in a different way. The mini-max variable objective function aims to minimise the maximum percentage deviations from goal targets. Therefore, the value that is used in the Robust Optimisation approach is the percentage deviation from the goal. These results are summarised in Table 6.18.

Table 6.18 Emissions Quantity Minimax Optimal Solution

	Optimal policy for given scenario, that is, x1 is optimal investment policy for Scenario 1													
Scen.	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
1	3.7%	3.7%	3.7%	15.0%	15.0%	15.0%	42.7%	42.7%	42.7%	34.2%	34.2%	34.2%	39.2%	39.2%
2	3.3%	3.3%	3.3%	14.3%	14.3%	14.3%	41.6%	41.6%	41.6%	34.4%	34.4%	34.4%	38.0%	38.0%
3	3.0%	3.0%	3.0%	13.9%	13.9%	13.9%	41.0%	41.0%	41.0%	34.5%	34.5%	34.5%	37.4%	37.4%
4	14.9%	14.9%	14.9%	3.5%	3.5%	3.5%	14.1%	14.1%	14.1%	43.6%	43.6%	43.6%	11.7%	11.7%
5	13.5%	13.5%	13.5%	2.0%	2.0%	2.0%	12.2%	12.2%	12.2%	43.7%	43.7%	43.7%	9.6%	9.6%
6	12.7%	12.7%	12.7%	1.1%	1.1%	1.1%	11.2%	11.2%	11.2%	43.8%	43.8%	43.8%	8.4%	8.4%
7	132.7%	132.7%	132.7%	125.4%	125.4%	125.4%	4.8%	4.8%	4.8%	80.5%	80.5%	80.5%	13.9%	13.9%
8	129.0%	129.0%	129.0%	121.5%	121.5%	121.5%	4.7%	4.7%	4.7%	76.6%	76.6%	76.6%	13.9%	13.9%
9	129.1%	129.1%	129.1%	123.3%	123.3%	123.3%	4.5%	4.5%	4.5%	77.7%	77.7%	77.7%	13.9%	13.9%
10	76.3%	76.3%	76.3%	70.7%	70.7%	70.7%	42.7%	42.7%	42.7%	36.7%	36.7%	36.7%	39.2%	39.2%
11	76.6%	76.6%	76.6%	70.7%	70.7%	70.7%	41.6%	41.6%	41.6%	36.2%	36.2%	36.2%	38.0%	38.0%
12	76.5%	76.5%	76.5%	72.1%	72.1%	72.1%	41.0%	41.0%	41.0%	36.9%	36.9%	36.9%	37.4%	37.4%
13	76.3%	76.3%	76.3%	70.7%	70.7%	70.7%	14.1%	14.1%	14.1%	43.6%	43.6%	43.6%	11.7%	11.7%
14	76.6%	76.6%	76.6%	70.7%	70.7%	70.7%	12.2%	12.2%	12.2%	43.7%	43.7%	43.7%	9.6%	9.6%
15	76.5%	76.5%	76.5%	72.1%	72.1%	72.1%	11.2%	11.2%	11.2%	43.8%	43.8%	43.8%	8.4%	8.4%
16	318.8%	318.8%	318.8%	305.7%	305.7%	305.7%	88.7%	88.7%	88.7%	224.9%	224.9%	224.9%	104.9%	104.9%
17	312.3%	312.3%	312.3%	298.7%	298.7%	298.7%	88.5%	88.5%	88.5%	217.9%	217.9%	217.9%	105.0%	105.0%
18	327.2%	327.2%	327.2%	302.0%	302.0%	302.0%	88.2%	88.2%	88.2%	219.8%	219.8%	219.8%	105.1%	105.1%
19	781.3%	781.3%	781.3%	753.6%	753.6%	753.6%	297.0%	297.0%	297.0%	583.7%	583.7%	583.7%	331.2%	331.2%
20	782.8%	782.8%	782.8%	753.6%	753.6%	753.6%	303.6%	303.6%	303.6%	580.8%	580.8%	580.8%	338.9%	338.9%
21	782.7%	782.7%	782.7%	760.4%	760.4%	760.4%	302.8%	302.8%	302.8%	584.5%	584.5%	584.5%	339.0%	339.0%
22	781.3%	781.3%	781.3%	753.6%	753.6%	753.6%	297.0%	297.0%	297.0%	583.7%	583.7%	583.7%	331.2%	331.2%
23	782.8%	782.8%	782.8%	753.6%	753.6%	753.6%	303.6%	303.6%	303.6%	580.8%	580.8%	580.8%	338.9%	338.9%
24	782.7%	782.7%	782.7%	760.4%	760.4%	760.4%	302.8%	302.8%	302.8%	584.5%	584.5%	584.5%	339.0%	339.0%
25	1994.2%	1994.2%	1994.2%	1928.3%	1928.3%	1928.3%	843.3%	843.3%	843.3%	1524.5%	1524.5%	1524.5%	924.7%	924.7%
26	1961.3%	1961.3%	1961.3%	1893.3%	1893.3%	1893.3%	842.5%	842.5%	842.5%	1489.7%	1489.7%	1489.7%	924.9%	924.9%
27	1962.0%	1962.0%	1962.0%	1909.9%	1909.9%	1909.9%	840.9%	840.9%	840.9%	1499.0%	1499.0%	1499.0%	925.4%	925.4%
max	**1994.2%**	**1994.2%**	**1994.2%**	**1928.3%**	**1928.3%**	**1928.3%**	**843.3%**	**843.3%**	**843.3%**	**1524.5%**	**1524.5%**	**1524.5%**	**925.4%**	**925.4%**

x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	
39.2%	54.7%	56.0%	56.0%	59.8%	61.8%	61.8%	61.8%	68.3%	68.3%	80.4%	80.4%	80.4%	
38.0%	53.5%	54.7%	54.7%	58.4%	60.4%	60.4%	60.4%	67.0%	67.0%	80.1%	80.1%	80.1%	
37.4%	52.8%	53.9%	53.9%	57.6%	59.6%	59.6%	59.6%	66.2%	66.2%	79.9%	79.9%	79.9%	
11.7%	30.4%	32.6%	32.6%	43.2%	43.3%	43.3%	43.3%	50.3%	50.3%	77.5%	77.5%	77.5%	
9.6%	28.2%	30.1%	30.1%	40.4%	40.7%	40.7%	40.7%	47.6%	47.6%	76.9%	76.9%	76.9%	
8.4%	26.9%	28.7%	28.7%	38.8%	39.2%	39.2%	39.2%	46.1%	46.1%	76.6%	76.6%	76.6%	
13.9%	19.3%	21.8%	21.8%	37.3%	36.2%	36.2%	36.2%	43.0%	43.0%	79.0%	79.0%	79.0%	
13.9%	18.2%	20.4%	20.4%	34.6%	33.9%	33.9%	33.9%	40.6%	40.6%	78.5%	78.5%	78.5%	
13.9%	17.7%	19.6%	19.6%	33.2%	32.7%	32.7%	32.7%	39.3%	39.3%	78.2%	78.2%	78.2%	
39.2%	54.7%	56.0%	56.0%	59.8%	61.8%	61.8%	61.8%	68.3%	68.3%	80.4%	80.4%	80.4%	
38.0%	53.5%	54.7%	54.7%	58.4%	60.4%	60.4%	60.4%	67.0%	67.0%	80.1%	80.1%	80.1%	
37.4%	52.8%	53.9%	53.9%	57.6%	59.6%	59.6%	59.6%	66.2%	66.2%	79.9%	79.9%	79.9%	
11.7%	30.4%	32.6%	32.6%	43.2%	43.3%	43.3%	43.3%	50.3%	50.3%	77.5%	77.5%	77.5%	
9.6%	28.2%	30.1%	30.1%	40.4%	40.7%	40.7%	40.7%	47.6%	47.6%	76.9%	76.9%	76.9%	
8.4%	26.9%	28.7%	28.7%	38.8%	39.2%	39.2%	39.2%	46.1%	46.1%	76.6%	76.6%	76.6%	
104.9%	20.1%	21.8%	21.8%	37.3%	36.2%	36.2%	36.2%	43.0%	43.0%	79.0%	79.0%	79.0%	
105.0%	22.0%	20.4%	20.4%	34.6%	33.9%	33.9%	33.9%	40.6%	40.6%	78.5%	78.5%	78.5%	
105.1%	21.7%	19.6%	19.6%	33.2%	32.7%	32.7%	32.7%	39.3%	39.3%	78.2%	78.2%	78.2%	
331.2%	152.8%	137.0%	137.0%	59.8%	61.8%	61.8%	61.8%	68.3%	68.3%	80.4%	80.4%	80.4%	
338.9%	161.3%	147.3%	147.3%	68.5%	60.4%	60.4%	60.4%	67.0%	67.0%	80.1%	80.1%	80.1%	
339.0%	160.4%	147.3%	147.3%	68.3%	59.6%	59.6%	59.6%	66.2%	66.2%	79.9%	79.9%	79.9%	
331.2%	152.8%	137.0%	137.0%	57.6%	47.2%	47.2%	47.2%	50.3%	50.3%	77.5%	77.5%	77.5%	
338.9%	161.3%	147.3%	147.3%	68.5%	57.8%	57.8%	57.8%	47.6%	47.6%	76.9%	76.9%	76.9%	
339.0%	160.4%	147.3%	147.3%	68.3%	57.4%	57.4%	57.4%	46.1%	46.1%	76.6%	76.6%	76.6%	
924.7%	500.7%	463.3%	463.3%	274.6%	249.8%	249.8%	249.8%	210.6%	210.6%	79.0%	79.0%	79.0%	
924.9%	510.1%	477.4%	477.4%	293.4%	268.5%	268.5%	268.5%	230.0%	230.0%	78.5%	78.5%	78.5%	
925.4%	508.3%	477.7%	477.7%	293.1%	267.6%	267.6%	267.6%	228.8%	228.8%	78.2%	78.2%	78.2%	Minimax
925.4%	510.1%	477.7%	477.7%	293.4%	268.5%	268.5%	268.5%	230.0%	230.0%	80.4%	80.4%	80.4%	80.4%

6.5.3 Emissions Quantity Model Absolute Robust Decision Criterion

As is shown in Table 6.18, the Optimal Solution Suite which minimises the maximum percentage deviation from the goals is the optimal solution for Scenarios 25 to 27 or Optimal Investment Suite 11. This produces a maximum percentage deviation of 80.4% from the goal targets whereas other optimal solutions, such as the optimal solution from Scenario 1, produce deviations up to 1,994% from the goals. Therefore the Absolute Robust Decision Solution is Optimal Investment Suite 11, which is the optimal solution for Scenarios 25 to 27. This solution involves the selection of Projects 1, 4 and 10 for a capital expenditure of $2,551 million with a net value of $1,898 million, $2,810 million or $3,723 million depending on the cash flow and corresponding emissions of 1,3546,517, 188,580,810 or 237,306,435 tonnes of CO_2e.

The Absolute Robust Solution is characteristically a very conservative solution and this solution is very conservative with respect to emissions and capital expenditure. The slack in the budget amounted to $$6,449 million or approximately 72%. The emissions are also dramatically reduced when compared to the other solutions to the order of 93%.

6.5.4 Emissions Quantity Model Robust Deviation Decision Criterion

To calculate the Robust Deviation solution an opportunity loss table must be constructed from the performance of each optimal solution in all 27 scenarios. As with the Absolute Robust solution, the figure used for this calculation is the percentage deviation from the goal. The opportunity loss table measures the level of regret. In this case regret is measured by the percentage deviation from the goal. Therefore, the Robust Deviation solution minimises the maximum percentage deviation from the goal for all scenarios. The Opportunity Loss/Regret Matrix is shown in Table 6.19. As can be seen from Table 6.19, the Optimal Solution that minimises the maximum percentage deviation also corresponds to the optimal solution in Scenarios 25 to 27 or Optimal Investment Suite 11. This solution involves the selection of Projects 1, 4 and 10 for a capital expenditure of $2,551 million and net revenue of $1,898 million, $2,810 million or $3,723 million depending on the cash flow and corresponding emissions of 5,344,238, 7,917,427 or 9,400,948 tonnes of CO_2e.

Usually the Robust Deviation and Absolute Deviation solutions differ due to the different emphasis in their calculation. However, in the Emissions Quantity Model the solutions are the same. Consequently analysis of the influence of each of the variables in selecting projects for the optimal solutions is examined below.

Table 6.19 Emissions Quantity Opportunity Loss/Regret Table

	Optimal value – policy solution for a given scenario													
Scenario	x1	x2	x3	x4	x5	x6	x7	x8	x9	x10	x11	x12	x13	x14
1	0.0%	0.0%	0.0%	11.3%	11.3%	11.3%	39.0%	39.0%	39.0%	30.5%	30.5%	30.5%	35.5%	35.5%
2	0.0%	0.0%	0.0%	11.1%	11.1%	11.1%	38.3%	38.3%	38.3%	31.1%	31.1%	31.1%	34.8%	34.8%
3	0.0%	0.0%	0.0%	10.9%	10.9%	10.9%	38.0%	38.0%	38.0%	31.5%	31.5%	31.5%	34.4%	34.4%
4	11.4%	11.4%	11.4%	0.0%	0.0%	0.0%	10.6%	10.6%	10.6%	40.1%	40.1%	40.1%	8.2%	8.2%
5	11.6%	11.6%	11.6%	0.0%	0.0%	0.0%	10.3%	10.3%	10.3%	41.8%	41.8%	41.8%	7.6%	7.6%
6	11.6%	11.6%	11.6%	0.0%	0.0%	0.0%	10.1%	10.1%	10.1%	42.7%	42.7%	42.7%	7.3%	7.3%
7	127.9%	127.9%	127.9%	120.5%	120.5%	120.5%	0.0%	0.0%	0.0%	75.7%	75.7%	75.7%	9.0%	9.0%
8	124.3%	124.3%	124.3%	116.8%	116.8%	116.8%	0.0%	0.0%	0.0%	71.9%	71.9%	71.9%	9.2%	9.2%
9	124.6%	124.6%	124.6%	118.8%	118.8%	118.8%	0.0%	0.0%	0.0%	73.1%	73.1%	73.1%	9.4%	9.4%
10	39.5%	39.5%	39.5%	34.0%	34.0%	34.0%	5.9%	5.9%	5.9%	0.0%	0.0%	0.0%	2.5%	2.5%
11	40.4%	40.4%	40.4%	34.6%	34.6%	34.6%	5.4%	5.4%	5.4%	0.0%	0.0%	0.0%	1.9%	1.9%
12	39.6%	39.6%	39.6%	35.2%	35.2%	35.2%	4.1%	4.1%	4.1%	0.0%	0.0%	0.0%	0.5%	0.5%
13	64.6%	64.6%	64.6%	59.0%	59.0%	59.0%	2.4%	2.4%	2.4%	31.9%	31.9%	31.9%	0.0%	0.0%
14	67.0%	67.0%	67.0%	61.2%	61.2%	61.2%	2.7%	2.7%	2.7%	34.2%	34.2%	34.2%	0.0%	0.0%
15	68.2%	68.2%	68.2%	63.7%	63.7%	63.7%	2.8%	2.8%	2.8%	35.4%	35.4%	35.4%	0.0%	0.0%
16	298.7%	298.7%	298.7%	285.5%	285.5%	285.5%	68.5%	68.5%	68.5%	204.8%	204.8%	204.8%	84.8%	84.8%
17	291.9%	291.9%	291.9%	278.3%	278.3%	278.3%	68.1%	68.1%	68.1%	197.6%	197.6%	197.6%	84.6%	84.6%
18	307.6%	307.6%	307.6%	282.4%	282.4%	282.4%	68.6%	68.6%	68.6%	200.2%	200.2%	200.2%	85.5%	85.5%
19	721.6%	721.6%	721.6%	693.8%	693.8%	693.8%	237.2%	237.2%	237.2%	523.9%	523.9%	523.9%	271.5%	271.5%
20	722.3%	722.3%	722.3%	693.2%	693.2%	693.2%	243.2%	243.2%	243.2%	520.4%	520.4%	520.4%	278.5%	278.5%
21	723.0%	723.0%	723.0%	700.8%	700.8%	700.8%	243.2%	243.2%	243.2%	524.9%	524.9%	524.9%	279.3%	279.3%
22	734.1%	734.1%	734.1%	706.3%	706.3%	706.3%	249.8%	249.8%	249.8%	536.4%	536.4%	536.4%	284.0%	284.0%
23	735.1%	735.1%	735.1%	706.0%	706.0%	706.0%	256.0%	256.0%	256.0%	533.2%	533.2%	533.2%	291.3%	291.3%
24	736.6%	736.6%	736.6%	714.3%	714.3%	714.3%	256.7%	256.7%	256.7%	538.4%	538.4%	538.4%	292.9%	292.9%
25	1915.3%	1915.3%	1915.3%	1849.3%	1849.3%	1849.3%	764.4%	764.4%	764.4%	1445.6%	1445.6%	1445.6%	845.8%	845.8%
26	1882.8%	1882.8%	1882.8%	1814.8%	1814.8%	1814.8%	764.0%	764.0%	764.0%	1411.2%	1411.2%	1411.2%	846.4%	846.4%
27	1883.7%	1883.7%	1883.7%	1831.7%	1831.7%	1831.7%	762.7%	762.7%	762.7%	1420.8%	1420.8%	1420.8%	847.2%	847.2%
Max	1915.3%	1915.3%	1915.3%	1849.3%	1849.3%	1849.3%	764.4%	764.4%	764.4%	1445.6%	1445.6%	1445.6%	847.2%	847.2%

x15	x16	x17	x18	x19	x20	x21	x22	x23	x24	x25	x26	x27	
35.5%	51.0%	52.3%	52.3%	56.0%	58.1%	58.1%	58.1%	64.6%	64.6%	76.7%	76.7%	76.7%	35.5%
34.8%	50.3%	51.4%	51.4%	55.1%	57.2%	57.2%	57.2%	63.7%	63.7%	76.9%	76.9%	76.9%	34.8%
34.4%	49.8%	50.9%	50.9%	54.6%	56.6%	56.6%	56.6%	63.2%	63.2%	76.9%	76.9%	76.9%	34.4%
8.2%	26.9%	29.1%	29.1%	39.7%	39.8%	39.8%	39.8%	46.8%	46.8%	74.0%	74.0%	74.0%	8.2%
7.6%	26.2%	28.2%	28.2%	38.4%	38.7%	38.7%	38.7%	45.7%	45.7%	75.0%	75.0%	75.0%	7.6%
7.3%	25.8%	27.6%	27.6%	37.7%	38.1%	38.1%	38.1%	45.0%	45.0%	75.5%	75.5%	75.5%	7.3%
9.0%	14.5%	17.0%	17.0%	32.5%	31.4%	31.4%	31.4%	38.2%	38.2%	74.1%	74.1%	74.1%	9.0%
9.2%	13.5%	15.6%	15.6%	29.9%	29.2%	29.2%	29.2%	35.8%	35.8%	73.8%	73.8%	73.8%	9.2%
9.4%	13.1%	15.0%	15.0%	28.7%	28.2%	28.2%	28.2%	34.7%	34.7%	73.7%	73.7%	73.7%	9.4%
2.5%	18.0%	19.3%	19.3%	23.0%	25.0%	25.0%	25.0%	31.6%	31.6%	43.7%	43.7%	43.7%	2.5%
1.9%	17.4%	18.5%	18.5%	22.2%	24.3%	24.3%	24.3%	30.8%	30.8%	44.0%	44.0%	44.0%	1.9%
0.5%	15.9%	17.0%	17.0%	20.7%	22.7%	22.7%	22.7%	29.3%	29.3%	43.0%	43.0%	43.0%	0.5%
0.0%	18.8%	20.9%	20.9%	31.5%	31.7%	31.7%	31.7%	38.6%	38.6%	65.8%	65.8%	65.8%	0.0%
0.0%	18.6%	20.6%	20.6%	30.8%	31.1%	31.1%	31.1%	38.1%	38.1%	67.4%	67.4%	67.4%	0.0%
0.0%	18.6%	20.4%	20.4%	30.4%	30.8%	30.8%	30.8%	37.7%	37.7%	68.2%	68.2%	68.2%	0.0%
84.8%	0.0%	1.7%	1.7%	17.2%	16.1%	16.1%	16.1%	22.9%	22.9%	58.8%	58.8%	58.8%	84.8%
84.6%	1.6%	0.0%	0.0%	14.3%	13.6%	13.6%	13.6%	20.2%	20.2%	58.1%	58.1%	58.1%	84.6%
85.5%	2.1%	0.0%	0.0%	13.6%	13.1%	13.1%	13.1%	19.7%	19.7%	58.6%	58.6%	58.6%	85.5%
271.5%	93.0%	77.3%	77.3%	0.0%	2.0%	2.0%	2.0%	8.5%	8.5%	20.7%	20.7%	20.7%	271.5%
278.5%	100.8%	86.9%	86.9%	8.1%	0.0%	0.0%	0.0%	6.5%	6.5%	19.7%	19.7%	19.7%	278.5%
279.3%	100.7%	87.7%	87.7%	8.6%	0.0%	0.0%	0.0%	6.6%	6.6%	20.3%	20.3%	20.3%	279.3%
284.0%	105.6%	89.8%	89.8%	10.4%	0.0%	0.0%	0.0%	3.1%	3.1%	30.3%	30.3%	30.3%	284.0%
291.3%	113.6%	99.6%	99.6%	20.9%	10.2%	10.2%	10.2%	0.0%	0.0%	29.3%	29.3%	29.3%	291.3%
292.9%	114.3%	101.2%	101.2%	22.1%	11.2%	11.2%	11.2%	0.0%	0.0%	30.5%	30.5%	30.5%	292.9%
845.8%	421.7%	384.3%	384.3%	195.6%	170.8%	170.8%	170.8%	131.7%	131.7%	0.0%	0.0%	0.0%	845.8%
846.4%	431.6%	398.9%	398.9%	214.9%	190.0%	190.0%	190.0%	151.5%	151.5%	0.0%	0.0%	0.0%	846.4%
847.2%	430.0%	399.5%	399.5%	214.8%	189.4%	189.4%	189.4%	150.5%	150.5%	0.0%	0.0%	0.0%	847.2%
847.2%	431.6%	399.5%	399.5%	214.9%	190.0%	190.0%	190.0%	151.5%	151.5%	76.9%	76.9%	76.9%	847.2%

6.5.5 Influence of Variables on Project Selection

The projects selected in each scenario and how they relate to the variables is shown in Table 6.20. As mentioned above, for the 27 scenarios there are 11 different optimal solutions and the influence of each variable on the optimal solution is examined below.

Table 6.20 Optimal Solutions, Variables and Project Selection

				Projects select 1/0										
Scen.	**Emis. redn**	**Disc. rate**	**Cash flow**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
1	L	L	L	1	1	1	0	0	1	1	0	0	1	0
2	L	L	M	1	1	1	0	0	1	1	0	0	1	0
3	L	L	H	1	1	1	0	0	1	1	0	0	1	0
4	L	M	L	0	0	1	0	0	0	1	0	1	0	0
5	L	M	M	0	0	1	0	0	0	1	0	1	0	0
6	L	M	H	0	0	1	0	0	0	1	0	1	0	0
7	L	H	L	1	1	1	1	0	0	0	0	1	1	1
8	L	H	M	1	1	1	1	0	0	0	0	1	1	1
9	L	H	H	1	1	1	1	0	0	0	0	1	1	1
10	M	L	L	0	0	0	0	0	0	1	1	0	0	0
11	M	L	M	0	0	0	0	0	0	1	1	0	0	0
12	M	L	H	0	0	0	0	0	0	1	1	0	0	0
13	M	M	L	1	1	1	1	1	0	0	1	1	1	1
14	M	M	M	1	1	1	1	1	0	0	1	1	1	1
15	M	M	H	1	1	1	1	1	0	0	1	1	1	1
16	M	H	L	1	0	1	1	0	0	0	0	1	1	0
17	M	H	M	1	1	0	1	1	0	0	0	1	1	0
18	M	H	H	1	1	0	1	1	0	0	0	1	1	0
19	H	L	L	1	0	0	0	0	0	0	1	1	1	0
20	H	L	M	1	0	0	0	0	0	0	0	1	1	0
21	H	L	H	1	0	0	0	0	0	0	0	1	1	0
22	H	M	L	1	0	0	0	0	0	0	0	1	1	0
23	H	M	M	1	0	0	0	0	0	0	0	1	0	0
24	H	M	H	1	0	0	0	0	0	0	0	1	0	0
25	H	H	L	1	0	0	1	0	0	0	0	0	1	0
26	H	H	M	1	0	0	1	0	0	0	0	0	1	0
27	H	H	H	1	0	0	1	0	0	0	0	0	1	0

Optimal Investment Suite 1
Optimal Investment Suite 2
Optimal Investment Suite 3
Optimal Investment Suite 4
Optimal Investment Suite 5
Optimal Investment Suite 6
Optimal Investment Suite 7

Optimal Investment Suite 8
Optimal Investment Suite 9
Optimal Investment Suite 10
Optimal Investment Suite 11

6.5.6 Emissions Quantity Model Solutions: GHG Emissions and NPV

As with the Emissions Cost Models, the purpose of the Emissions Quantity Models is to evaluate the business case of voluntary emissions reductions and explore a suitable method for implementing such a policy. The Emissions Quantity Models are more explicit than the Emissions Cost Models in terms of emissions reductions as an objective of the model, as opposed to the emissions costs model which explore emissions reductions through pricing of emissions. As with the Emissions Cost Model, the emissions generated by the investments are a direct function of the revenue or cash flow and consequently the figures vary depending on the undiscounted cash flows and not the discount rate or emissions cost.

The emissions intensity for each project is shown in Table 6.1, while the total emissions from the 11 different Optimal Investment Suites are shown in Table 6.21 and Figures 6.11 to 6.21 below.

Table 6.21 Optimal Solutions Emissions

Optimal project selections																
				Projects select 1/0												
Scen.	**Emis. cost**	**Disc. rate**	**Cash flow**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total emissions**	**NPV**
1	L	L	L	1	1	1	0	0	1	1	0	0	1	0	283,761,507	77,007
2	L	L	M	1	1	1	0	0	1	1	0	0	1	0	388,717,241	105,668
3	L	L	H	1	1	1	0	0	1	1	0	0	1	0	489,314,308	134,328
4	L	M	L	0	0	1	0	0	0	1	0	1	0	0	274,822,203	20,129
5	L	M	M	0	0	1	0	0	0	1	0	1	0	0	375,896,144	28,362
6	L	M	H	0	0	1	0	0	0	1	0	1	0	0	476,970,085	36,594
7	L	H	L	1	1	1	1	0	0	0	0	1	1	1	127,816,134	8,785
8	L	H	M	1	1	1	1	0	0	0	0	1	1	1	177,734,048	12,723
9	L	H	H	1	1	1	1	0	0	0	0	1	1	1	223,293,294	16,661
10	M	L	L	0	0	0	0	0	0	1	1	0	0	0	218,163,491	52,622
11	M	L	M	0	0	0	0	0	0	1	1	0	0	0	297,216,332	71,695
12	M	L	H	0	0	0	0	0	0	1	1	0	0	0	376,269,174	90,768
13	M	M	L	1	1	1	1	1	0	0	1	1	1	1	138,849,264	18,420
14	M	M	M	1	1	1	1	1	0	0	1	1	1	1	193,276,657	26,161
15	M	M	H	1	1	1	1	1	0	0	1	1	1	1	243,345,382	33,902
16	M	H	L	1	0	1	1	0	0	0	0	1	1	0	81,388,412	7,280

17	M	H	M	1	1	0	1	1	0	0	0	1	1	0	108,886,024	10,403
18	M	H	H	1	1	0	1	1	0	0	0	1	1	0	137,094,591	13,754
19	H	L	L	1	0	0	0	0	0	0	1	1	1	0	50,751,017	32,185
20	H	L	M	1	0	0	0	0	0	0	0	1	1	0	69,496,747	43,235
21	H	L	H	1	0	0	0	0	0	0	0	1	1	0	87,236,557	55,887
22	H	M	L	1	0	0	0	0	0	0	0	1	1	0	47,398,270	11,817
23	H	M	M	1	0	0	0	0	0	0	0	1	0	0	62,232,847	15,150
24	H	M	H	1	0	0	0	0	0	0	0	1	0	0	78,015,534	19,935
25	H	H	L	1	0	0	1	0	0	0	0	0	1	0	21,376,953	1,898
26	H	H	M	1	0	0	1	0	0	0	0	0	1	0	31,669,707	2,810
27	H	H	H	1	0	0	1	0	0	0	0	0	1	0	37,603,794	3,723
Max.															**489,314,308**	**134328**
Min.															**21,376,953**	**1,898**

As Table 6.21 shows, the Absolute Robust and Robust Deviation Solutions, Optimal Investment Suite 11, Scenarios 25 to 27, have a range in emissions from a low of 21,376,953 to 37,603,794 tonnes CO_2e depending on the cash flow. The highest emissions occur with Optimal Investment Suite 1 which range from 283,761,507 to 489,314,308 tonnes of CO_2e. This represents a factor of nearly 13 times larger than the emissions from Optimal Investment Suite 11. These results are shown Figure 6.10.

Figure 6.10 Scenarios, Optimal Solution NPV and Emissions

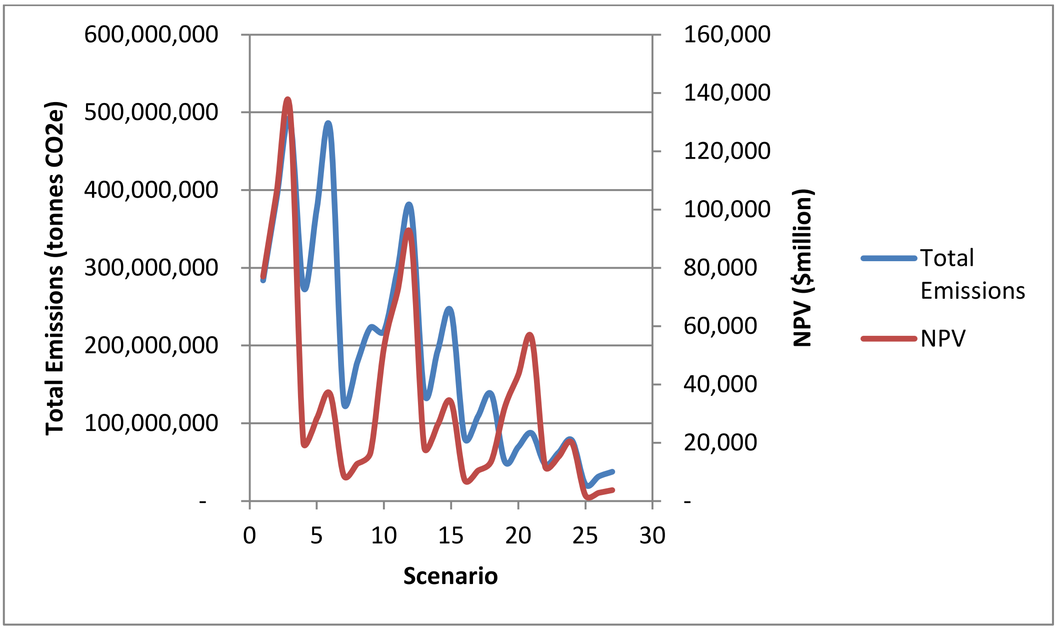


Table 6.22 Emissions Quantity Model Optimal Solutions all Suites in all Scenarios

	Optimal Invest Suite 1		Optimal Invest Suite 2		Optimal Invest Suite 3		Optimal Invest Suite 4		Optimal Invest Suite 5		Optimal Invest Suite 6	
Scen.	**Total emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total emissions (tonnes CO_2e)**	**NPV ($ million)**
1	283,761,507	77,007	274,822,203	67,951	127,816,134	45,841	218,163,491	52,622	138,849,264	48,608	81,388,412	36,198
2	388,717,241	105,668	375,896,144	93,595	177,734,048	63,791	297,216,332	71,695	193,276,657	67,680	115,045,365	50,761
3	489,314,308	134,328	476,970,085	119,239	223,293,294	81,741	376,269,174	90,768	243,345,382	86,753	144,343,651	65,324
4	283,761,507	17,748	274,822,203	20,129	127,816,134	17,915	218,163,491	11,765	138,849,264	18,420	81,388,412	14,509
5	388,717,241	25,020	375,896,144	28,362	177,734,048	25,386	297,216,332	16,276	193,276,657	26,161	115,045,365	20,772
6	489,314,308	32,292	476,970,085	36,594	223,293,294	32,858	376,269,174	20,787	243,345,382	33,902	144,343,651	27,036
7	283,761,507	5,782	274,822,203	8,849	127,816,134	8,785	218,163,491	4,082	138,849,264	8,921	81,388,412	7,280
8	388,717,241	8,583	375,896,144	12,765	177,734,048	12,723	297,216,332	5,763	193,276,657	12,969	115,045,365	10,680
9	489,314,308	11,385	476,970,085	16,681	223,293,294	16,661	376,269,174	7,443	243,345,382	17,017	144,343,651	14,080
10	283,761,507	77,007	274,822,203	67,951	127,816,134	45,841	218,163,491	52,622	138,849,264	48,608	81,388,412	36,198
11	388,717,241	105,668	375,896,144	93,595	177,734,048	63,791	297,216,332	71,695	193,276,657	67,680	115,045,365	50,761
12	489,314,308	134,328	476,970,085	119,239	223,293,294	81,741	376,269,174	90,768	243,345,382	86,753	144,343,651	65,324
13	283,761,507	17,748	274,822,203	20,129	127,816,134	17,915	218,163,491	11,765	138,849,264	18,420	81,388,412	14,509
14	388,717,241	25,020	375,896,144	28,362	177,734,048	25,386	297,216,332	16,276	193,276,657	26,161	115,045,365	20,772
15	489,314,308	32,292	476,970,085	36,594	223,293,294	32,858	376,269,174	20,787	243,345,382	33,902	144,343,651	27,036
16	283,761,507	5,782	274,822,203	8,849	127,816,134	8,785	218,163,491	4,082	138,849,264	8,921	81,388,412	7,280
17	388,717,241	8,583	375,896,144	12,765	177,734,048	12,723	297,216,332	5,763	193,276,657	12,969	115,045,365	10,680
18	489,314,308	12,984	476,970,085	16,681	223,293,294	16,661	376,269,174	7,443	243,345,382	17,017	144,343,651	14,080
19	283,761,507	77,007	274,822,203	67,951	127,816,134	45,841	218,163,491	52,622	138,849,264	48,608	81,388,412	36,198
20	388,717,241	105,668	375,896,144	93,595	177,734,048	63,791	297,216,332	71,695	193,276,657	67,680	115,045,365	50,761
21	489,314,308	134,328	476,970,085	119,239	223,293,294	81,741	376,269,174	90,768	243,345,382	86,753	144,343,651	65,324
22	283,761,507	17,748	274,822,203	20,129	127,816,134	17,915	218,163,491	11,765	138,849,264	18,420	81,388,412	14,509
23	388,717,241	25,020	375,896,144	28,362	177,734,048	25,386	297,216,332	16,276	193,276,657	26,161	115,045,365	20,772
24	489,314,308	32,292	476,970,085	36,594	223,293,294	32,858	376,269,174	20,787	243,345,382	33,902	144,343,651	27,036
25	283,761,507	5,782	274,822,203	8,849	127,816,134	8,785	218,163,491	4,082	138,849,264	8,921	81,388,412	7,280
26	388,717,241	8,583	375,896,144	12,765	177,734,048	12,723	297,216,332	5,763	193,276,657	12,969	115,045,365	10,680
27	489,314,308	11,385	476,970,085	16,681	223,293,294	16,661	376,269,174	7,443	243,345,382	17,017	144,343,651	14,080

	Optimal Invest Suite 7		Optimal Invest Suite 8		Optimal Invest Suite 9		Optimal Invest Suite 10		Optimal Invest Suite 11	
Scen.	**Total Emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total Emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total Emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total Emissions (tonnes CO_2e)**	**NPV ($ million)**	**Total Emissions (tonnes CO_2e)**	**NPV ($ million)**
1	76,318,791	35,171	50,751,017	32,185	47,398,270	30,582	42,091,493	25,359	21,376,953	15,646
2	108,886,024	49,481	74,192,594	45,479	69,496,747	43,235	62,232,847	36,085	31,669,707	21,712
3	137,094,591	63,791	93,275,504	58,773	87,236,557	55,887	78,015,534	46,811	37,603,794	27,778
4	76,318,791	14,053	50,751,017	11,842	47,398,270	11,817	42,091,493	10,364	21,376,953	4,692
5	108,886,024	20,211	74,192,594	17,251	69,496,747	17,162	62,232,847	15,150	31,669,707	6,674
6	137,094,591	26,368	93,275,504	22,661	87,236,557	22,508	78,015,534	19,935	37,603,794	8,656
7	76,318,791	7,051	50,751,017	5,655	47,398,270	5,753	42,091,493	5,138	21,376,953	1,898
8	108,886,024	10,403	74,192,594	8,537	69,496,747	8,631	62,232,847	7,764	31,669,707	2,810
9	137,094,591	13,754	93,275,504	11,420	87,236,557	11,509	78,015,534	10,390	37,603,794	3,723
10	76,318,791	35,171	50,751,017	32,185	47,398,270	30,582	42,091,493	25,359	21,376,953	15,646
11	108,886,024	49,481	74,192,594	45,479	69,496,747	43,235	62,232,847	36,085	31,669,707	21,712
12	137,094,591	63,791	93,275,504	58,773	87,236,557	55,887	78,015,534	46,811	37,603,794	27,778
13	76,318,791	14,053	50,751,017	11,842	47,398,270	11,817	42,091,493	10,364	21,376,953	4,692
14	108,886,024	20,211	74,192,594	17,251	69,496,747	17,162	62,232,847	15,150	31,669,707	6,674
15	137,094,591	26,368	93,275,504	22,661	87,236,557	22,508	78,015,534	19,935	37,603,794	8,656
16	76,318,791	7,051	50,751,017	5,655	47,398,270	5,753	42,091,493	5,138	21,376,953	1,898
17	108,886,024	10,403	74,192,594	8,537	69,496,747	8,631	62,232,847	7,764	31,669,707	2,810
18	137,094,591	13,754	93,275,504	11,420	87,236,557	11,509	78,015,534	10,390	37,603,794	3,723
19	76,318,791	35,171	50,751,017	32,185	47,398,270	30,582	42,091,493	25,359	21,376,953	15,646
20	108,886,024	49,481	74,192,594	45,479	69,496,747	43,235	62,232,847	36,085	31,669,707	21,712
21	137,094,591	63,791	93,275,504	58,773	87,236,557	55,887	78,015,534	46,811	37,603,794	27,778
22	76,318,791	14,053	50,751,017	11,842	47,398,270	11,817	42,091,493	10,364	21,376,953	4,692
23	108,886,024	20,211	74,192,594	17,251	69,496,747	17,162	62,232,847	15,150	31,669,707	6,674
24	137,094,591	26,368	93,275,504	22,661	87,236,557	22,508	78,015,534	19,935	37,603,794	8,656
25	76,318,791	7,051	50,751,017	5,655	47,398,270	5,753	42,091,493	5,138	21,376,953	1,898
26	108,886,024	10,403	74,192,594	8,537	69,496,747	8,631	62,232,847	7,764	31,669,707	2,810
27	137,094,591	13,754	93,275,504	11,420	87,236,557	11,509	78,015,534	10,390	37,603,794	3,723

Figure 6.11 Optimal Solutions Suite 1 (Scenarios 1 to 3), Performance in all Scenarios

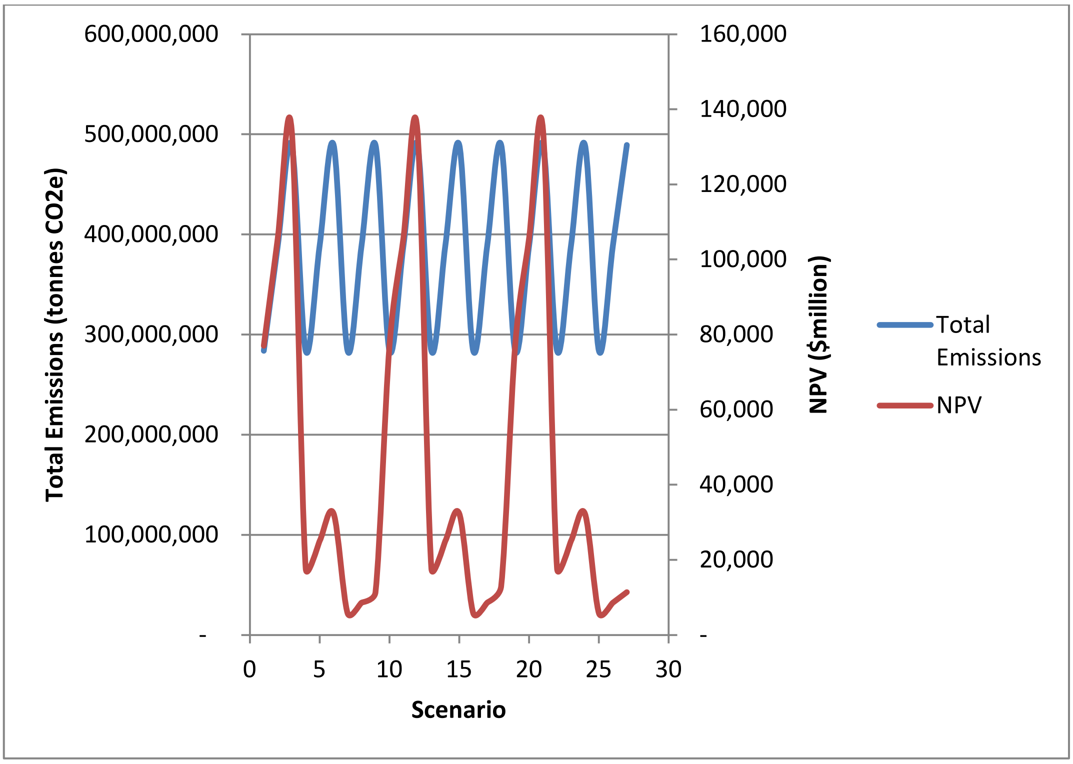


Figure 6.12 Optimal Solutions Suite 2 (Scenarios 4 to 6), Performance in all Scenarios

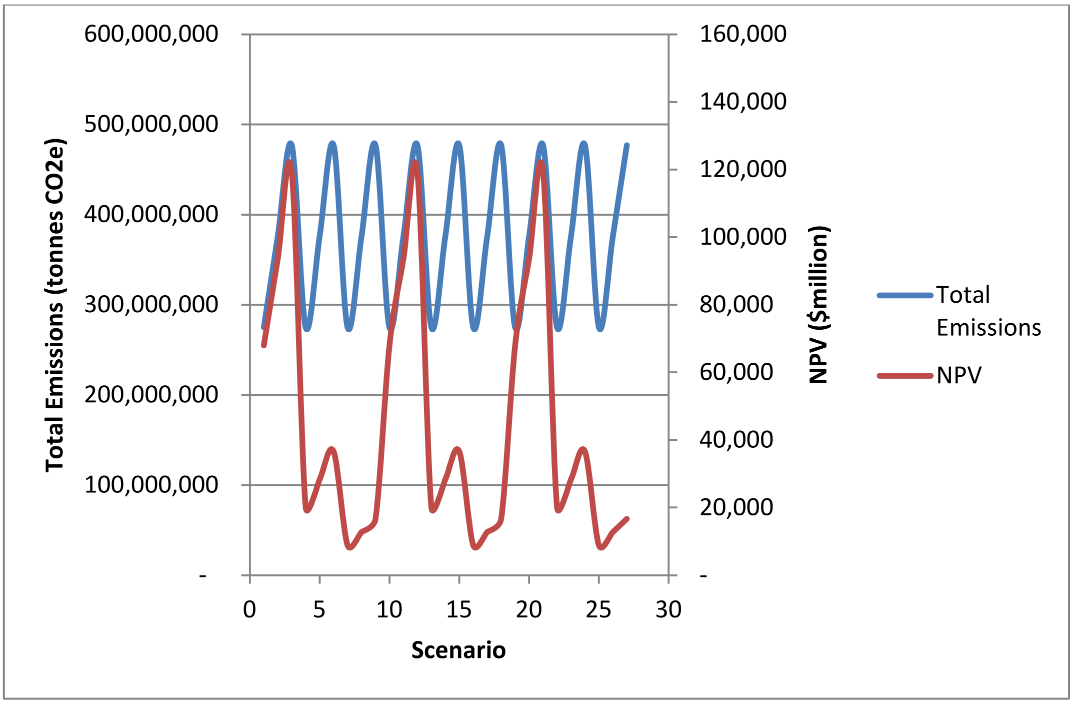


Figure 6.13 Optimal Solutions Suite 3 (Scenarios 7 to 9), Performance in all Scenarios

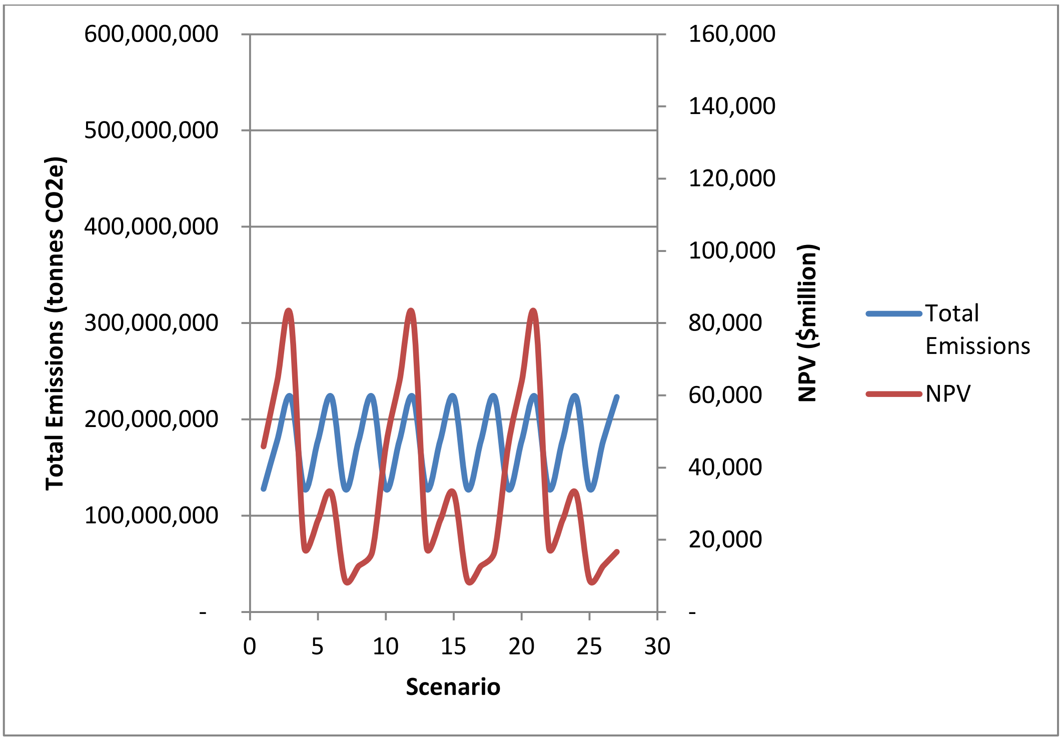


Figure 6.14 Optimal Solutions Suite 4 (Scenarios 10 to 12), Performance in all Scenarios

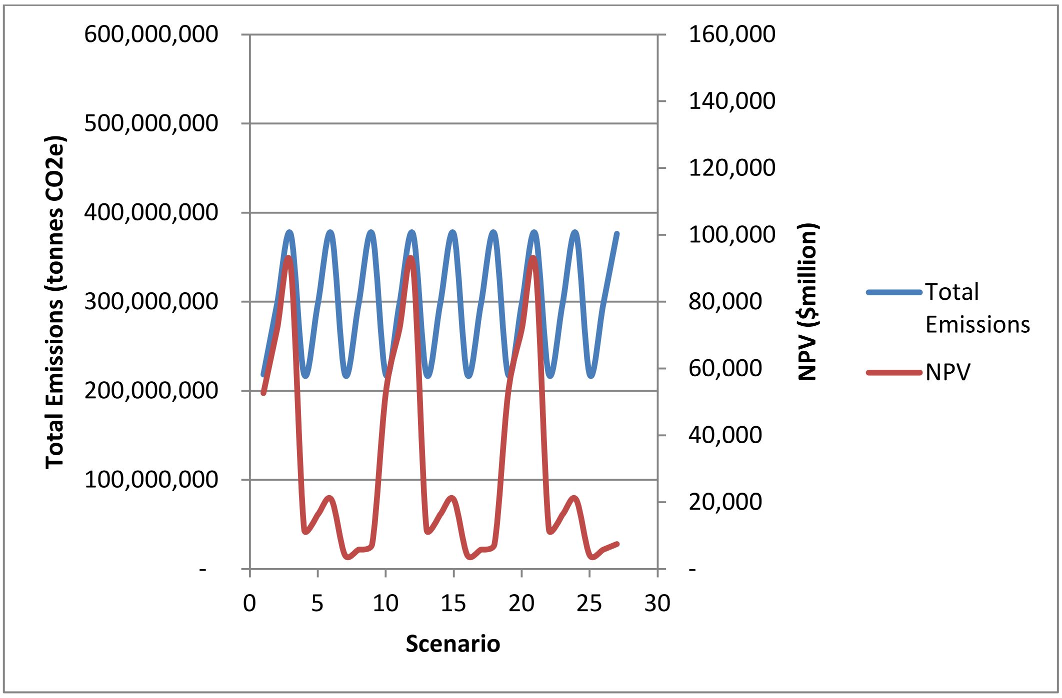


Figure 6.15 Optimal Solutions Suite 5 (Scenarios 13 to 15), Performance in all Scenarios

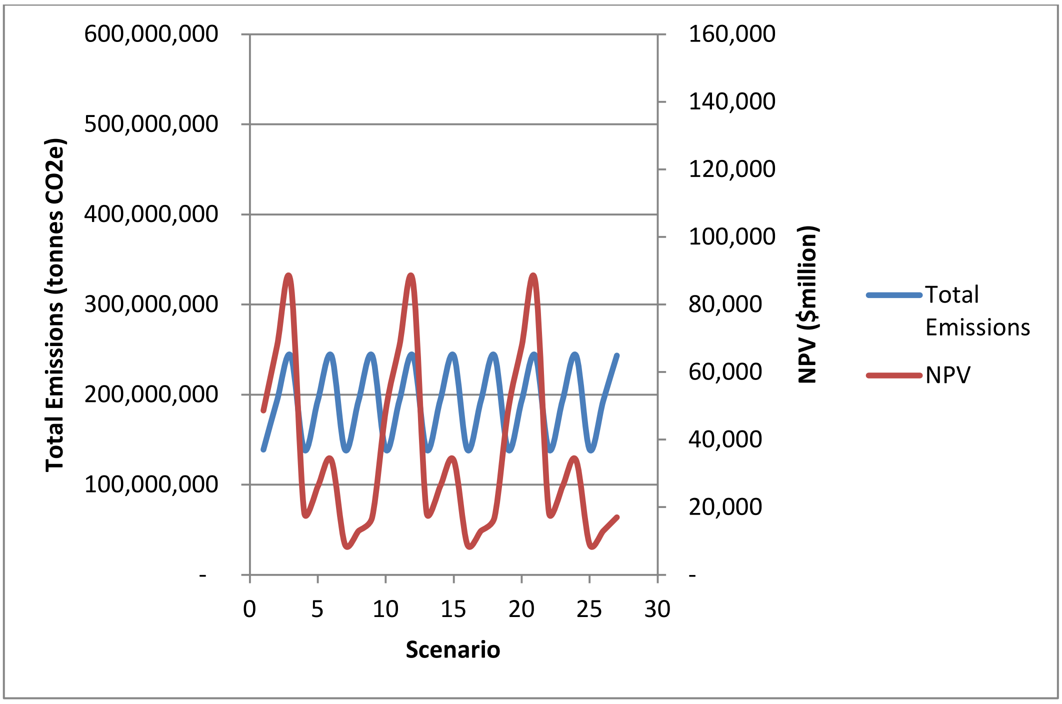


Figure 6.16 Optimal Solutions Suite 6 (Scenario 16), Performance in all Scenarios

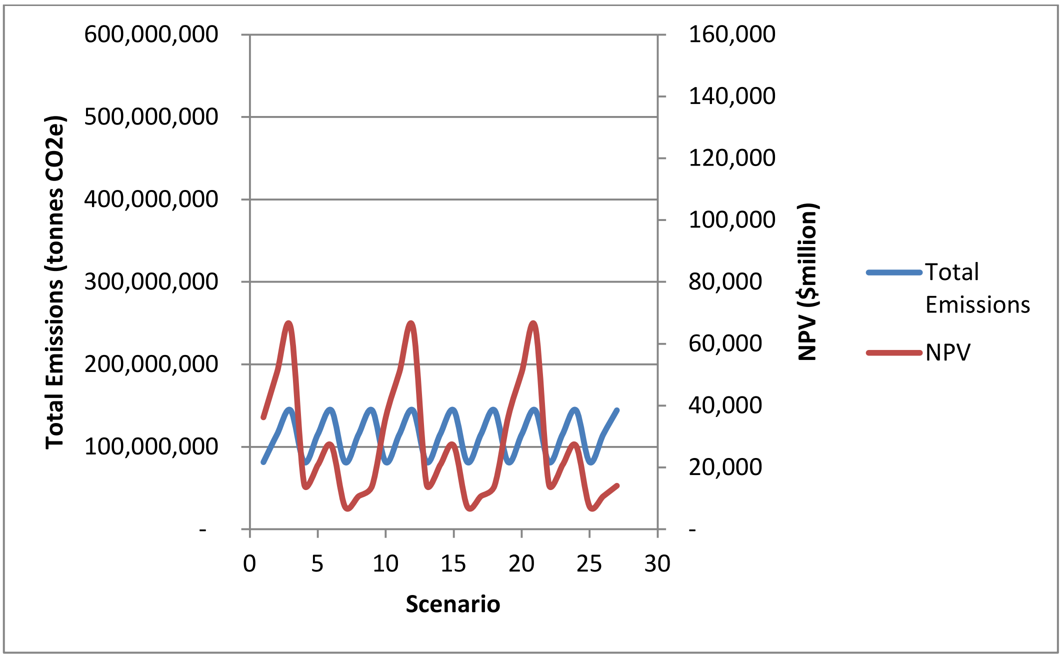


Figure 6.17 Optimal Solutions Suite 7 (Scenarios 17 to 18), Performance in all Scenarios

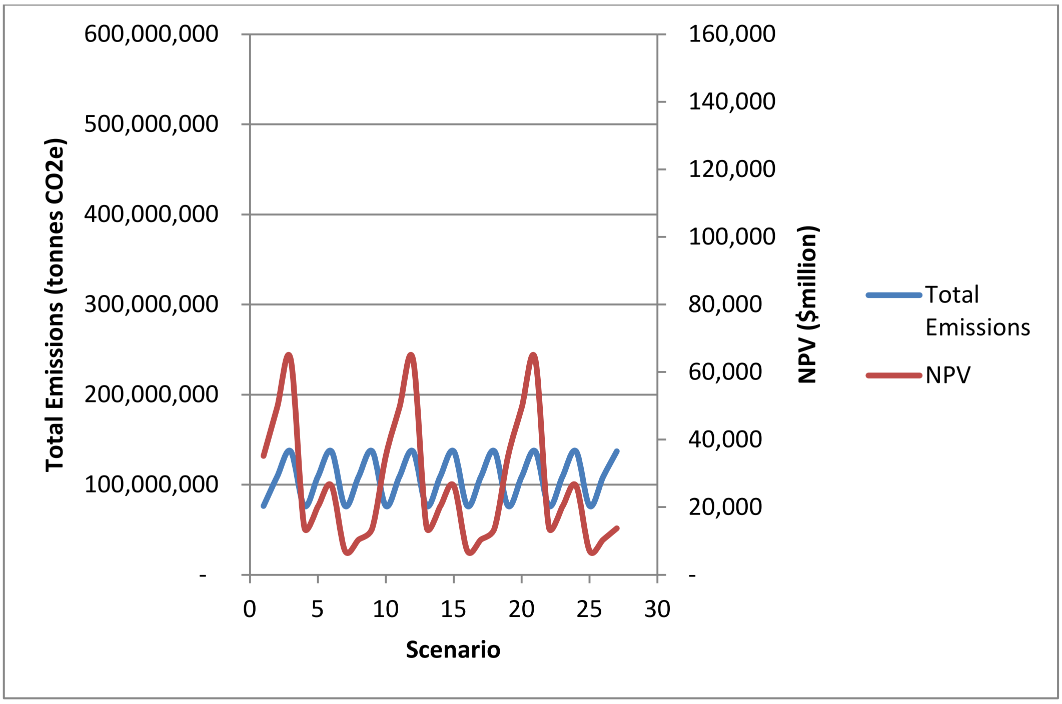


Figure 6.18 Optimal Solutions Suite 8 (Scenario 19), Performance in all Scenarios

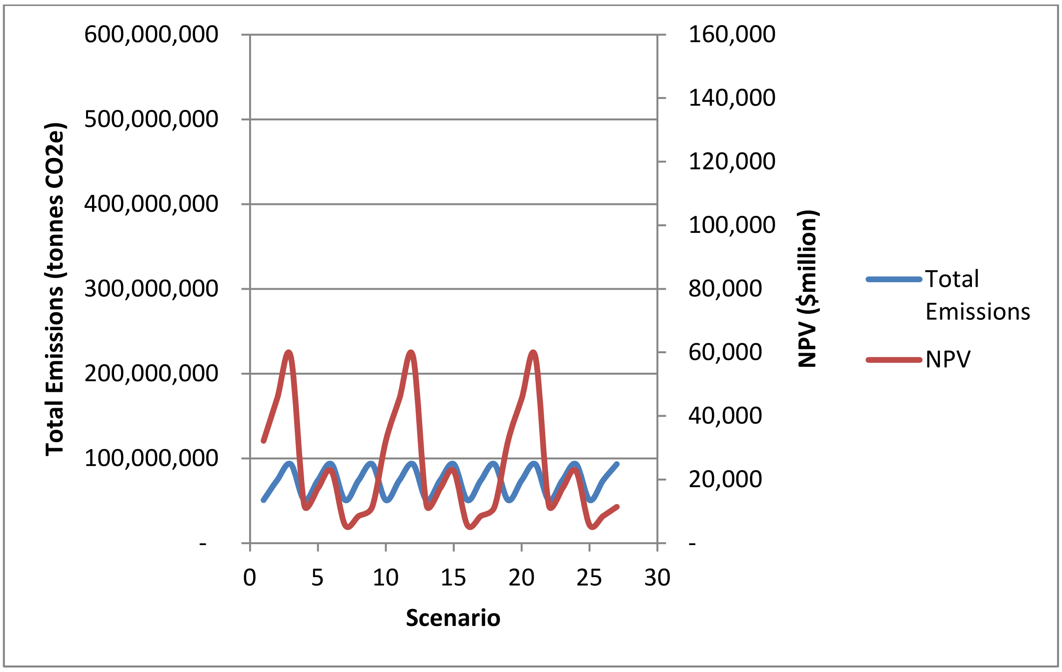


Figure 6.19 Optimal Solutions Suite 9 (Scenarios 20 to 22), Performance in all Scenarios

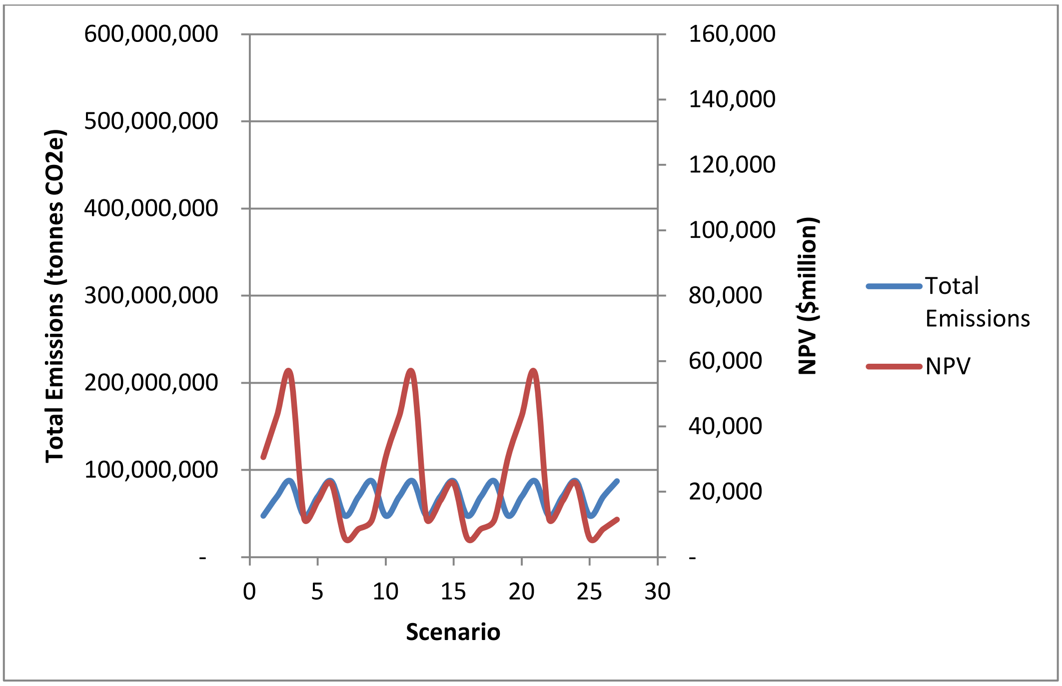


Figure 6.20 Optimal Solutions Suite 10 (Scenarios 23 to 24), Performance in all Scenarios

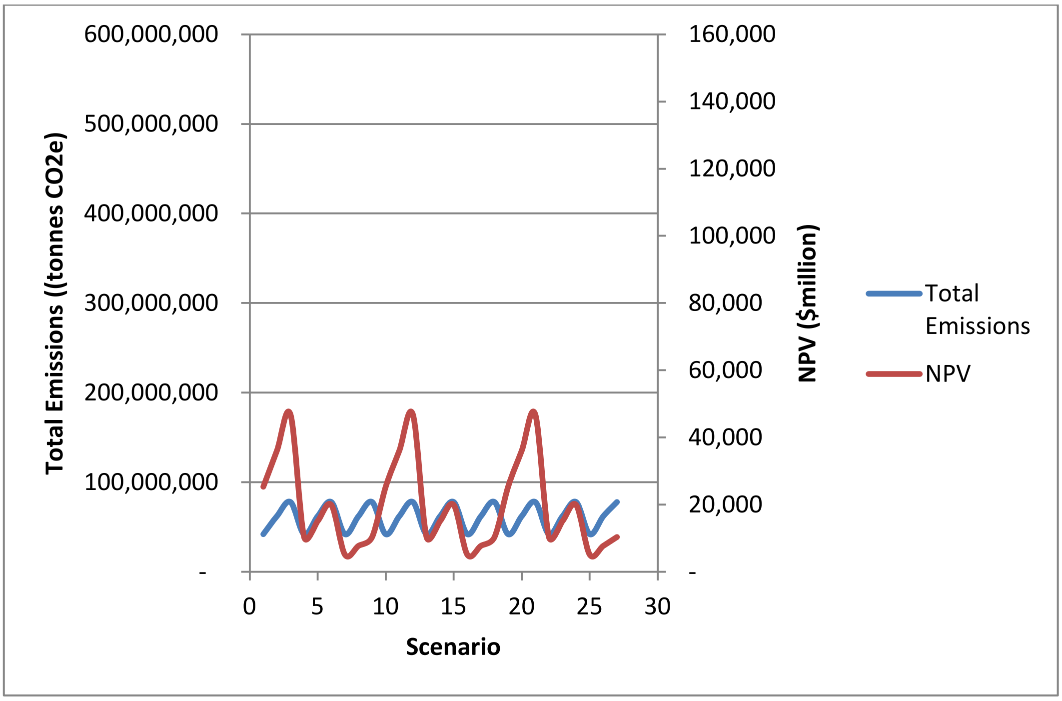
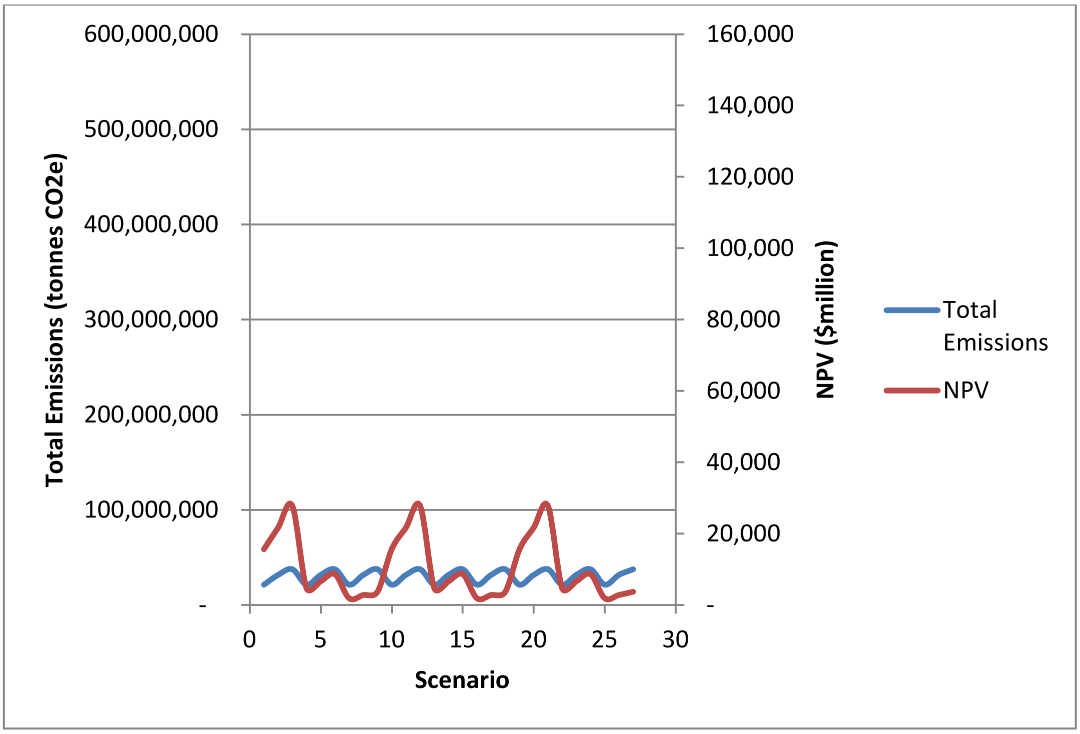


Figure 6.21 Optimal Solutions Suite 11 (Scenarios 25 to 27), Performance in all Scenarios



6.5.7 Emissions Quantity Model Eco-efficiency Implications

As discussed earlier in this thesis, the concept of corporate eco-efficiency is defined as creating more value with fewer environmental resources resulting in less environmental impact, for example, less pollution (Schaltegger et al., 2003). In this study a simplified eco-efficiency is defined as NPV divided by emissions. Guenster, Bauer et al. (2010) report that eco-efficient companies provide anomalously positive equity returns relative to their less eco-efficient peers. Generally the evidence is uniform and points to a positive and significant relationship between environmental management policies and Tobin's *Q*.

This correlation enables the use of Guenster, Bauer et al.'s (2010) results in the consideration of the market valuation of a firm. Their results show that the gain in market valuation from receiving a high eco-efficiency score ranges between 0 to 7% depending upon the relative eco-efficiency scores.

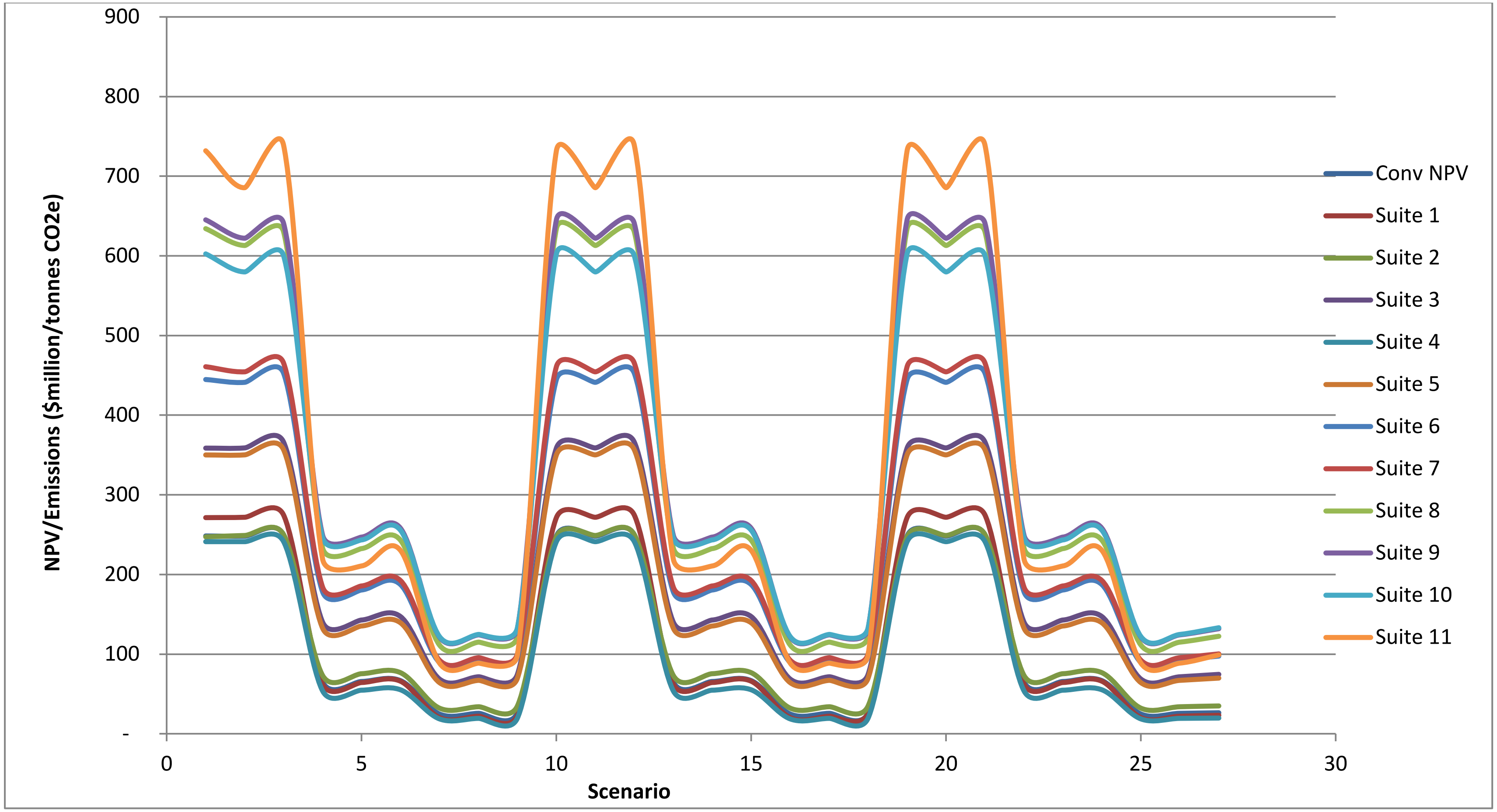
The results of the simplified eco-efficiency are shown in Table 6.23 and Figure 6.22. As shown in these results, it is difficult to pinpoint the performance of the different solutions as the relative eco-efficiency performance varies depending upon which scenario eventuates.

However, a significant result is the Absolute Robust/Robust Deviation solution which produces the highest eco-efficiency at a low discount rate; it does not do so at the medium and high discount rates. Also the conventional NPV solution outperforms some solutions in terms of eco-efficiency even though these solutions have a 10% emissions reduction as a goal. As a consequence of this, it is difficult to assess whether a firm may have eco-efficiency dividend ascribed to it due to the inherent uncertainty involved and the varying levels of eco-efficiency achieved for different scenarios.

Table 6.23 Eco-efficiency of Optimal Investment Suites in all Scenarios

	NPV/Emissions ($million/tonnes CO_2e)											
Scen.	**Conv. NPV**	**Suite 1**	**Suite 2**	**Suite 3**	**Suite 4**	**Suite 5**	**Suite 6**	**Suite 7**	**Suite 8**	**Suite 9**	**Suite 10**	**Suite1 1**
1	248	271	247	359	241	350	445	461	634	645	602	732
2	248	272	249	359	241	350	441	454	613	622	580	686
3	250	275	250	366	241	357	453	465	630	641	600	739
4	65	63	73	140	54	133	178	184	233	249	246	219
5	66	64	75	143	55	135	181	186	233	247	243	211
6	67	66	77	147	55	139	187	192	243	258	256	230
7	25	20	32	69	19	64	89	92	111	121	122	89
8	26	22	34	72	19	67	93	96	115	124	125	89
9	26	23	35	75	20	70	98	100	122	132	133	99
10	248	271	247	359	241	350	445	461	634	645	602	732
11	248	272	249	359	241	350	441	454	613	622	580	686
12	250	275	250	366	241	357	453	465	630	641	600	739
13	65	63	73	140	54	133	178	184	233	249	246	219
14	66	64	75	143	55	135	181	186	233	247	243	211
15	67	66	77	147	55	139	187	192	243	258	256	230
16	25	20	32	69	19	64	89	92	111	121	122	89
17	26	22	34	72	19	67	93	96	115	124	125	89
18	26	27	35	75	20	70	98	100	122	132	133	99
19	248	271	247	359	241	350	445	461	634	645	602	732
20	248	272	249	359	241	350	441	454	613	622	580	686
21	250	275	250	366	241	357	453	465	630	641	600	739
22	65	63	73	140	54	133	178	184	233	249	246	219
23	66	64	75	143	55	135	181	186	233	247	243	211
24	67	66	77	147	55	139	187	192	243	258	256	230
25	25	20	32	69	19	64	89	92	111	121	122	89
26	26	22	34	72	19	67	93	96	115	124	125	89
27	26	23	35	75	20	70	98	100	122	132	133	99
Max	**250**	**275**	**250**	**366**	**241**	**357**	**453**	**465**	**634**	**645**	**602**	**739**
Min	**25**	**20**	**32**	**69**	**19**	**64**	**89**	**92**	**111**	**121**	**122**	**89**

Figure 6.22 Eco-efficiency of Optimal Investment Suites in all Scenarios



6.6 Conclusion

The results from the Conventional NPV, Emissions Cost and Emissions Quantity models show marked differences in their solutions. Overall, in scenarios with a higher emissions cost or greater emissions reduction, then the optimal solution incorporates reduced emissions. Importantly, in some scenarios, the Conventional NPV solution produces a substantially negative NPV result. Also of significance is the Absolute Robust and Robust Deviation solutions (maximin and minimax regret respectively) for both the Emissions Cost and Emissions Quantities models produce the same result with the greatest emissions reductions. This means that, should a firm wish to maximise their minimum potential NPV outcome or to minimise the maximum financial regret, they should reduce emissions substantially as selecting a project with no regard for emissions, that is, the Conventional NPV model, is likely to generate assets with a negative NPV.

Another significant result is that, while the Absolute Robust and Robust Deviation solutions produced the largest emissions reductions, they did not necessarily generate the largest eco-efficiency values.

Chapter 7 Discussion

7.1 Introduction

This study has examined the issue of voluntary emissions reductions for firms and whether there is a business case for such action when investing in large-scale, long-lived projects. The study has also examined whether the proposed models for assessing voluntary emissions reductions are appropriate.

This study was motivated by claims within the CSR literature that it is in the interest of firms to voluntarily reduce emissions. Consequently this study has also examined the business conditions in which such CSR claims may hold true. The benefits from voluntary emissions reductions are suggested to come from the anticipation of regulatory changes and avoidance of stranded assets, as well as an increase in reputation and market valuation due to improved eco-efficiency greater investment flexibility and option value due to decreased GHG emissions. This chapter discusses the model and these goals as well as the implications that flow from the results of the models for assessing voluntary emissions reductions.

As well as including an emissions factor, either as a price or physical emissions reduction, the models developed in Chapter 5 incorporated uncertainty as this is a central feature of Climate Change and potential regulations that relate to emissions and consequently must be included in any study of business decisions and Climate Change. The results from the models were analysed in Chapter 6 where potential emissions and revenue from the solutions of the different models were compared and contrasted with the other models as well as a conventional NPV model. The conventional NPV model represents the standard method of analysing prospective investments and represents Business As Usual (BAU). The implication of these results is discussed in this chapter in the broader context of the distinctive characteristics of Climate Change and how these impact on investment decisions for the firm.

7.2 Models

7.2.1 Conventional NPV Model

The Conventional NPV (CNPV) Model was constructed using Linear Programming methods with the objective function being to maximise the NPV while the constraint was a cumulative budgetary constraint for all of the prospective projects. The linear programming model produced a solution using the Simplex algorithm whereby the NPV was maximised by choosing some of the 11 potential projects and the sum of the Capex of those projects fell below the budgetary constraint. In this case study the CNPV model selected projects 1 to 5, 7, 8, 10 and 11. This group of projects is the solution for the CNPV model and this serves as a BAU reference for the other models.

7.3 Emissions Cost Model

The Emissions Cost Model was constructed as a method of analysing the impact on business impacts of voluntary emissions reductions by incorporating an emissions price into the project selection process. As with nearly all aspects of Climate Change, a future price on emissions is uncertain. The model incorporated 3 potential prices and this uncertainty is incorporated in the decision-making process through a Robust Optimisation approach. Robust Optimisation incorporates both linear programming and scenario modelling. For each scenario a linear programming model with an objective function (to maximise NPV) was solved for a given set of values for the different criteria. For example, a low discount rate, high emissions cost, medium cash flow with a budgetary constraint. This means for each scenario a given set of projects are selected which is optimal for that scenario, such as in Scenario 1, the selection of projects 1 to 5, 7, 8, 10 and 11 produces the highest NPV and hence is optimal for that scenario, while in Scenario 19 the selection of projects 1, 4, 9 and 10 produced the highest NPV and is optimal for that scenario.

The performance of each optimal solution for each scenario was then analysed in every other scenario. The rationale for this is that each particular scenario may or may not eventuate and hence the performance of that solution should be examined when the criteria have other values.

When the performance of a particular optimal solution for a given scenario is examined in other scenarios, two criteria were used to reach a decision. One decision criterion was a maximin criterion which is identified as the Absolute Robust Decision Criterion (ARDC) in the literature. This decision criterion involves analysing how the NPV of each optimal solution for each scenario performs in the other scenarios and the optimal solution which generates the maximum minimum across all the scenarios is deemed the ARDC.

The other decision criterion also analysed the performance of each scenario's optimal solution in every other scenario. However, the NPV performance is examined in terms of minimising the maximum regret. Minimax regret is defined in terms of NPV and seeks to minimise the maximum possible regret, that is, the opportunity cost that will be incurred as a result of having made the wrong decision. Theoretically, a risk- neutral decision-maker would use this decision criterion based on the assumption that the maximum regret will occur for all the available decision options. Within the Robust Optimisation literature the minimax regret decision criterion has been identified as the Robust Deviation Decision Criterion (RDDC).

As many scientists express doubt about the validity of the probabilities associated with Climate Change outcomes (Stainforth et al., 2007) a method which incorporates the use of non-probabilistic approaches like maximin and minimax regret is suitable. Such an approach emphasises the robustness of a decision that is appropriate for exploring emissions reductions.

Figure 7.1 Economic Performance of Conventional NPV and ARRD Solutions

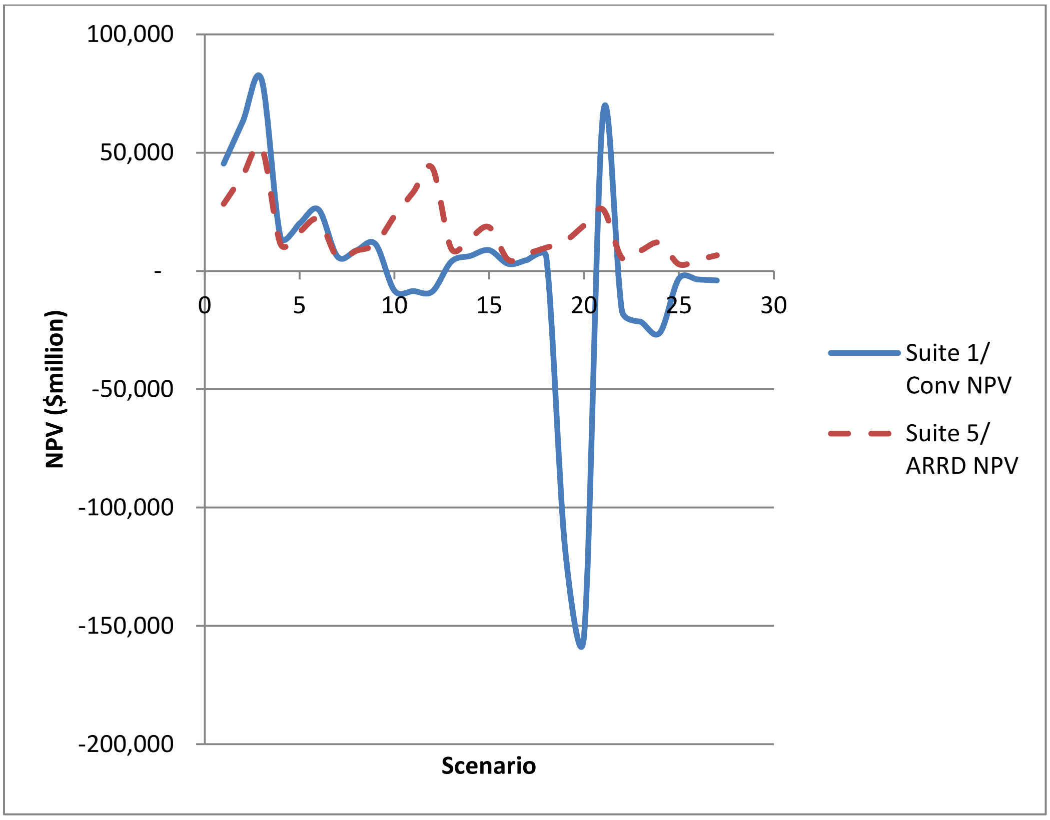
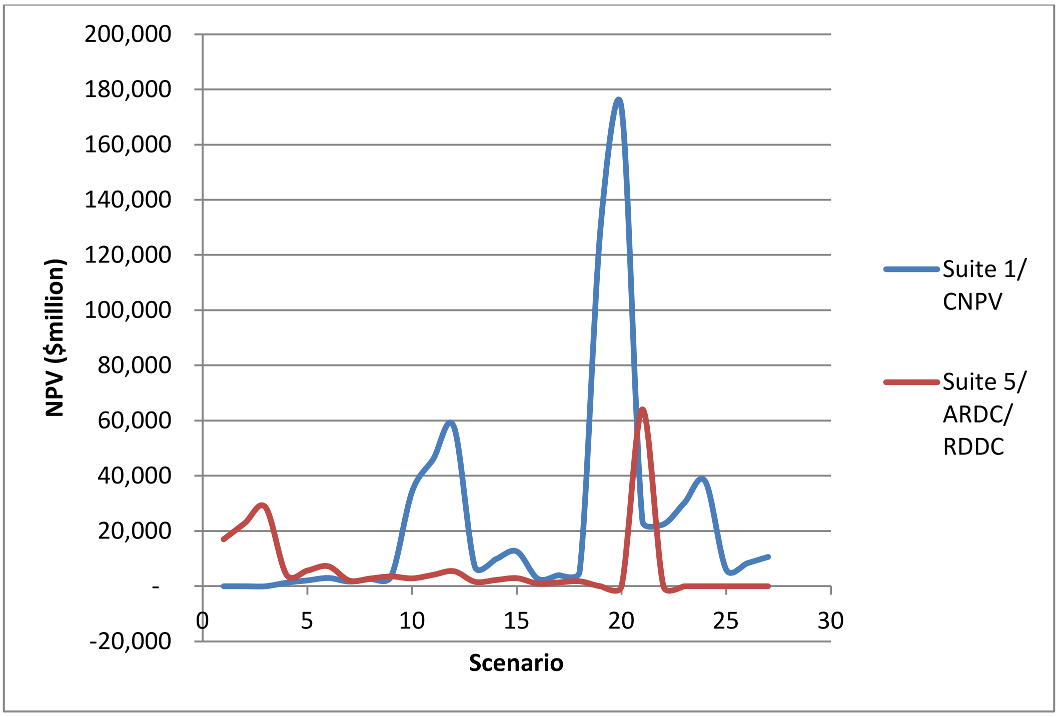


Figure 7.2 NPV Regret Performance of Conventional NPV and ARDC/RDDC Solutions



7.3.1 Eco-efficiency Dividend

Several studies have documented increases in market valuation of firms with the best eco-efficiency relative to the least eco-efficient all other things being equal (Guenster et al., 2010). As explained in Chapter Six, this represents a type of eco-efficiency dividend which Guenster suggests can be up to a 7% increase in market valuation. Such increases in valuation are substantial and are a significant factor in determining the potential benefits of voluntary emissions reductions.

If such a dividend is applied to the results of the Emissions Cost Model, then the ARDC and RDDC solution becomes more attractive to a risk-averse decision-maker leading to a further 7% increase over the business as usual approach, or a 7% decrease in the difference between the two. However, using such a method to determine whether a firm may benefit from an eco-efficiency dividend requires examination of the relative eco-efficiencies as the 7% increase only occurs between firms which have the highest eco-efficiency when compared to those firms which have the lowest eco-efficiency. These are shown in Figure 7.3. As can be seen, the

ARDC and RDDC model is consistently and substantially higher across nearly all scenarios compared to the CNPV model solution.

Not surprisingly, the solution which produced the greatest emissions reduction also produced the greatest eco-efficiency. Hence should a firm choose the ARDC/RDDC, it would also potentially increase its market valuation up to 7% due to eco-efficiency improvements and consequent reputation increases that Guenster (2010) suggests is the case. However, while an increase in 7% of market valuation is considerable, it does not change the decision reached with the data set used in this model. The relative performance of the ARDC/RDDC solution and CNPV solution are shown in Figure 7.4. The scenarios with negative values indicate these are the scenarios with negative NPVs for the CNPV solution.

Figure 7.3 Eco-efficiencies of ARRD and Conventional NPV across Scenarios

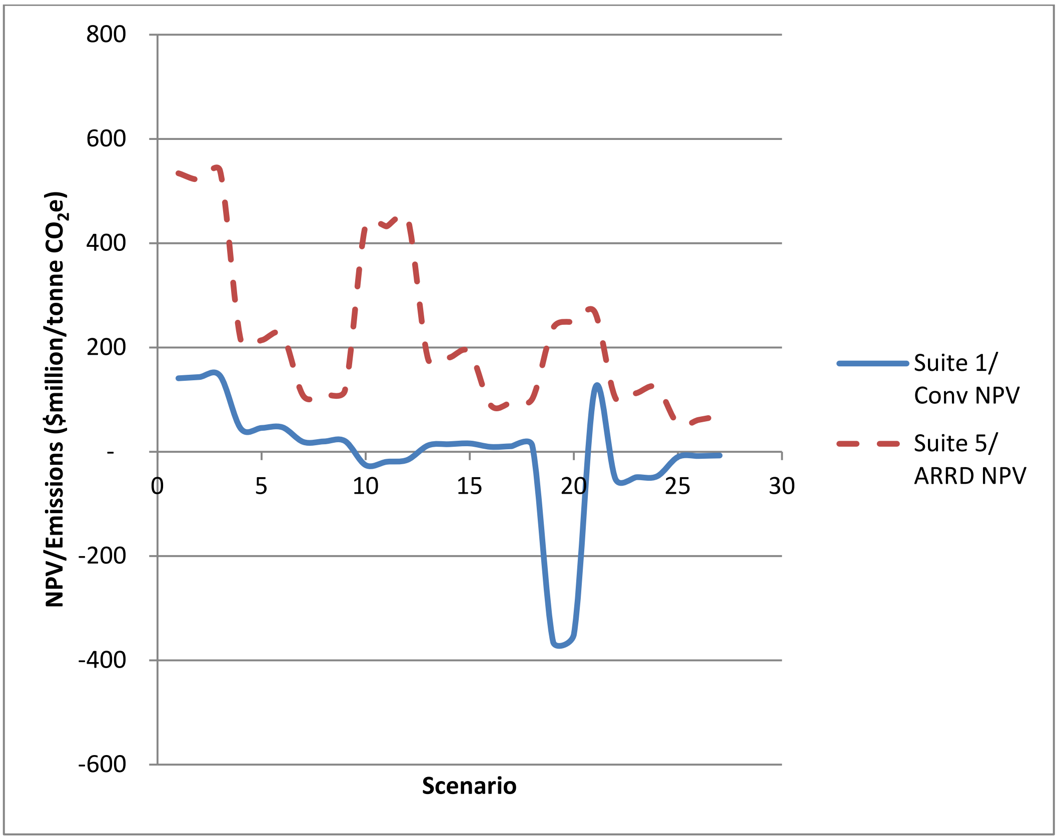
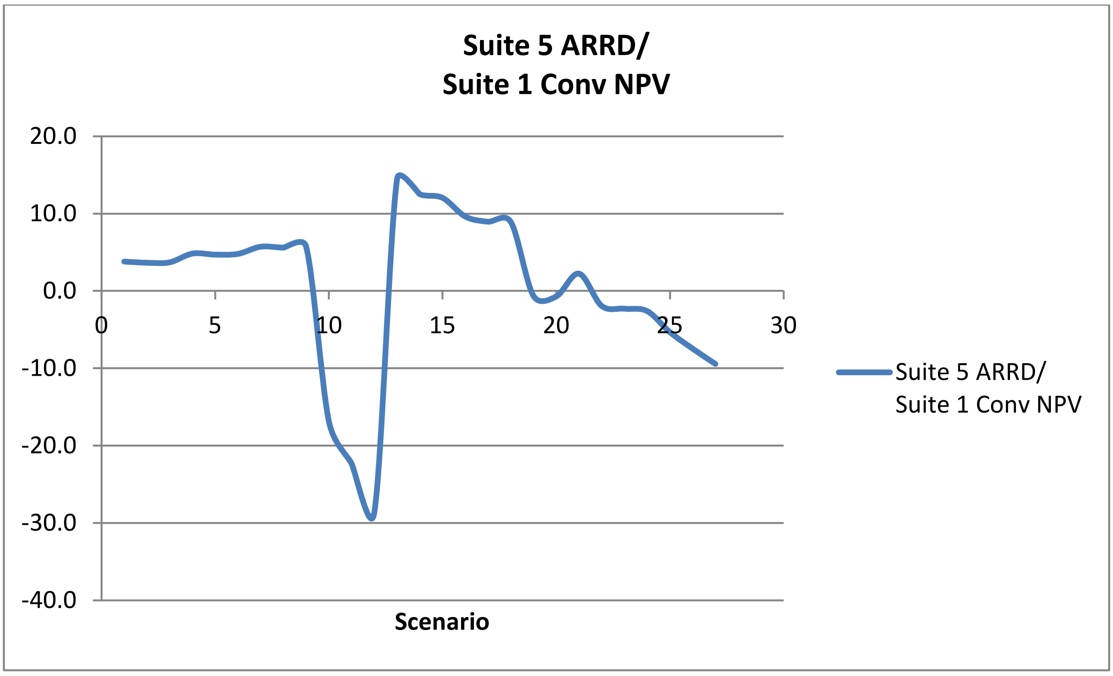


Figure 7.4 Relative Eco-efficiency ARRD and Conventional NPV across Scenarios

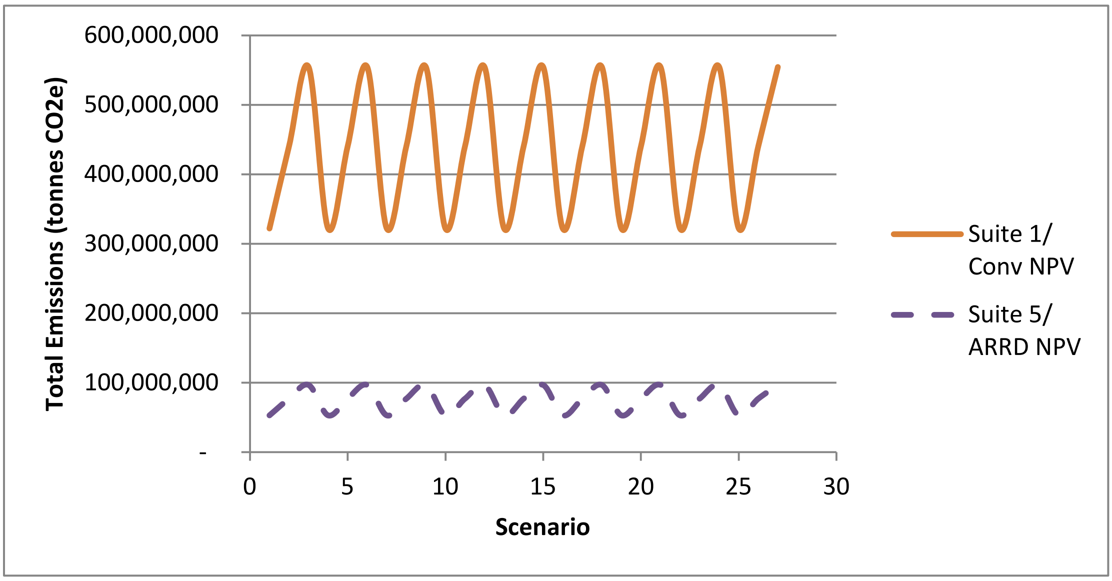


7.3.2 Real Option Value and Flexibility

Real Option Value is a notoriously difficult concept to quantify yet has relevance to the issue of Corporate Social Responsibility and emissions. In this study, Real Option Value is linked to flexibility and in this sense refers to a firm to being able to keep investment options open and responsive to future uncertainties (Borison, 2005, Busch and Hoffman, 2009). As such, real options involve a firm 'buying' a possibility to keep opportunities open for a particular project or suite of projects with the cost of buying this flexibility being any opportunity cost. With respect to Climate Change and long-term investments, if a firm reduces its emissions by not investing in all potential projects it is buying flexibility to respond to future regulatory uncertainty through foregone revenue (Anda et al., 2009). This form of real option has a value in waiting for more information because if emissions turn out to be less than expected or cause less impact than expected, the possibility exists for emissions reductions to be relaxed. However, if emissions and impacts turn out to be greater than expected, there is little that can be done to correct the situation. Hence any investment decision which decreases emissions has an option value, as is the case with this solution.

With this study the Emissions Costs Model Absolute Robust/Robust Deviation Decision Criteria solution provides flexibility in the sense of keeping future options open by a reduction in emissions compared to the BAU CNPV model as shown in Figure 7.5. Figure 7.5 shows how the emissions of the CNPV model and the ARDC/RDDC model perform in the different scenarios. Emissions were calculated as proportional to cash flow only and consequently each model only has 3 values (low, medium or high) across the 27 scenarios. Figure 7.5 highlights the substantial difference in emissions between the CNPV and ARDC/RDDC models. This substantial difference implies a significant option value with the flexibility of the solution lying in the balance between emissions reductions and returns and keeping investment options open in the future should Climate Change turn out to be less severe than is currently projected; a hedge of sorts.

Figure 7.5 Different Investment Suite Emissions



However, the precise real option value of the Emissions Cost Model and ARDC/RDDC cannot be calculated in this study as, according to Kim and Miller (2012) such calculations require interest-earning opportunity, expected opportunity gain, present value and investment cost. Despite the lack of quantification, a Real Option Value would exist due to the flexibility of this approach and in this approach may be significant. As Ha Duong (1998) suggests, in the case of Climate Change real option value may be up to 50% of the opportunity cost from foregone revenue due to a decision not to invest in a particular project. However, such a calculation may be superfluous in this case as in some scenarios there is no opportunity cost as the reduced emissions option has a higher NPV.

Emissions Quantity Model

The Emissions Quantity Model was constructed as an additional method of assessing and analysing the impacts of voluntary emissions reductions to compare with the Emissions Cost Model and the Conventional NPV model. This was modelled for a potential imposition of government regulation stipulating an annual decrease in emissions (or cap) without the trade aspect. As with the Emissions Cost Model, the Emissions Quantity model incorporated emissions reductions constraints into the project selection process. However, this model incorporated 3 potential emissions percentage reductions and factored in this uncertainty in the decision-making process through the same multiple scenario Robust Optimisation approach used with the Emissions Cost Model. The two robust optimisation decision criteria were also the same, the ARDC and RDDC which applied the same decision logic as with the Emissions Cost model where the Robust Deviation decision was one of minimising the maximum regret and the Absolute Robust decision involved a form of maximising the minimum outcome (maximin). However, due to the construction of the model with different units between emissions (kilograms of CO_2e) and NPV (dollars) this necessitated the introduction of a minimax variable. Consequently the Absolute Robust decision became one of minimising the maximum deviation from the target values and the Robust Deviation was one of minimising the maximum value of the minimax variable.

As with the Emissions Cost Model, the project selection process depended upon a complex combination of emissions reduction, the discount rate and cash flow.

7.3.3 Absolute Robust/Robust Deviation Decision Criteria

The Emission Quantity Model Absolute Robust and Robust Deviation decisions produced the same solution as the Emissions Cost Model. Due to the different construction of the model, this meant the Absolute Robust decision criterion minimised the maximum deviation from the two goals of maximising NPV and certain emissions reductions. The Robust Deviation decision criterion minimised the maximum deviation from goals for each scenario. The NPV figures for the CNPV model and the ARDC/RDDC model are shown in Figure 7.6. As this figure shows, the opportunity cost of such an approach can be large; however, the difference can be smaller and hence much less of an issue depending upon the scenario and this graph does not take into consideration emissions permits. The emissions for the CNPV model and the ARDC/RDDC solutions are shown in Figure 7.6. While the NPV differences between the CNPV model and the

ARDC/RDDC are minimal in some scenarios, the differences between their emissions are large in all scenarios, as shown in Figure 7.6. As with the Emissions Cost Model, the emissions profile of the Emissions Quantity Model was only dependent upon cash flow and hence has only 3 values across the 27 scenarios. As Figure 7.6 and Figure 7.7 demonstrate, the benefit in reducing emissions is not always countered by a commensurate reduction in NPV. However, the NPV of the ARDC/RDDC model is always lower than the CNPV model which is in stark contrast to the results from the Emissions Cost Model. This can be explained by the lack of inclusion of permits prices which is discussed below.

Figure 7.6 Optimal Investment Suites' NPV

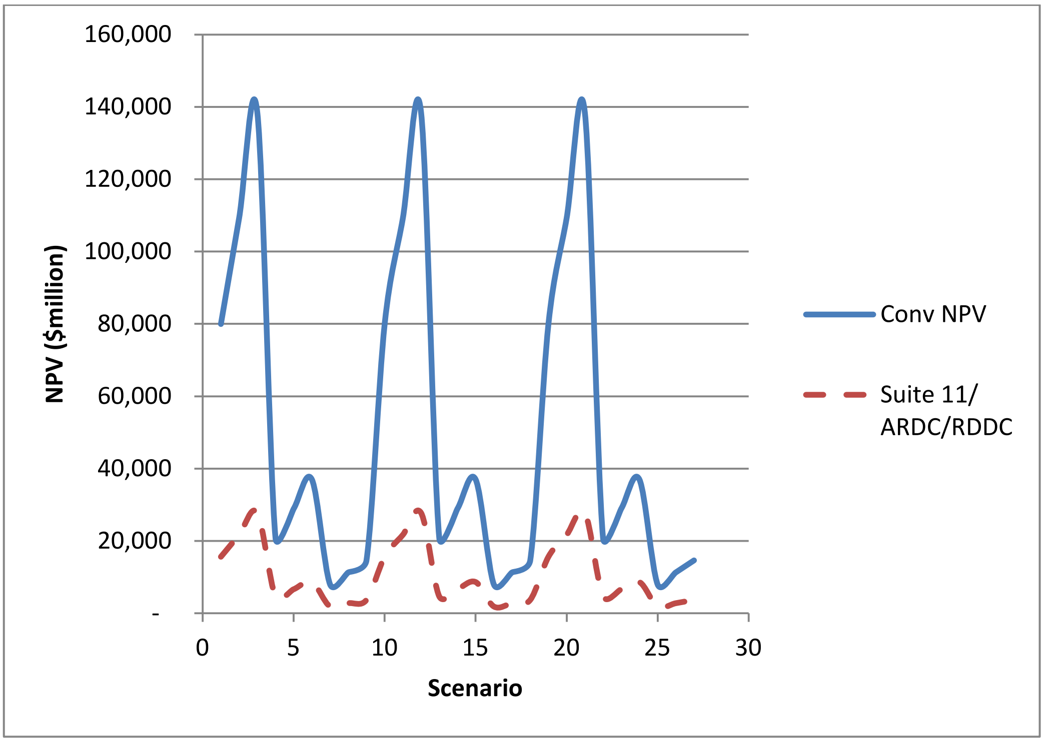
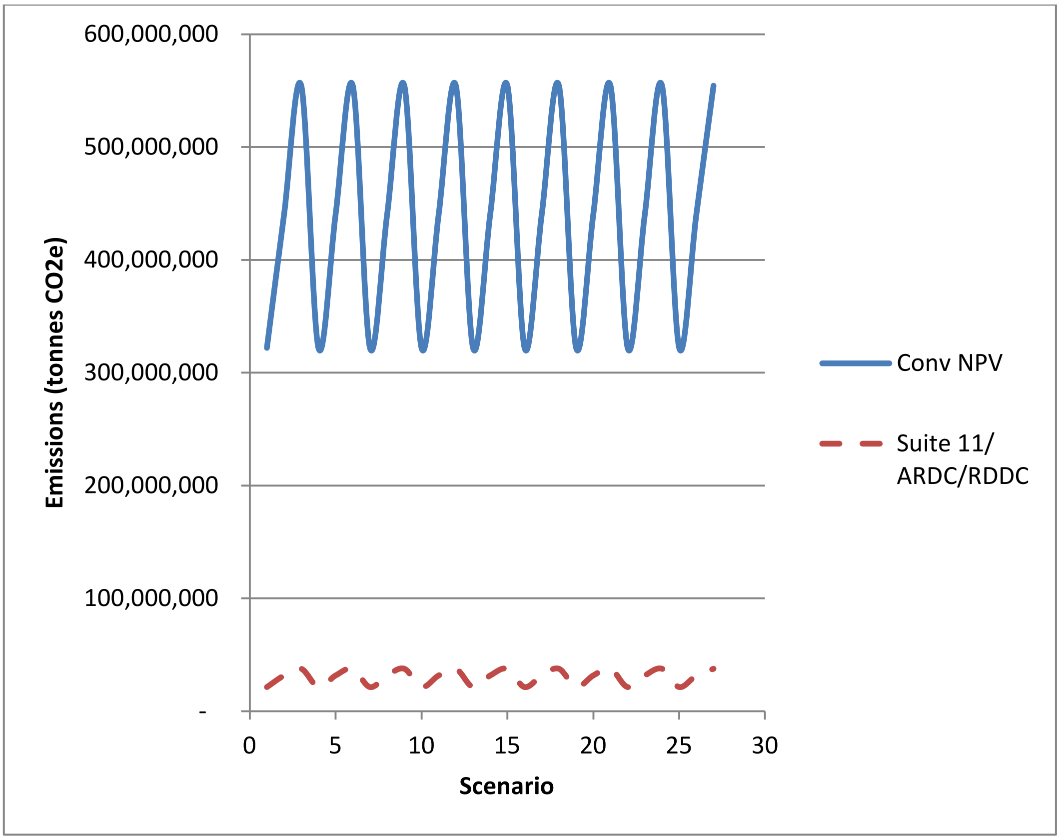


Figure 7.7 Conventional NPV and ARDC/RDDC Solution Emissions



7.3.4 Real Option Value and Flexibility

As with the Emissions Cost Model, the Climate Change flexibility of the Emissions Quantity Model Absolute Robust/Robust Deviation Decision Criteria is greater than the Conventional NPV solution as there is an approximately 90% reduction in emissions. Should regulatory uncertainty be resolved, which leads to a low reduction scenario, the option to invest in further projects remains open and should a high reduction scenario occur, then the firm may choose to invest or not.

As with the Emissions Cost ARDC/RDDC decision criteria, there is some option value and hence flexibility attached to a decision which reduces emissions.

Emissions Quantity Model Eco-efficiency

The eco-efficiency of the ARDC/RDDC model and the CNPV model is shown in Figure 7.8. A significant result is that while the Absolute Robust/Robust Deviation solution produced the greatest reduction in emissions, it did not generate the highest eco-efficiency in all scenarios. This makes it difficult to conclude whether a firm's market valuation would increase due to eco-efficiency and hence reputation benefits, however, the eco-efficiency of this solution varies by a factor between 2.8 and 3.7 as shown in Table 7.1 and Figure 7.9. which is within the range which would provide a eco-efficiency dividend as described by Guenster (2010).

Figure 7.8 Eco-efficiency of Optimal Investment Suites and Conventional NPV solution

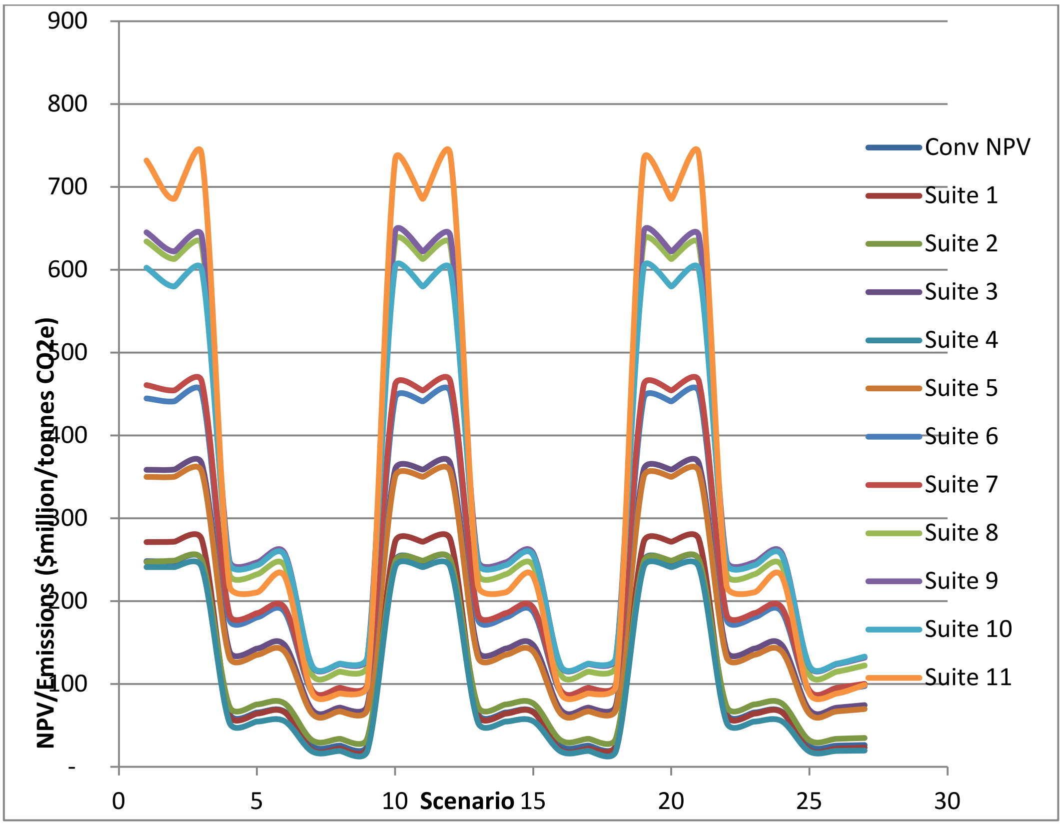
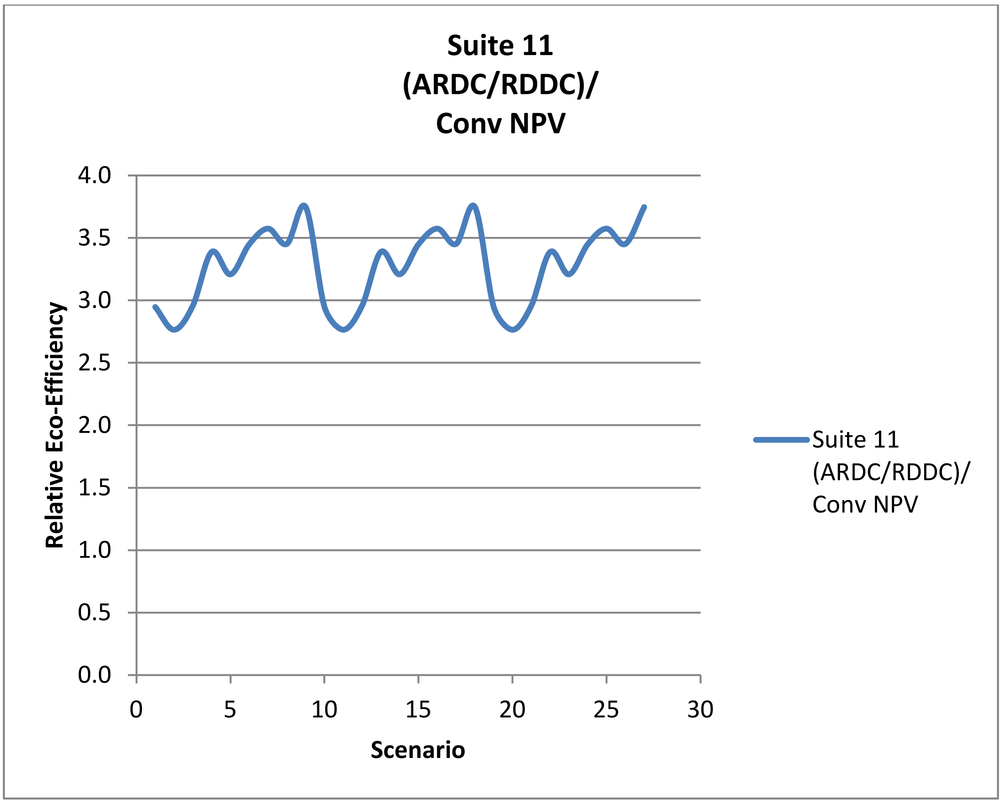


Table 7.1 Conventional NPV model and Absolute Robust/Robust Deviation Eco-efficiency

Scen.	Conv. NPV	Suite 11	Suite 11/ Conv. NPV
1	248	732	2.9
2	248	686	2.8
3	250	739	3.0
4	65	219	3.4
5	66	211	3.2
6	67	230	3.4
7	25	89	3.6
8	26	89	3.5
9	26	99	3.7
10	248	732	2.9
11	248	686	2.8
12	250	739	3.0
13	65	219	3.4
14	66	211	3.2
15	67	230	3.4
16	25	89	3.6
17	26	89	3.5
18	26	99	3.7
19	248	732	2.9
20	248	686	2.8
21	250	739	3.0
22	65	219	3.4
23	66	211	3.2
24	67	230	3.4
25	25	89	3.6
26	26	89	3.5
27	26	99	3.7

Figure 7.9 Conventional NPV model and Absolute Robust/Robust Deviation Eco-efficiency



7.3.5 Emissions Penalties

For the regulatory emissions quantity model it is reasonable to expect such a scheme would be backed by a penalty payment. Therefore this section examines and calculates the penalty that firms could pay under different quantity regimes to equalise the conventional NPV result.

For a firm to be indifferent to the CNPV and Emissions Quantity ARDC/RDDC policies then the cost of the penalties with the CNPV model would have to equal to the difference in NPV between the CNPV and the Emissions Quantity Model ARDC/RDDC and this depends upon which scenario eventuates. The cost of each penalty is dependent upon the difference in NPV and difference in emissions. If the low reduction scenario were to occur then this would eventuate in emissions penalties to account for the 10% of emissions reductions that have not occurred. If the high reduction scenario occurs then emissions penalties would be imposed to cover 90% of the emissions.

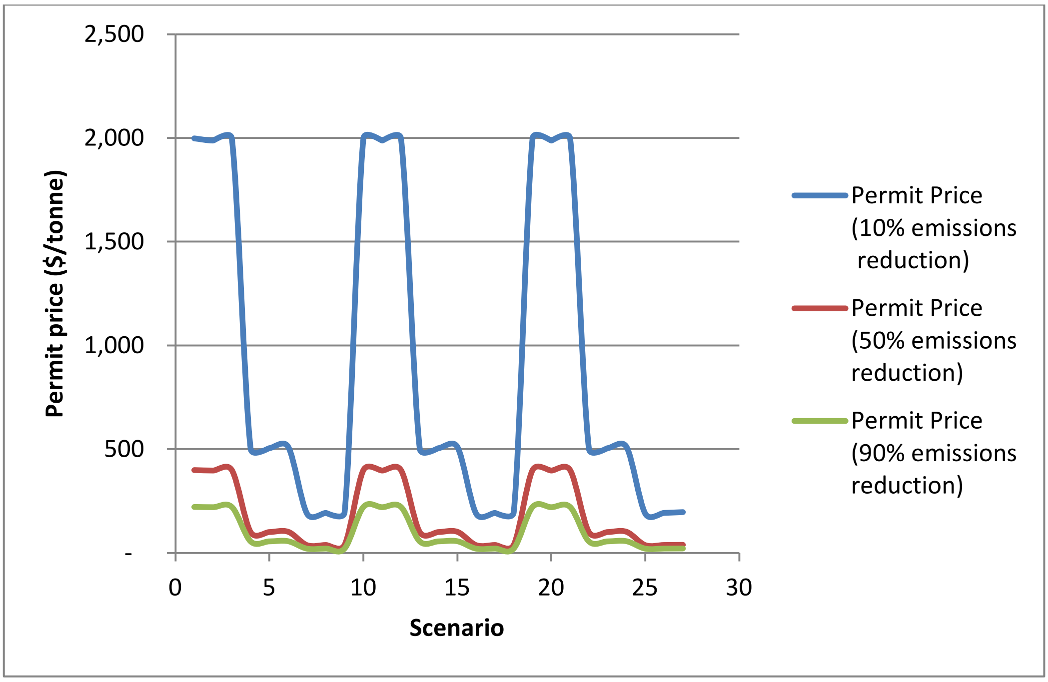
The price per tonne of CO_2e emissions that would be required for the CNPV model and the Emissions Quantity Model ARDC/RDDC to have equal value is shown in Table 7.2. If a low reduction scenario eventuated and the firm had chosen the CNPV model, the firm would be penalised for the 10% of their emissions they had not reduced. If the firm had chosen the Emissions Quantity model ARDC/RDDC they would not have been penalised as their emissions are already reduced by approximately 90%, though their revenue would be between 71% and 80% lower.

If a 10% reduction were to eventuate, then for the two solutions to have equivalent value the cost per tonne would vary between $189 and $1,998. If a 90% reduction were to eventuate then the price per tonne would vary between $21 and $222 depending upon which scenario eventuated as shown in Table 7.2 **Error! Reference source not found.**and Figure7.10.

Table 7.2 Permit Price for EQM and NPV Model Equivalence

Scenario	NPV dif/10% emission reduction	NPV dif/50% emission reduction	NPV dif/90% emission reduction
1	1,998	400	222
2	1,987	397	221
3	1,997	399	222
4	502	100	56
5	505	101	56
6	511	102	57
7	189	38	21
8	193	39	21
9	197	39	22
10	1,998	400	222
11	1,987	397	221
12	1,997	399	222
13	502	100	56
14	505	101	56
15	511	102	57
16	189	38	21
17	193	39	21
18	197	39	22
19	1,998	400	222
20	1,987	397	221
21	1,997	399	222
22	502	100	56
23	505	101	56
24	511	102	57
25	189	38	21
26	193	39	21
27	197	39	22
Min	**189**	**38**	**21**
Max	**1,998**	**400**	**222**

Figure 7.10 Permit Price for EQM and NPV Model Equivalence



The cost per tonne of emissions is indicative only as the way penalties are imposed varies between regulatory models. These results show that if a firm chose the CNPV model approach and the 10% reduction scenario eventuated then the CNPV model would be the preferred choice if the penalty was less than $1,998 or $189 depending upon the discount rate and cash flow. Conversely, if the 90% reduction scenario eventuated, then the CNPV model would be preferred if the penalties were less than $222 or $21, depending upon the discount rate and cash flow. Obviously, if the 90% reduction scenario eventuated, then it is very likely conceivable the size of penalty would be above this figure. In addition, the option value and eco-efficiency dividend associated with such an approach makes this choice more advantageous; as discussed below.

7.3.6 Models Compared

The private and public benefits are the same with the Emissions Quantity Model as with the Emissions Cost Model, and have similarly large reductions in emissions. A significant difference is that the Emissions Cost Model clearly highlights the possibility of negative NPVs and stranded assets with some solutions generating very large negative returns in various scenarios, while the Emissions Quantity Model ARDC/RDDC implies negative values through the potential penalty, though these are far less obvious. As the scenarios for the two models are different it is not possible to make direct comparisons. However, both the Absolute Robust

Decision Criterion and Robust Deviation Decision Criterion in both models generated solutions with the highest emissions reductions which highlights the importance of potential regulatory changes and potentially stranded assets.

It is clear the eco-efficiency of both the Emissions Cost Model ARDC/RDDC and Emissions Quantity Model ARDC/RDDC is larger when compared to the CNPV model and, according to various studies (Guenster et al., 2010, Derwall et al., 2004a), either method should lead to a increased market valuation of up to 7% with eco-efficiencies several fold larger than the CNPV model. However, while 7% is a substantial figure, the potential negative NPV results and possible stranded assets far outweigh the potential eco-efficiency benefit.

7.4 Suitable Approach

The results of this study highlight the advantages of multiple scenarios modelling as opposed to using single points such as mean or median as being representative of a given probability distribution. The different investment suites for the different scenarios demonstrate this worth as the various optimal solutions perform differently across the scenarios both financially and with respect to emissions, thus avoiding potential stranded assets and negative effects of financial irreversibility. Assessing the performance across the scenarios makes a decision-maker better able to make a more informed decision and consequently this decision criterion highlights the worth of such an approach. Such information is vital for such a complex and uncertain field as Climate Change and large scale investments.

7.5 Discount Rate Implications

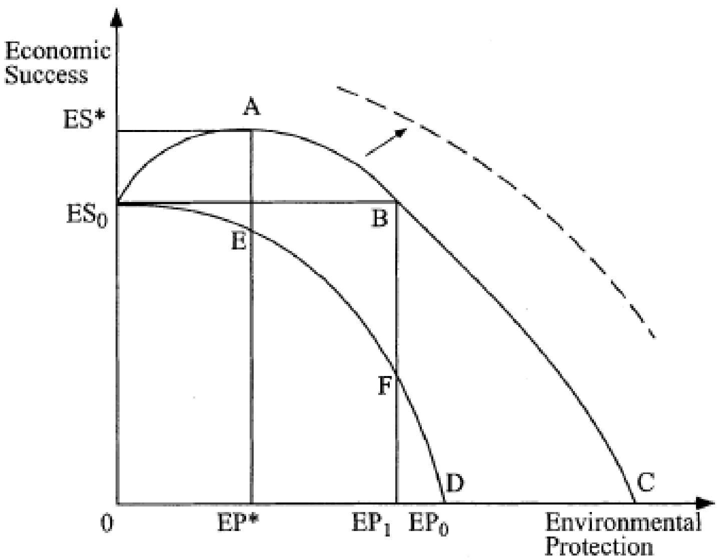
It is often stated in economics literature that a low, to extremely low, discount rate should be used in order to take into consideration the welfare of future generations. For example, the Stern Review (2006) used a discount rate just above 1%. However, the solutions from this study suggest that such a conclusion is not as straight forward as theory would suggest. With the Emissions Cost Model the solution with the lowest discount rate, combined with the lowest emissions cost, generated the highest emissions. Unsurprisingly, this solution was the same as solution which had no emissions cost attached to it.

With respect to the Emissions Quantity model, the scenarios that produced the lowest collective emissions also occurred with the highest discount rate and the ARDC/RDDC had the highest discount rate. While the discount rate was not the sole determinant in the project selection for the different solutions, it would appear the link between low discount rates and considering environmental affects in the form of GHG emissions, is more nuanced than may have previously been accepted.

7.6 Corporate Governance and Corporate Social Responsibility Implications

According to stakeholder model, it has been viewed that the corporation in fact cannot be run without the contributions of different stakeholder groups like customers, employees, suppliers, the community of which it is a part and the environment in which it operates. Therefore at the event of decision-making, and especially large long lived projects, a firm should take into account how their decisions impact these constituents. Although the shareholder model has the ascendancy over the stakeholder model which is growing slowly as a part of governance framework, the exercise of both the models suggest that there is no scope to look narrowly into the corporate governance aspects. Rather it would appear more appropriate to state, a CSR approach is extends corporate governance whereby corporate responsibilities range from its fiduciary duties towards the owners to the analogous fiduciary duties towards all the firm’s stakeholders. While it is admittedly a hard task to distinguish between CSR and CG. Erik Belfrage of Sweden‟s SEB Bank views “corporate governance and corporate social responsibility are both extremely important to a company (SEB, 2007). But it is not a natural thing to separate them. If you have a well formed corporate governance programme in place that would probably take care of most CSR issues.” However, it can be argued that CSR issues are of voluntary or softer nature and it is based on the self-regulatory corporate codes and the corporate governance is more often mandatory based on statutory provisions applicable at national level. For example, the company law of a country defines the composition of the board of directors, their rights and duties towards shareholders, duties of the managers and other organisational activities. Security and Exchange law provides the principles regarding the mandatory financial disclosures, auditing and so on. The duties of the managers and directors may be of softer issues when they concern the promotion of ethical behaviour towards the environment. Consequently the theoretical justification for voluntary greenhouse gas emissions reductions stems from the concept of CSR which suggests that it makes business sense to take actions that are beneficial socially and/or environmentally. As described in earlier chapters, the different interpretations taken towards CSR have been represented graphically by Schaltegger and Synnestvedt (2002) as shown in Figure 7.11. This figure illustrates the view of some scholars who suggest that implementing CSR simply means a reduction in economic success (curve ES_0 to EP_0) while others suggest that some level of CSR activity leads to increased economic success (Curve ES_0 to ES* to A to C).

Figure 7.11 Relationships Between Corporate Environmental Protection and Economic Success



Source: (Schaltegger and Synnestvedt, 2002 p341).

This study provides some support for the claim of economic success from implementing voluntary greenhouse gas emissions reductions. A CNPV model solution produced results which generated substantial negative NPVs in 11 out of the 27 Emissions Cost scenarios modelled. On the other hand, the preferred ARDC/RDDC produced a NPV maximin and minimax regret and also produced a significant increase in eco-efficiency across all scenarios.

Both the Emissions Cost Model and Emissions Quantity Model decision criteria lead to significant gains in eco-efficiency and (theoretically) reputation which flow through to increased firm valuation and the value of flexibility. This may be offset by the opportunity costs of such an approach. Consequently, it is difficult to locate either the Emissions Cost Model Absolute Robust Decision Criterion or the Emissions Quantity Model on the graph of Figure 7.11. However, the evidence suggests that the result could be on either, depending upon which is the true state of nature to eventuate. Such benefits are derived from anticipating regulatory changes, not from acting in a manner that is independent of regulatory changes and as a best practice leader. Such benefits refer to the upward market appraisal from initiatives to improve eco-efficiency. While such action has been shown to be beneficial to firms (Guenster 2010), the size of the benefit is dwarfed by the benefit anticipating regulatory changes.

7.7 Real Option Value, Flexibility, Irreversibility and the Precautionary Principle

Any discussion of Climate Change investment strategies should raise the issue of the precautionary principle that is also relevant to this study. In turn, the precautionary principle has been linked to the concepts of uncertainty, irreversibility and flexibility and has led to substantial amounts of research in the literature as documented in Chapter 2.

The precautionary principle takes many forms but the key concept is that decision-makers should take steps to prevent future harm even when the causal chain between action and outcome is unclear and the likelihood of these outcomes uncertain. Such interpretations of the precautionary principle suggest implementing a response proportional to the level of protection required as well as one that can accommodate future learning. This is a defining characteristic of the precautionary principle in that it enables learning without risking the most severe consequences associated with an action. Consequently, if a firm takes this approach it must decide upon what represents a proportional response and how that can add to the firm's value. In deciding how to apply the principle, firms must consider both the opportunity cost of not acting and the option value associated with taking a precautionary approach as suggested by voluntary emissions reductions.

If it becomes apparent in the coming decades that society does not value a stable climate, the option will exist for further investment which may further destabilise the climate. If, on the other hand, investment proceeds now that precludes the option of a stable environment then the flexibility that this option entailed is lost. However, a second type of irreversibility, financial irreversibility, acts in the opposite direction as measures that protect the environment have a cost and foregone flow of benefits. This involves sunk costs which cannot be recaptured.

Scholars including Epstein (1980) as well as Arrow and Fischer (1974) showed that an option value was created by the irreversibility of possible future environmental and financial consequences and that this should persuade a 'risk-neutral' society towards making decisions that lead to more flexibility at a future date. Gollier, Bruno et al. (2000a) suggest that 'more scientific uncertainty as to the distribution of a future risk — that is, a larger variability of beliefs — should induce society to take stronger prevention measures today'. Such studies, while admittedly examining the issue from society's point of view, as opposed to an individual firm's, tend to support both the Emissions Cost Absolute Robust/Robust Deviation and Emissions Quantity Model Absolute Robust/Robust Deviation decisions.

Another section of the literature makes the connection between the precautionary principle and decision-making under uncertainty (Iverson and Perrings, 2009, Quiggin, 2007, Lempert and Collins, 2007), as exemplified by the issue of Climate Change. Such an approach to decision-making under uncertainty suggests that the decision-making criterion that most clearly captures the notion of potentially catastrophic results is maximin (that is, Absolute Robust Decision Criterion). By their design maximin policies purportedly encapsulate the possibility of catastrophe in that they are implement the optimal response to a worst case scenario.

In this study the Absolute Robust decision is a form of maximin and Robust Deviation a form of minimax regret. Various scholars have suggested maximin and minimax regret represent different forms of the mathematimisation of the precautionary principle. Therefore, theoretically, these decision criteria should maximise future flexibility by maintaining the current climate system and therefore keeps the most options open for the future and hence provide the maximum option value regardless of what quantity that option value is. As Hof, Van Vuuren et al. (2010) note, the focus of minimax regret analysis should not be on the exact quantitative outcome as the uncertainty cannot be determined, but their results show it is more robust than standard cost benefit analysis as this study supports.

By definition, robust strategies are intended to be insensitive to uncertainty about the future. For risk-averse policy makers such strategies should perform reasonably well, at least compared to the alternatives, even if confronted with unexpected events or catastrophes.

It is possible to base decisions on scenario analysis and to choose the most robust solution, that is, the one that is the most insensitive to future climate conditions, instead of looking for the best choice under one scenario (Hallegatte, 2009).

If a firm takes this approach it must decide what represents a proportional response and how that can add to the firm's value. In deciding how to apply the principle, it is necessary to consider both the opportunity cost of not acting and the option value associated with taking a precautionary approach as well as issues such as stranded assets and reputation. One of the difficulties of the application of the principle in modern policy-making is that there is often an irreconcilable conflict between the two as well as the difficulty in quantifying the option value, as is the case in this study.

The implications for this study are that to maximise flexibility and, in theory, option value, a firm should take an approach which guarantees both emissions trajectory flexibility as well as investment flexibility. Should this be the defining criteria, then the ARDC/RDDC of both the Emissions Cost and Emissions Quantity models appear to be the appropriate decision. However, given the relative importance of option value and difficulty quantifying it, it is not possible to definitively say that such a decision is in the interests of a firm.

However, the quantification of real option value has been the subject of considerable research with little consensus. One researcher, Ha Duong (1998), estimates that option value, especially with regard to Climate Change, is in the region of 50% of the opportunity costs. Such a value should give a firm pause for thought, however, even if this value is accepted there is still a considerable opportunity cost a firm is absorbing.

The difficulty in determining the quantity of option value of the different decision criteria in this study and corresponding flexibility is due in no small part to a lack of specified maturation date for the option. Various other studies have attempted to calculate option values, such as Maler and Fisher (2006), who base their calculations on an indirect utility function with a one dimensional supply environmental resources. However, these are very difficult to apply operationally and they do not provide absolute results. Busch and Hoffman (2009) also examine ecology-driven real options without attempting to quantify them as does Husted (2005). Pindyck (2007) balanced the opportunity costs versus the opportunity benefits of early action and concluded greater uncertainty leads to a higher threshold for policy adoption but does not quantify option value, again relying on utility functions to arrive at an optimal timing for the implementation of emissions reductions.

The approach that comes closest to quantifying option value for individual projects or portfolios is that which is based on the classic option pricing from finance theory (the Black-Scholes model) to real assets. This approach calculates the option value as an estimation of the shareholder wealth created by the investment based on the NPV and decision tree analysis based on replicating prior values. However, this approach lacks substantiation as to whether a particular proposal would be correlated with a particular share price (Borison, 2005). None of these techniques are useable for this study which highlights the difficulty in quantifying option value, particularly with respect to Climate Change and investment flexibility.

However, the quantity of the option value and corresponding flexibility are only of consequence if there is uncertainty, as is the case with Climate Change. When future events are certain, then the correct decision can be calculated as all future benefit and costs can be incorporated in to the decision-making process. Both environmental and financial irreversibilities create the possibility of severe regret, especially in the case of Climate Change and consequently increase the value of flexibility and hence option value. Thus, maximising flexibility and option value as well as potential benefits associated with anticipating regulatory changes appears to be in the interests of a firm.

7.8 Conclusion

This chapter has discussed the implications of the results of the 3 models developed in this study examining whether there is a business case for voluntary emissions reductions for large scale, long-lived projects and whether the approach developed is appropriate.

The first model developed was a CNPV model which served as a BAU case to compare the other models. The CNPV model is the standard method firms use to assess large-scale projects. This involves using linear programming with the objective function being to maximise NPV within a budgetary constraint. Two other models were developed to incorporate greenhouse gas emissions as part of the project selection process. The Emissions Cost Model incorporated an emissions price. However, due to the extreme uncertainty involved with all aspects of Climate Change, the Emissions Cost model incorporate three different emissions prices as well as different discount rate and cash flows. This model produced 27 scenarios with a separate optimal solution for each scenario. The optimal solution for each scenario was then examined in all other scenarios to see how it performed. This approach is known as Robust Optimisation and 2 decision criteria are used. One is a maximin criterion known as Absolute Robust Decision Criterion, while the other is a minimax regret criterion known as Robust Deviation Decision Criterion. With the Emissions Cost Model both the ARDC and the RDDC reached the same solution which reduced emissions the most when compared to all other solutions. The ARDC/RDDC solution outperformed the CNPV in nearly all scenarios with a medium or high emissions price, while the CNPV model generated large negative NPV results in several scenarios. These results suggest that it is very likely to be in the interests of a firm to anticipate regulatory changes. The wildly varying results for the CNPV model highlight the importance of the anticipating such regulations.

The ARDC/RDDC solution also substantially improves the eco-efficiency relative to the CNPV model, which some research suggests should increase the valuation of the firm by up to 7% due to reputational benefits. In addition, the ARDC/RDDC solution also has an implied Real Option Value and flexibility associated with such a decision. Some scholars suggest that the Real Option Value can be up to 50% of any potential opportunity cost, however, both the eco-efficiency and real option benefits are dwarfed by the benefits of anticipating regulatory changes.

The third model, an Emissions Quantity Model was also constructed in which percentage physical emissions reductions were incorporated into the project selection process with 27 scenarios as per the Emissions Cost Model. The Emissions Quantity Model was also a Robust Optimisation model with both an ARDC and RDDC; as with the Emissions Cost Model both the ARDC and RDDC produced the same result selecting a solution with the most emissions reductions. From this results, the cost of implied emissions permits were calculated depending on the percentage reduction of emissions. With a high emissions reduction, permits would only have to be above $21 for it to be in the firm’s interest to reduce emissions by the large amount. Given such a figure is already being used, this suggests that the Emissions Quantity Model also reaches the same conclusion it is in the interests of a firm to voluntary reduce emissions in anticipation of regulatory changes.

The Emissions Quantity Model also improved eco-efficiency which would lead to an improvement in firm valuation of 7% as well as a Real Option Value and increased flexibility. However, as with the Emissions Cost Model, the Emissions Quantity Model was unable to quantify the Real Option Value and value of flexibility and as such the value of anticipating regulatory changes appears to be the most significant.

When the Emissions Cost and Emissions Quantity Models are compared similarities become apparent. For example, they both chose a very similar group of projects, namely projects 1, 4, 9 and 10 and 1, 4 and 10 respectively. In addition, both produced the same result for the ARDC and RDDC and both models highlight the significance of scenario modelling and how the CNPV and ARDC/RDDC solutions performed very differently in different scenarios as opposed to models which use single representative figures such as means or medians.

However, in terms of clarity for decision-makers the Emissions Cost Model is more transparent in terms of NPV for the CNPV and ARDC/RDDC with the Emissions Quantity Model requiring further interpretation of the cost of Emissions Permits for various emissions reductions.

The results also demonstrate the need for a nuanced interpretation of the importance of the discount rate in project selection. Within the field of environmental economics a low discount rate is considered appropriate so as to value the future more closely to the present. However, in this study, solutions for high discount rates produced lower emissions.

The CSR implications of this study suggest that benefits of reputation and real option are far outweighed by the benefit of anticipating regulatory changes which are may or may not fall within the realm of CSR. Consequently, it is difficult to locate such an approach on the graph proposed by Schaltegger and Synnestvedt (2002), especially given the multiple scenario approach of this study. However, given the modelling approach and the belief by some scholars that maximin and minimax regret are 2 forms of the 'mathematimisation' of the precautionary principle which maximises option value, regardless of whether that value can be quantified. Consequently, the large emissions reductions suggested by this model would appear to be very likely in the interests of a firm.

Chapter 8 Conclusion

8.1 Introduction

This thesis set out to explore the business case of voluntary GHG emissions reductions and the associated short-term costs and long-term benefits that may flow from taking such action. Such voluntary action is difficult to operationalise due to the complexity both in terms of how such decisions should be made and how large the emissions reduction should be given the extreme levels of uncertainty associated with all facets of climate change. Numerous reports by respected consultants have suggested that voluntary emissions reductions are economically advantageous but equivalent studies do not exist in the climate change economics literature. In order to examine this question, this thesis has taken the approach of a case study incorporating an emissions factor into capital budgeting techniques for the selection of large scale, long-term projects. Such an approach is fitting as large scale, long-term projects may define the emissions profile of a firm for decades. The significance of the environmental and financial implications of such investment decisions highlights the importance of such a study

8.1.1 Climate Change

Climate Change is an extremely important issue for the ongoing viability of current patterns of life and is due to the increasing levels of CO_2 in the atmosphere (Garnaut, 2008).

The Earth's atmosphere contains certain molecules which have the effect of increasing the average temperature of the atmosphere; this is known as the Greenhouse Effect. Without the Greenhouse Effect due to these molecules it is estimated the global average temperature on Earth would be approximately –18° Celsius whereas with the greenhouse effect the global average temperature is approximately 14° Celsius(IPCC, 2013).

Currently the molecule that is being studied the most is carbon dioxide (CO_2) as this is the molecule which human activity has increased in atmospheric concentrations. Since the beginning of the Industrial Revolution in the late 1700s, atmospheric levels of CO_2 have been increasing as has the level of radiative forcing, i.e. the warming effect of CO_2 (IPCC, 2013). The increase in atmospheric levels of CO_2 is due to CO_2 being released into the atmosphere through the combustion of fossil fuels such as coal, oil and gas. The increased levels of CO_2 and the commensurate increase in strength of the Greenhouse Effect has led to the theory of an Enhanced Greenhouse Effect (Hansen, 2005).

8.1.2 Enhanced Greenhouse Effect (Callender Effect)

The concept of an Enhance Greenhouse Effect through increased combustion of fossil fuels was first proposed by Guy Callender in 1938 and is known as the Callender Effect (Fleming, 2007).

The concentration of CO_2 has increased from 270ppm prior to the Industrial Revolution to approximately 400ppm in 2013 (IPCC, 2013). The increase in CO_2 levels has been due to the strong correlation between economic development and energy consumption (Cleveland et al., 2000). The Callender Effect has become more widely known as Anthropogenic Climate Change or more simply Climate Change (Bolin, 2007).

8.2 Corporate Governance, CSR and Voluntary Emissions Reductions

The issue of voluntary emissions reductions has been repeatedly visited over the past few years by multinational consultant firms who assert that such actions are in the business interests of firms. The theoretical underpinnings of such actions fall within the realm of CSR which itself is considered to be one of the four pillars of corporate governance. However, this specific issue has not been examined in the academic literature and given that climate change is emerging as one of the most important issues to face society in the 21st century this is a significant gap in the literature. The potential effects of effects of climate change include flooding due to sea level rise, increased rainfall in some areas with droughts in other areas, as well as habitat and species loss (CSIRO, 2005). Some economic impacts from climate change are predicted to have a substantially negative impact on the outputs of most economies (Stern, 2006). The social impacts of climate change due to a reduction in clean water and food supplies will also lead to security issues with enormous numbers of people moving from lower lands in an attempt to escape flooding (Barnett, 2003).

The potential impacts of climate change have led to various responses from governments around the world in an attempt to reduce emissions. Currently over 30 countries around the world have introduced a price on carbon emissions. The European Union (EU) introduced an Emissions Trading Scheme (ETS) in 2005, many states in the USA have introduced legislation promoting renewable energy and while an ETS has recently been introduced and subsequently rescinded in Australia, the USA and China are moving ahead with plans to put a price on carbon dioxide emissions (Productivity Commission, 2011).

The environmental, economic, social and security impacts from climate change are related to but distinct from the business impacts associated with climate change. The business impacts of climate change include shareholder, legal, reputational and regulatory impacts (Walsh, 2006) and as such these factors are necessarily part of the corporate governance of a firm and CSR.

Corporations invest billions of dollars annually in many projects that contribute to anthropogenic climate change through their emissions, thereby contributing to climate change and the dangers that presents to the environment and society as well as the business impacts posed from emissions from the projects (Walsh, 2006).

Nearly all corporations select projects through the use of capital budgeting techniques (Graham and Harvey, 2002). At present there appears to be an absence of capital budgeting models in the literature which examine voluntary reduction of greenhouse gas emissions. This is surprising given numerous multinational consulting firms have advocated the business benefits of voluntary emissions reductions (Carbon Trust, 2004, CERES, 2006, Sadler, 2006, Walsh, 2006) and represents a significant gap in the knowledge required for the efficient allocation of funds in a carbon and financially constrained world.

8.3 The Economics of Climate Change

Complex regulatory regimes have been put in place in some countries in order to facilitate this mitigation, with more than 30 countries having a price on carbon of one sort or another and are proposed in others (Productivity Commission, 2011). These regimes have been implemented as it is believed that left to their own devices, firms will not voluntarily reduce emissions to the extent required to avoid runaway climate change (Webster et al., 2008).

Broadly speaking there are currently two market based approaches to climate change mitigation that have been the subject of much discussion; these are emissions trading schemes and taxes on carbon dioxide emissions (Kossoy and Guigon, 2012) . Such regulatory changes will have a major impact on business. Other economic factors to impact on business stem from the reputation a firm may gain from its action or inaction regarding climate change. Reputation is an important issue for businesses with some scholars suggesting that up to 80% of the market value of corporations is due to non-tangible factors such as reputation (Kiernan, 2001). Consequently another factor for firms to consider with respect to climate change is how shareholders may respond to any actions, or lack thereof, the firm may take with respect to climate change (Cosman, 2008).

Given it seems very likely firms will face these issues in the future, this raises the subject of firms undertaking short-term costs for long-term gains as argued for in the Corporate Social Responsibility literature (see for example, Jones and Bartlett, 2009, Reinhardt et al., 2008, Lo and Sheu, 2007). Many studies in this branch of corporate governance literature suggest that it does pay for a firm to incur short-term costs where it is beneficial to either society or the environment or both. However, there are many studies that suggest the opposite and that it is never in a firm's interest to incur such costs. One study incorporates both conclusions by suggesting it that sometimes it may be in a firm's interests to make incur some costs whilst in other conditions such costs will only reduce economic performance (Schaltegger and Synnestvedt, 2002). This is represented by two curves; one is an inverse U curve, indicating some CSR induced actions will improve economic performance whilst the other curve show only decreased economic performance with more CSR actions.

The issue of short-term costs and long-term benefits relates to climate change where the short-term costs are in the form of voluntary emissions reductions, and the long-term gains manifests themselves through the beneficial effects of anticipating regulatory changes, improved reputation, positive shareholder response and potential option value. In particular, this study examines the case of voluntarily reducing emissions incorporated into the assessment of large scale, long-term projects. This assessment nearly always employs capital budgeting techniques.

8.3.1 Conceptual Framework for Investment and Climate Change

A Conceptual Framework for the assessment of climate change issues into project appraisal is inherently complex due to the innate uncertainty in the field of climate change. Nearly all aspects of climate change have large degrees of uncertainty from the amount of change they may be expected from the concentration of a particular greenhouse gas atmospheric, the economic effects of that change, the emissions concentration trajectory; the severity of the regulatory response in attempting mitigation; the list of uncertainties is extensive and diverse.

This analysis is also complicated by the conclusions drawn by some studies that an increase in regional temperatures may have a local beneficial effect, for example through increased crop yields (van den Bergh, 2004). The economic study of climate change is further complicated by the concept of irreversibility which applies to the effects of climate change. Irreversibility was first discussed by Arrow and Fisher (1974) in their landmark study concerning environmental preservation, uncertainty and irreversibility. Arrow and Fisher suggested that if the damage to a particular environmental asset was likely to be irreversible (for example, species extinction or forest cover) and the relative benefits of conservation and development were uncertain then preserving that asset had a value, an option value, in order to keep options open in the future, and this value should be taken into account when assessing such a development. Such logic applies to climate change as the effects of climate change are considered to be irreversible in the time frame of human civilisation. However, irreversibility has two facets, environmental irreversibility discussed above, and financial irreversibility. Financial irreversibility is commonly thought of as sunk costs; once an investment is made, it is all but impossible to retrieve those funds should the project be unsuccessful. Financial irreversibility and environmental irreversibility usually pull in opposite directions and the relative importance of both should be examined in order to provide a comprehensive analysis. However, irreversibility can also be viewed by its reciprocal, flexibility, which is simpler to model. Increased irreversibility means decreased flexibility, and decreased irreversibility means increased flexibility. Consequently where climate change is concerned it would appear that an approach that increases flexibility is beneficial, or has a value; specifically a real option value.

Therefore for climate change to be included in the assessment of large scale, long-term projects, then these factors should be included in the project appraisal. This presents a difficult task as when assessing the case of voluntarily reducing emissions for it is uncertain how strict regulations and uncertain what the correct level of emissions reductions are. In addition, it is uncertain what type of regulatory response will occur, be it a price instrument or a quantity instrument. Consequently if a firm decides to voluntarily reduce emissions it is unclear how much they should reduce them, and they should also maintain investment flexibility should the emissions reduction prove either too large or too small.

The standard form of project appraisal is capital budgeting which examines projected cash flows at a given discount rate to arrive at a net present value. Linear programming techniques are often employed in capital budgeting calculations when capital rationing is present, however, normal linear programming techniques do not take into account uncertainty, nor do they take into account competing goals such as minimising pollution whilst maximising value.

Traditional linear programming has been extended in recent times to goal programming and multiple objective linear programming which specifically take into consideration multiple goals. Such an approach is suitable here given the aim of reducing emissions whilst also maximising net present value.

8.4 Empirical Findings

A Business As Usual model was constructed using a conventional NPV approach with generating the largest profit the only criteria subject to a budgetary constraint. This model was used as a reference case to compare the other models with. This Conventional NPV (CNPV) model use a linear programming method which is commonly employed to evaluate large scale, long lived projects. Linear programming involves setting an objective function (ie maximise profit) subject to constraints, i.e. budget.

In addition to the business as usual model, two additional models were developed which incorporated greenhouse gas emissions into the project selection process. These two models included 27 scenarios with one model utilising a cost on emissions and the other model utilising a physical quantity reduction in emissions into the project assessment process.

An optimal solution was generated for each scenario for the Emissions Cost Model. The optimal solution from each scenario was then compared with all other solutions in all other scenarios in a technique known as Robust Optimisation. The results from this comparison of optimal solutions were then analysed in two separate ways, namely a maximin criterion known as the Absolute Robust Decision Criterion (ARDC) and the other being a mnimax regret criterion known as the Robust Deviation Decision Criterion (RDDC). The two decision criteria selected the same projects which reduced emissions the most in comparison to all other solutions. The ARDC/RDDC solution performed better than the CNPV in nearly all scenarios with a medium or high emissions price with substantially lower emissions than the CNPV solution. The CNPV generated negative results in numerous scenarios. This suggest that it could very likely be in the interests of the firm to anticipate regulatory changes with respect to a price on emissions in order to avoid potential stranded assets. The results for the CNPV model varied enormously, however, the emissions generated for each scenario were substantially higher than the ARDC/RDDC solution.

Due to the combination of higher NPV and lower emissions, the eco-efficiency relative to the CNPV model was substantially higher and according to additional research suggests that the firm may have an increased valuation by up to 7% due to the benefits of an improved reputation.

The final model, an Emissions Quantity Model also used 27 scenarios but the emissions criteria involved a physical reduction of emissions in the selection of projects. An optimal solution was generated for each of the scenarios and the optimal solutions were compared against the optimal solutions in the other scenarios as per the Emissions Cost Model. Also consistent with the Emissions Cost Model is that both the ARDC and RDDC models selected the same projects which reduced emissions by the greatest amount. From this result, the cost of implied emissions were calculated depending on the percentage reduction of emissions. With a high emissions reduction permits would have to be above $21 for it to be in the firm's interests to reduce emissions by the large amount suggested in the model. This figure is higher than currently being discussed though in line with the amount modelled by Treasury in 2008. As with the Emissions Cost Model, the Emissions Quantity Model also increased the eco-efficiency relative to the CNPV model which would also increase the valuation of the firm by 7%.

The results of the Emissions Cost and Emissions Quantity Models have similar results in several ways. Both these models chose a very similar group of projects, namely projects, 1, 4, 8 and 10 and 1, 4 and 10 respectively as well as both decision criteria for both models were consistent.

Both models also illustrated the significance of scenario modelling in being able to demonstrate how the CNPV and ARDC/RDDC solutions performed very differently in different scenarios. This result highlights the instructive nature of multiple scenario modelling as opposed to using a single representative figure such as average or median. The use of a representative figure would not capture these wildly varying results and the resulting implications and potentially ambiguous effects.

In terms of intelligibility and reducing ambiguity for decision makers the Emissions Cost Model is clearer in terms of NPV for the CNPV and ARDC/RDDC with the Emissions Quantity Model requiring further interpretation of the cost of Emissions Permits for various emissions reductions.

8.5 Theoretical Implications

Economic theory suggests that emissions will reduce when they have a price attached to them. Such action represents internalising the externality associated with damaging GHG emissions and as such the results from the Emissions Cost Model support this concept. In addition, the ARDC/RDDC solution also has an implied maximum flexibility and hence maximised Real Option Value as some researchers have suggested maximin and minimax regret are different forms of the mathematimisation of the precautionary principle. Therefore theoretically these decision criteria should maximises future flexibility by maintaining the current climate system and therefore keeps the most options open for the future and hence provide the maximum option value regardless of what quantity that option value is (Hof et al., 2010). Some scholars suggest that the Real Option Value can be significant (Busch and Hoffman, 2009, Figge, 2005) with one scholar suggesting real option value can be up to 50% of any potential opportunity cost (Ha-Duong, 1998). However, both the eco-efficiency and real option benefits are dwarfed by the financial benefits of anticipating regulatory changes and the avoidance of stranded assets.

As also with the Emissions Cost Model, the Emissions Quantity Model was unable to quantify the Real Option Value and value of flexibility but as maximin and minimax regret were also used, this suggests that the option value is maximised without knowing its value. Nevertheless as with the Emissions Cost Model, the value of anticipating regulatory changes appears to be the most significant through the avoidance of stranded assets.

The results also demonstrate the need for a nuanced interpretation of the importance of the discount rate in project selection. Within the field of environmental economics, theoretically a low discount rate is considered correct so as to value the future more closely in line to the present. However, in this study, solutions for high discount rates produced lower emissions and consequently the opposite conclusion is reached.

The Corporate Social Responsibility (CSR) implications of this study suggest that benefits of reputation and real option are far outweighed by the benefit of anticipating regulatory changes which are not necessarily considered to fall within the realm of CSR. Consequently the theoretical CSR implications of this thesis suggest it is in the best interest of a firm to adopt an approach which reduces emissions due to increasing eco-efficiency and the resulting improvement in reputation. However, while anticipating emissions regulations leads to an improved eco-efficiency but with this data set improving eco-efficiency in the absence of emissions regulations may improve reputation and market valuation but this gain is an order of magnitude lower than the opportunity cost associated with foregone revenue. This would suggest it is not in the interest of the firm to take such an approach. Despite this, the results of this thesis add more evidence to the suggestion that the difficult issues of uncertainty, investment and climate change may be best approached using ex ante scenario modelling as opposed ex post methods such as sensitivity analysis. This is due to the important theoretical implications of financial and environmental irreversibility which make ex post measures inappropriate. Such an approach may also avoid stranded assets.

There has also been a significant theoretical question regarding whether price or quantity instruments are best for assessing environmental initiatives. This study has not been able to contribute to this question due to the lack of impact an emissions price has on the selection of projects, consequently examination of the respective marginal cost curves is not possible.

Corporate Social Responsibility (CSR) implications of this study as described by Schaltegger and Synnestvedt (2002) suggest that if option value and eco-efficiency are not included in calculations of economic success then it is not in the business interest of a firm to voluntarily reduce emissions and that such actions only lead to reduced economic success. However, inclusion of such factors makes such theoretical considerations more complex. With such calculations it is conceivable that voluntary emissions reductions are in the business interests of a firm but such calculations are very difficult to quantify and further research is required.

The theoretical implications of option value are a significant finding also. With respect to climate change and investment option value appears to be very important and further research needs to be undertaken in this area as this issue is the major stumbling block to a definitive conclusion regarding the business case for voluntary emissions reductions.

8.6 Research Contributions

This thesis has made research contributions by employing a Robust Optimisation framework in a capital budgeting case study which includes climate change regulatory uncertainty. To the author's knowledge this has not been done before.

This study has also indicated that the current levels of prices on emissions are within the correct order of magnitude to alter an optimal suite of projects within a budget constraint. This study has also emphasised the importance of the discount rate in selecting the optimal suite, however, the surprising result is that the optimal suite for high discount rates achieves the lowest emissions which runs counter to the conclusions many scholars have drawn in the sphere of environmental economics.

Another contribution this study has made is the solution of a model which incorporates emissions reductions suggests that when the competing priorities of net present value and emissions are given equal weighting, the solution which minimises the deviation from both goals is one with the lowest emissions.

Overall, this case study has found that it is difficult to conclude such actions are in a firm's business interest to make voluntary emissions reductions.

8.7 Recommendations for Future Research

The most significant area of further research is the quantification of real option value. Such quantification studies would provide the definitive answer to the question of the business case for voluntary emissions reductions. At present it is only possible to specify the level of opportunity cost that such actions imply and the corresponding level at which option value should take

Also further studies should examine the impact of different prices on emissions and discount rates in project selection to verify the findings of this study.

8.8 Limitation of the Study

Despite the research contributions of this study, there are several limitations or assumptions that potentially could affect the results. Assumptions have been made with respect to eco-efficiency and firm value. In addition, the issue of optimisation has also been debated in the literature. These are discussed in greater detail below.

8.8.1 Eco-efficiency

The evidence linking eco-efficiency and shareholder valuation is primarily provided by Guenster, Bauer et al. (2010). To undertake this study they used eco-efficiency scores from Innovest Strategic Value Advisors who used approximately 60 weighted criteria across 5 main areas in their assessment. These include historical liabilities, operating risk, sustainability risk, managerial risk efficiency and potential opportunities for eco-efficiency benefit. These eco-efficiency scores have 20 different data sources in order to make the scores as rigorous as possible, however, their approach has been criticised as having little to do with sustainability from a thermodynamic and ecological point of view as well as the methodology not being transparent (Lockwood, 2009). Nevertheless, the Derwell, Guenster et al. (2004a) study appears to be the most rigorous of the studies to examine this issue. Using performance attribution models controlling for differences in risk, investment style and sector exposure. This study was re-performed by Guenster, Bauer et al. (2010) with a data set covering a longer time frame and reached a similar conclusion with a slightly revised eco-efficiency dividend from 6% up to 7% using Tobin's Q to illustrate the rise in market value. However, these results were not immediately priced into the share valuation but the increased valuation occurred over a period of more than 2 years. If this result is correct, it has implication for the short-term value of eco-efficiency, as well as wider implications of the efficient pricing of markets.

However, in this study the definition of eco-efficiency is not the same; energy intensity is taken to be a proxy for the eco-efficiency. The World Business Council for Sustainable Development suggested the critical elements of eco-efficiency included improving energy intensity but also

- A reduction in the material intensity of goods or services;
- Reduced dispersion of toxic materials;
- Improved recyclability;
- Maximum use of renewable resources;
- Greater durability of products; and
- Increased service intensity of goods and services.

At best, energy intensity is an approximation for eco-efficiency, however, to the author's knowledge no studies have examined the intangible benefits to a firm of reducing energy intensity. The lack of evidence to support this assumption is provides difficulty in establishing the rigour of this study's conclusions.

8.8.2 Firm Value

An assumption in this study is that the NPV is equivalent to the shareholder value which itself is equivalent to market value.

Rappaport's model of firm valuation is based on the present value of future free cash flows (1986), as shown in the equation below:

$$Shareholder\_Value = \sum_{i=1}^{n} \frac{FCF_n}{(1+i)^n} - IC$$

where FCF = free cash flow, n = number of time periods, i = discount rate, IC = invested capital.

However, the theory behind this view of shareholder value has been the subject of some criticism. An example of this is that management and investors can exert considerable influence on the selection of the discount rate and the estimates of the future cash flow and if these do not eventuate then the calculations will not correspond to the correct shareholder value. However, these concerns have been accommodated for in the robust optimisation model which models multiple scenarios and multiple discount rates (Schaltegger and Figge, 2000).

8.8.3 Model Validity: Is Optimisation Appropriate?

The choice of linear programming optimisation for this study is debatable as some scholars argue that the issue of climate change with its inherent uncertainty and irreversibilities is inappropriate to model in terms of optimal outcomes, but rather a strategy should be chosen that is adequate to meet conflicting irreversible priorities (Schwartz et al., 2010).

Optimum policies do not always perform well in catastrophic scenarios, or other low probability but high consequence occurrences. Consequently is has been suggested that an optimum policy is a delicate foundation on which to construct a climate change policy (van den

Bergh, 2004). This is especially the case as policy recommendations based on optimal decisions can be criticised by others who believe different scenarios of the future.

The Robust Optimisation approach taken in this study combines the two approaches by optimising scenarios and then choosing solutions which work best in all scenarios. However, such conflicting priorities have led to the concept of satisficing; a portmanteau of satisfy with suffice, which was coined by Herbert Simon (1957). Satisficing is considered to be decision making which endeavours to attain at least some minimum level of a given variable, but not necessarily maximize its value. In economics this concept has been applied in the behavioural theory of the firm, which, as distinct from long-established points of view, suggests that profit should be viewed as a constraint as opposed to a goal to be maximised. Viewed from this perspective, a certain level of profit must be achieved by firms but beyond that point the attainment of other goals becomes a priority. If the Satisficing approach were to be taken then the Emissions Quantity Model Absolute Robust/Robust Deviation criteria would be seen in a different light.

8.9 Conclusion

Examining the business case for voluntary GHG emissions is an extremely important issue given the potential repercussions of climate change for business as well as society.

The large uncertainty associated with all facets of climate change led to the development of a CSR conceptual framework with multiple scenario modelling to investigate a case study to assess large scale, long lived projects with the potential to define emissions profiles for decades.

When compared with a conventional NPV model, the multiple scenario models incorporating an emissions price or emissions reduction goal and using decision criteria of maximin and minimax regret reached the same solution; that is, it is in a firm’s interest to anticipate emissions regulations and reduce emissions but over 90%. However, such action does not fall strictly within the realm of CSR and actions that do such as eco-efficiency leading to market valuation increases are far outweighed by anticipating regulatory changes.

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Appendices

Appendix A: Emissions Cost Model Optimal Solutions for each Scenario

	Projects	Select 0 = no 1 = yes										
Scenarios	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**
1	$8,388	$1,524	$3,080	$929	$684	$6,565	$19,981	$975	$14,358	$4,659	$5,121	
Select?	1	1	1	1	1	0	1	1	0	1	1	$45,341
Capex												-$7,786
2	$11,835	$2,054	$4,132	$1,252	$1,004	$9,513	$27,989	$1,407	$20,765	$6,397	$6,979	
Select?	1	1	1	1	1	0	1	1	0	1	1	$63,050
Capex												-$7,786
3	$15,283	$2,584	$5,183	$1,576	$1,324	$12,462	$35,997	$1,840	$27,173	$8,136	$8,837	
Select?	1	1	1	1	1	0	1	1	0	1	1	$80,759
Capex												-$7,786
4	$2,252	$703	$1,396	$635	$299	$312	$5,872	-$52	$7,086	$1,341	$1,774	
Select?	1	1	1	1	1	0	0	0	1	1	1	$15,487
Capex												-$8,286
5	$3,335	$949	$1,872	$857	$445	$827	$8,343	-$13	$10,446	$1,864	$2,426	
Select?	1	1	1	1	1	0	0	0	1	1	1	$22,194
Capex												-$8,286
6	$4,418	$1,195	$2,349	$1,079	$590	$1,342	$10,813	$25	$13,806	$2,387	$3,078	
Select?	1	1	1	1	1	0	0	1	1	1	1	$28,926
Capex												-$8,610
7	$668	$388	$745	$459	$155	-$605	$2,382	-$107	$3,971	$581	$761	
Select?	1	1	1	1	1	0	0	0	1	1	1	$7,729
Capex												-$8,286
8	$1,117	$525	$1,000	$619	$233	-$491	$3,448	-$105	$5,982	$822	$1,044	

Select?	1	1	1	1	1	0	0	0	1	1	1	$11,342
Capex												-$8,286
9	$1,565	$662	$1,255	$779	$311	-$377	$4,515	-$104	$7,994	$1,062	$1,328	
Select?	1	1	1	1	1	0	0	0	1	1	1	$14,955
Capex												-$8,286
10	$6,939	$282	$855	$663	-$61	$3,996	-$22,516	$1	$11,756	$3,785	$1,716	
Select?	1	1	1	1	0	0	0	1	1	1	1	$25,998
Capex												-$8,334
11	$9,904	$399	$1,165	$899	$11	$6,089	-$28,674	$109	$17,297	$5,231	$2,438	
Select?	1	1	1	1	1	0	0	1	1	1	1	$37,453
Capex												-$8,610
12	$12,868	$515	$1,475	$1,134	$83	$8,182	-$34,832	$217	$22,838	$6,678	$3,161	
Select?	1	1	1	1	1	0	0	1	1	1	1	$48,969
Capex												-$8,610
13	$1,880	$230	$546	$462	$19	-$40	-$1,011	-$171	$5,867	$1,168	$807	
Select?	1	1	1	1	1	0	0	0	1	1	1	$10,978
Capex												-$8,286
14	$2,840	$318	$739	$625	$71	$357	-$835	-$172	$8,820	$1,633	$1,137	
Select?	1	1	1	1	1	0	0	0	1	1	1	$16,182
Capex												-$8,286
15	$3,799	$407	$932	$789	$122	$755	-$658	-$173	$11,774	$2,098	$1,466	
Select?	1	1	1	1	1	0	0	0	1	1	1	$21,386
Capex												-$8,286
16	$547	$175	$366	$338	$31	-$669	$699	-$121	$3,319	$528	$425	
Select?	1	1	1	1	1	0	0	0	1	1	1	$5,729
Capex												-$8,286

17	$956	$240	$494	$458	$67	-$577	$1,205	-$123	$5,113	$751	$596	
Select?	1	1	1	1	1	0	0	0	1	1	1	$8,675
Capex												-$8,286
18	$1,364	$306	$622	$578	$104	-$485	$1,710	-$126	$6,907	$974	$766	
Select?	1	1	1	1	1	0	0	0	1	1	1	$11,621
Capex												-$8,286
19	$3,995	-$2,240	-$3,667	$124	-$1,574	-$1,223	-$108,881	-$1,978	$6,470	$2,008	-$5,205	
Select?	1	0	0	1	0	0	0	0	1	1	0	$12,597
Capex												-$7,417
20	$5,977	-$2,965	-$4,865	$180	-$2,006	-$870	-$143,828	-$2,529	$10,249	$2,862	-$6,789	
Select?	1	0	0	1	0	0	0	0	1	1	0	$19,268
Capex												-$7,417
21	$7,960	-$3,689	-$6,063	$236	-$2,439	-$518	$78,112	-$3,080	$14,027	$3,716	-$8,373	
Select?	1	0	0	1	0	0	1	0	0	1	0	$90,024
Capex												-$6,593
22	$1,125	-$732	-$1,182	$109	-$551	-$756	-$14,999	-$413	$3,389	$815	-$1,158	
Select?	1	0	0	1	0	0	0	0	1	1	0	$5,438
Capex												-$7,417
23	$1,833	-$964	-$1,564	$155	-$689	-$597	-$19,485	-$494	$5,516	$1,163	-$1,484	
Select?	1	0	0	1	0	0	0	0	1	1	0	$8,666
Capex												-$7,417
24	$2,541	-$1,196	-$1,947	$201	-$828	-$438	-$23,971	-$576	$7,643	$1,510	-$1,810	
Select?	1	0	0	1	0	0	0	0	1	1	0	$11,895
Capex												-$7,417
25	$302	-$260	-$406	$94	-$222	-$800	-$2,721	-$148	$1,995	$421	-$260	

Select?	1	0	0	1	0	0	0	0	1	1	0	$2,811
Capex												-$7,417
26	$628	-$339	-$535	$133	-$270	-$751	-$3,355	-$159	$3,347	$608	-$317	
Select?	1	0	0	1	0	0	0	0	1	1	0	$4,716
Capex												-$7,417
27	$955	-$419	-$665	$171	-$318	-$702	-$3,989	-$171	$4,699	$795	-$374	
Select?	1	0	0	1	0	0	0	0	1	1	0	$6,620
Capex												-$7,417
										average	$23,660
Capex	-$1,953	-$67	-$74	-$43	-$276	-$2,281	-$4,042	-$323	-$4,866	-$556	-$452	
Budget	-9000											

Appendix B: Emissions Quantity Model Optimal Solution for 27 Scenarios

	Projects														
Scenarios	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**Total**	**NPV goal % devn**	**EQ goal % devn**	**Minimax Variable *Q***
1	9,323	2,325	4,516	1,100	1,164	8,222	47,399	1,603	16,036	5,223	7,318				
Select?	1	1	1	0	0	1	1	0	0	1	0	77,007	3.7%	−2.1%	3.7%
Capex												−8,973		3.6	
2	13,082	3,122	6,046	1,480	1,644	11,723	64,546	2,245	23,003	7,150	9,908				
Select?	1	1	1	0	0	1	1	0	0	1	0	105,668	3.3%	−1.9%	3.3%
Capex												−8,973		3.8	
3	16,841	3,919	7,576	1,861	2,124	15,224	81,692	2,887	29,970	9,076	12,498				
Select?	1	1	1	0	0	1	1	0	0	1	0	134,328	3.0%	−1.9%	3.0%
Capex												−8,973			
4	2,492	1,008	1,944	748	480	539	10,312	25	7,873	1,453	2,398				
Select?	0	0	1	0	0	0	1	0	1	0	0	20,129	3.5%	−5.2%	3.5%
Capex												−8,982			
5	3,655	1,356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258				
Select?	0	0	1	0	0	0	1	0	1	0	0	28,362	2.0%	−5.2%	2.0%
Capex												−8,982			
6	4,818	1,704	3,263	1,266	891	1,721	18,214	153	15,117	2,573	4,118				
Select?	0	0	1	0	0	0	1	0	1	0	0	36,594	1.1%	−4.4%	1.1%
Capex												−8,982			
7	746	526	990	536	235	−563	3,467	−99	4,392	615	978				
Select?	1	1	1	1	0	0	0	0	1	1	1	8,785	2.6%	4.8%	4.8%

Capex												−8,011		4.8	
8	1,221	709	1,327	722	340	−436	4,896	−94	6,543	867	1,334				
Select?	1	1	1	1	0	0	0	0	1	1	1	12,723	2.6%	4.7%	4.7%
Capex												−8,011			
9	1,695	892	1,663	908	445	−308	6,324	−89	8,695	1,119	1,690				
Select?	1	1	1	1	0	0	0	0	1	1	1	16,661	2.6%	4.5%	4.5%
Capex												−8,011			
10	9,323	2,325	4,516	1,100	1,164	8,222	47,399	1,603	16,036	5,223	7,318				
Select?	0	0	0	0	0	0	1	0	0	1	0	52,622	34.2%	36.7%	36.7%
Capex												−4,598			
															p
11	13,082	3,122	6,046	1,480	1,644	11,723	64,546	2,245	23,003	7,150	9,908				
Select?	0	0	0	0	0	0	1	0	0	1	0	71,695	34.4%	36.2%	36.2%
Capex												−4,598			
12	16,841	3,919	7,576	1,861	2,124	15,224	81,692	2,887	29,970	9,076	12,498				
Select?	0	0	0	0	0	0	1	0	0	1	0	90,768	34.5%	36.9%	37.4%
Capex												−4,598			
13	2,492	1,008	1,944	748	480	539	10,312	25	7,873	1,453	2,398				
Select?	1	1	1	1	1	0	0	1	1	1	1	18,420	11.7%	−13.8%	11.7%
Capex												−8,610			
14	3,655	1,356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258				
Select?	1	1	1	1	1	0	0	1	1	1	1	26,161	9.6%	−12.2%	9.6%
Capex												−8,610			
15	4,818	1,704	3,263	1,266	891	1,721	18,214	153	15,117	2,573	4,118				
Select?	1	1	1	1	1	0	0	1	1	1	1	33,902	8.4%	−12.2%	8.4%
Capex												−8,610			

16	746	526	990	536	235	–563	3,467	–99	4,392	615	978				
Select?	1	0	1	1	0	0	0	0	1	1	0	7,280	19.3%	20.1%	20.1%
Capex												–7,491			
17	1,221	709	1,327	722	340	–436	4,896	–94	6,543	867	1,334				
Select?	1	1	0	1	1	0	0	0	1	1	0	10,403	20.4%	15.5%	20.4%
Capex												–7,760			
18	1,695	892	1,663	908	445	–308	6,324	–89	8,695	1,119	1,690				
Select?	1	1	0	1	1	0	0	0	1	1	0	13,754	19.6%	15.5%	19.6%
Capex												–7,760			
19	9,323	2,325	4,516	1,100	1,164	8,222	47,399	1,603	16,036	5,223	7,318				
Select?	1	0	0	0	0	0	0	1	1	1	0	32,185	59.8%	57.6%	59.8%
Capex												–7,698		p	
20	13,082	3,122	6,046	1,480	1,644	11,723	64,546	2,245	23,003	7,150	9,908				
Select?	1	0	0	0	0	0	0	0	1	1	0	43,235	60.4%	57.8%	60.6%
Capex												–7,375			
21	16,841	3,919	7,576	1,861	2,124	15,224	81,692	2,887	29,970	9,076	12,498				
Select?	1	0	0	0	0	0	0	0	1	1	0	55,887	59.6%	57.4%	59.6%
Capex												–7,375			
22	2,492	1,008	1,944	748	480	539	10,312	25	7,873	1,453	2,398				
Select?	1	0	0	0	0	0	0	0	1	1	0	11,817	43.3%	47.2%	47.2%
Capex												–7,375			
23	3,655	1,356	2,603	1,007	686	1,130	14,263	89	11,495	2,013	3,258				
Select?	1	0	0	0	0	0	0	0	1	0	0	15,150	47.6%	41.3%	47.6%
Capex												–6,819			
24	4,818	1,704	3,263	1,266	891	1,721	18,214	153	15,117	2,573	4,118				
Select?	1	0	0	0	0	0	0	0	1	0	0	19,935	46.1%	40.7%	46.1%

Capex												−6,819			
25	746	526	990	536	235	−563	3,467	−99	4,392	615	978				
Select?	1	0	0	1	0	0	0	0	0	1	0	1,898	79.0%	57.8%	79.0%
CapexPete												−2,551	79	57.8	
26	1,221	709	1,327	722	340	−436	4,896	−94	6,543	867	1,334				
Select?	1	0	0	1	0	0	0	0	0	1	0	2,810	78.5%	67.9%	78.5%
Capex												−2,551			
27	1,695	892	1,663	908	445	−308	6,324	−89	8,695	1,119	1,690				
Select?	1	0	0	1	0	0	0	0	0	1	0	3,723	78.2%	58.5%	78.2%
Capex												−2,551			
											average	35,256			
Capex	−1,953	−67	−74	−43	−276	−2,281	−4,042	−323	−4,866	−556	−452				
Budget	−9000														