A Portfolio Approach To Climate Change Investment And Policy

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Introduction

The London Accord and other climate change investigations conclude that there is no single solution to the problem of climate change. Mankind must deploy a diverse range of potential solutions - market solutions, technological solutions and social solutions. The 'supply side' of potential solutions does not contain one guaranteed single solution, a 'silver bullet'. Pacala and Socolow [2004] note, "Although no element is a credible candidate for doing the entire job (or even half the job) by itself, the portfolio as a whole is large enough that not every element has to be used." On the 'demand side', Stern [2006] highlights the limitations of cost/benefit analysis where one cannot afford to fail; cost/benefit analysis is of little use in Russian roulette unless you accept extinction as an option. A portfolio approach to climate change solutions is warranted given the catastrophic nature of failure – "don't put all your eggs in one basket".

Policy is important; more so is investment. According to the UNFCCC, "When considering the means to enhance financial and investment flows to address climate change in the future, it is important to focus on the role of private-sector investments as they constitute the largest share of investment and financial flows (86%)." [UNFCCC, 2007] As noted elsewhere in the London Accord submissions, "there will be winners and losers". Investors realise that there is rarely a single winner in any investment field. Long-term investment is about having a range of options. Any single solution may fail or, at the extreme, even increase climate change. Investors analyse a range of options as a portfolio. For the majority of investors, the 'most effective' portfolio means the most profitable selection of options for a given level of investment and financial risk. Similarly for policy-makers, 'most effective' is likely to mean a portfolio that delivers a desired level of emissions reduction for the lowest cost and level of social risk. But policy-makers have a strong tendency to try and pick winners.

As explained in A1: **Review of the Contents**, there is a wide range of investment options, and all of them are sensitive to dynamic factors such as energy prices, carbon prices, policies, standards, regulation, taxation, and rates of technology improvement. Larger investors with longer-term views, e.g. investment managers, asset managers or pension funds, need to develop their own portfolios. The participants in the London Accord have donated their research with the aim of helping longer-term investors develop their thinking on climate change, so it would be useful to demonstrate a basic approach to analysing investment weightings, a Monte Carlo analysis of possible climate change portfolios, a London Accord Portfolio Model.

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A London Accord Portfolio Model can be neither comprehensive nor rigorous. The data needed for a comprehensive model is not available. Investors and policy-makers have their own assumptions about the dynamic factors, opinions on factor interactions, and views on likely scenarios. There is no consensus view on many important factors. However, Intergovernmental Panel on Climate Change (IPCC) data and London Accord information, in conjunction with a number of 'heroic' assumptions, can produce an outline London Accord Portfolio Model as a starting point for further thinking by investors and climate change policy-makers.

Modern Portfolio Theory (MPT)

Harry Markowitz proposed Modern Portfolio Theory (MPT) in 1952, later sharing a Nobel Prize with Merton Miller and William Sharpe for founding a school of thought on the rational selection of investment portfolios. Before MPT, investors assessed the risks and rewards of securities individually with little thought for the overall risk or reward in their portfolios. It was assumed that the best portfolio consisted of the amalgamation of securities with the most opportunity for gain at the least risk. An investor might invest solely in automobile companies because all automobile companies' securities seem to offer better risk/reward than all other industries' securities. In the extreme, an investor might invest solely in the 'best' automobile company, to the exclusion of all other securities. The overall portfolio risk and reward might be ignored. Today, such an approach seems naïve. Markowitz set out the mathematics behind diversification, recommending that investors select portfolios based on their overall risk/reward characteristics. Investors should select for their portfolios, not just pick individual securities.

The Efficient Frontier

And they should select portfolios along the "efficient frontier". From Wikipedia:

> "Every possible asset combination can be plotted in risk-return space, and the collection of all such possible portfolios defines a region in this space. The line along the upper edge of this region is known as the efficient frontier (sometimes "the Markowitz frontier"). Combinations along this line represent portfolios (explicitly excluding the risk-free alternative) for which there is lowest risk for a given level of return. Conversely, for a given amount of risk, the portfolio lying on the efficient frontier represents the combination offering the best possible return. Mathematically the Efficient Frontier is the intersection of the Set of Portfolios with Minimum Variance and the Set of Portfolios with Maximum Return … The efficient frontier is a parabola (hyperbola) when expected return is plotted against variance (standard deviation). The region above the frontier is unachievable by holding risky assets alone. No portfolios can be constructed corresponding to the points in this region. Points below the frontier are suboptimal. A rational investor will hold a portfolio only on the frontier."

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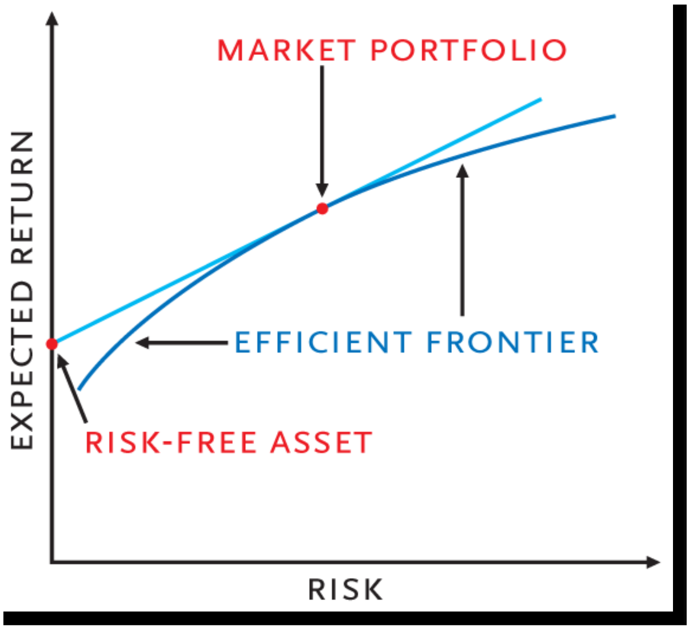


[Source: http://en.wikipedia.org/wiki/Modern_portfolio_theory]

> Specific risk is the risk associated with individual options. Within a diversified portfolio overall specific risk starts to cancel out. From the universe of possible portfolios, certain ones will balance risk and reward better than others. James Tobin developed the idea of the "risk-free asset" permitting the selection of the super-efficient portfolio and introducing the use of leverage. Sharpe developed the capital asset pricing model (CAPM), introducing beta as a measure of asset or portfolio expected risk against the market. Sharpe pointed out that the overall market portfolio should intersect the efficient frontier at Tobin's super-efficient portfolio. According to CAPM, investors should mimic the market portfolio, leveraged or de-leveraged with positions in the risk-free asset.

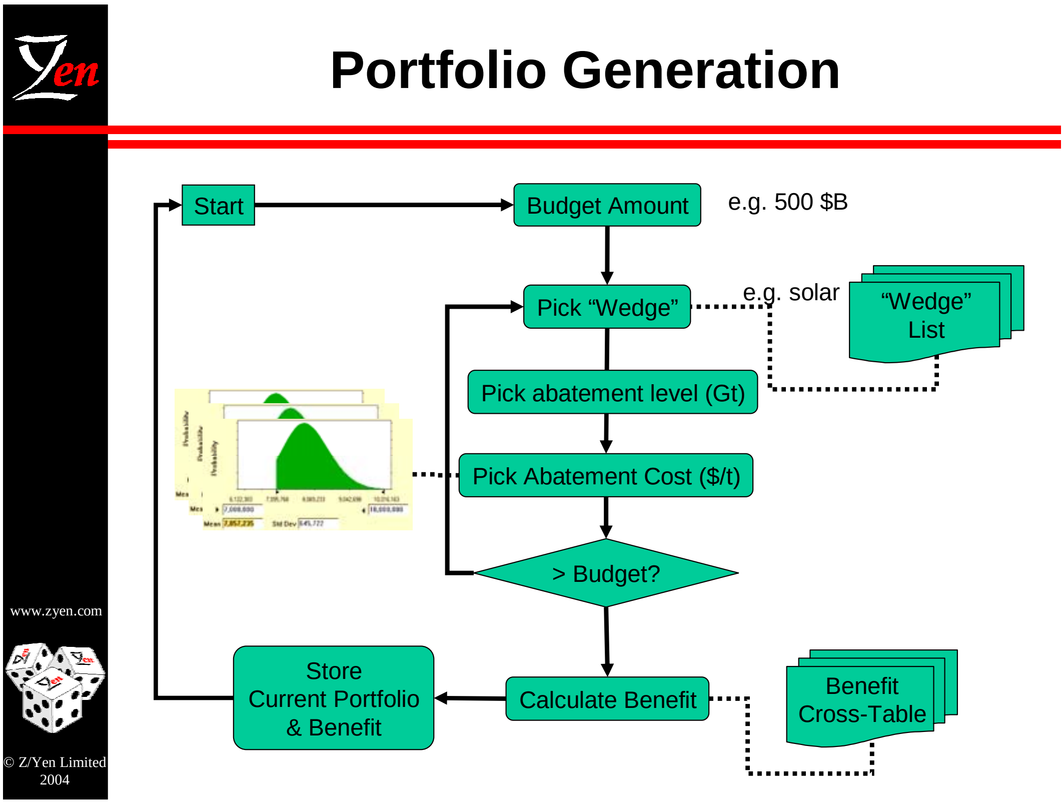
MPT gave a context for understanding systematic risk and reward, led to structured management of institutional portfolios and inspired passive, 'tracker', investment management approaches. Naturally, MPT has been followed by a 'Post-Modern' Portfolio Theory which tries to model more closely a real world situation where the underlying distributions are non-normal, risks and rewards are non-linear, and where human behaviour matters. So, in summary, the basic concepts of MPT are diversification, the efficient frontier and the capital asset pricing model.

Approach

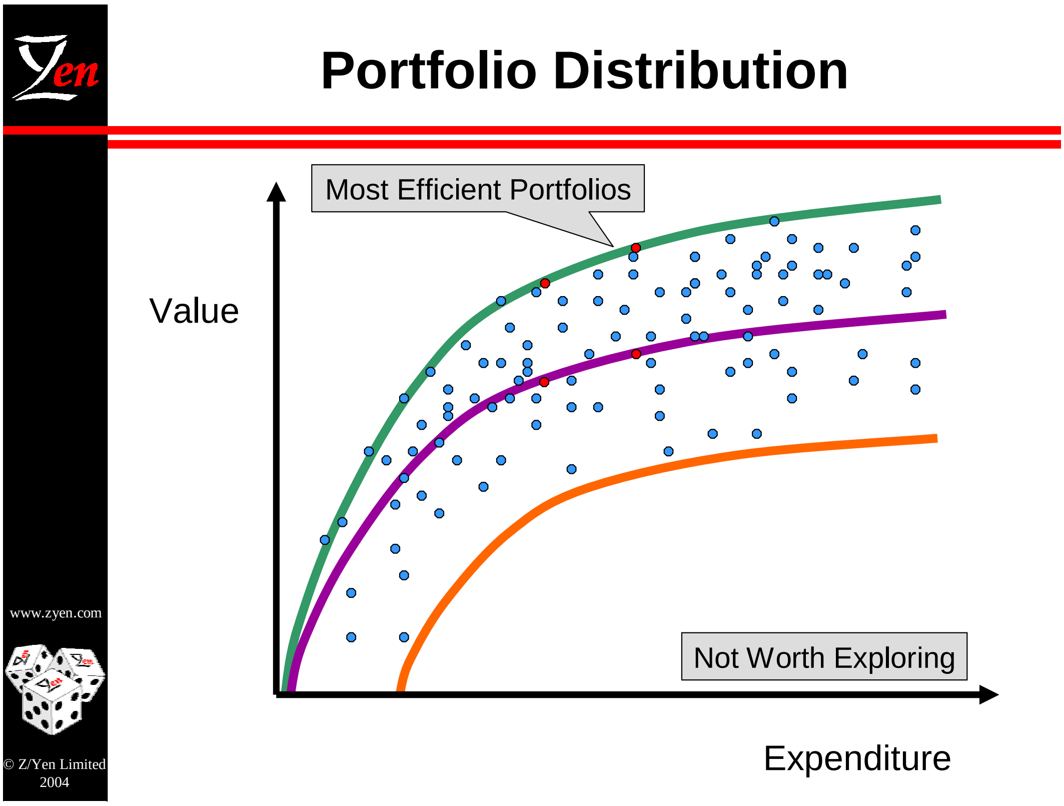
The efficient frontier of a portfolio model should produce sensible combinations of climate change solutions for further discussion. The model should produce combinations across a range of expenditures and returns, but in the case of climate change expenditure and returns are not sufficient. The model must also produce combinations across a range of greenhouse gas emission reductions. For the London Accord, the goal of this paper was to produce an illustrative, dual output portfolio model that provides combinations of returns and greenhouse gas emission reductions across a range of expenditures. In line with the London Accord's core concept, the goal was to produce not just "cash in, cash out", but also "cash in, carbon out".

For our model we have used a Monte Carlo approach to generate the portfolios. Monte Carlo analysis is a computational technique that can be used to simulate complex systems, by randomly (within constraints) generating a large number of potential solutions, in this case portfolios.

The portfolio generation algorithm is illustrated below:



Basically, the algorithm steps through a loop, each time generating a random annual budget up to $850 billion/year more than the world invests today. Within this budgetary loop there is an inner loop that first randomly selects an investment option (equivalent to a Socolow "wedge"), and then selects a random level of abatement up to the maximum potential of that technology. The third step in the inner loop generates an abatement cost from the assigned cost distribution. The inner loop is repeated until the allocated budget for each portfolio is reached. When this occurs, the portfolio benefit is calculated and stored, and then the outer loop is repeated until the desired number of portfolios is generated, in this case ten thousand. The benefit cross-table was not used, but is discussed briefly later in the document as to way to model synergies between investment options. Once a large range of portfolios have been generated, they are plotted for further analysis, as below:



The key input data are costs and returns. Returns are investment returns or greenhouse gas emission reductions. One interesting niggle is "negative abatement costs". Negative abatement costs relate to investment options that are profitable without a value for greenhouse gas emission reductions, e.g. being able to reduce the need to purchase cap-and-trade permits or avoid a 'carbon tax'. Investing in building efficiency is an example of negative abatement cost. The investment often pays for itself in reduced energy costs, regardless of the additional greenhouse gas emissions reduction.

Three scenarios were examined:

Scenario A – The Base Case - This scenario excluded negative abatement costs on the basis that these investments should be undertaken under any business-as-usual scenario and, therefore, are not strictly investment measures as a response to climate change. For example, if using energy-saving lighting is already economically advantageous, the only question is whether to accelerate this, not whether it should be the proper economic decision for infrastructure replacement (see Merrill Lynch's contribution to the London Accord - C5: "Efficiency: The Potential for Selected Investment Opportunities"). So the base case focuses on 'positive' investments to ameliorate climate change, additional marginal costs;

Scenario B –Sarasin's Views on Solar - In Sarasin Bank's contribution to the London Accord - C1: "Solar Energy" - Sarasin's forecasts for solar power's potential differ markedly from those of the IPCC. In Scenario B the forecast abatement cost and potential for solar power are in line with Sarasin's view, though it is important to note that neither Sarasin nor the IPCC have had an opportunity to contribute to this paper. By way of example, the contrast between Sarasin's and the IPCC's views highlights the importance of investors forming their own views on the future potential of technologies, and constructing their own scenarios;

Scenario C – Including Negative Abatement Costs - Negative abatement costs are those where the expenditure pays for itself. The use of this scenario highlights the importance of (what should be) business-as-usual investments in reducing future greenhouse gas emissions.

Data

The IPCC 2030 Reference Scenario Emissions by sector are the starting point for the London Accord Portfolio Model. These sectors cover almost all anthropogenic emissions and potential abatements, e.g. nuclear, hydro, wind, bioenergy, geothermal, solar, carbon capture & storage (CCS, also known as carbon capture & sequestration, see JP Morgan Chase's London Accord submission, C6: "Carbon Capture & Sequestration"), biofuels, forestry (including avoided deforestation), and efficiency in buildings, transport &industry. The London Accord Portfolio Model attempts to cover the investment options considered by the IPCC abatement model, apart from these specific exclusions:

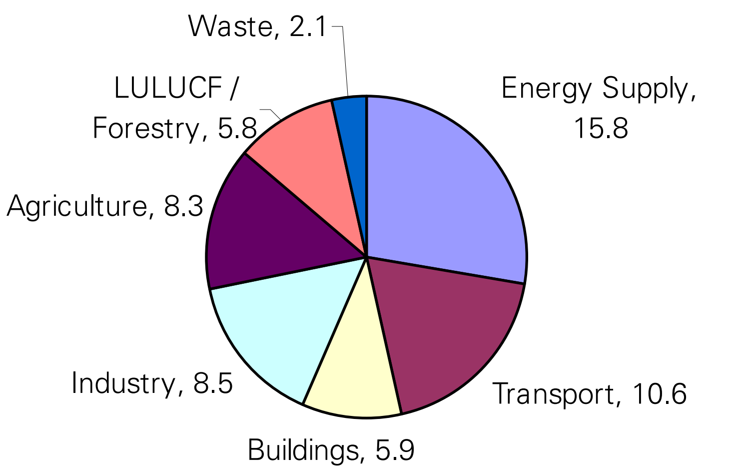
additional use of natural gas for power generation was not one of the London Accord topics and could be considered to be similar to a negative abatement cost in that it should be a business-as-usual decision;

agriculture and waste sectors were excluded as they were not properly analysed during the London Accord;

solar thermal collectors were omitted because they are not included in the IPCC data. The solar investment option includes photovoltaics and concentrating solar power (CSP). Interestingly, Sarasin's London Accord submission, C1: "Solar Energy" suggests that solar thermal collectors are likely to be one of the most significant of the solar technologies;

CCS and related process changes at industrial sites are problematic. CCS is not considered viable until the carbon price is well above the consensus range, significantly in excess of US$50. The estimates for existing industrial site improvements are difficult to assess and, again, can be similar to negative abatement costs in many sectors.

**IPCC 2030 Reference Scenario Emissions
(Gt CO2e per year)**



The primary source of data was the 2007 IPCC Working Group III Report "Mitigation of Climate Change". The cost distributions used for the London Accord Portfolio Model are simplified approximations of the IPCC data. Where there were gaps in the IPCC data, assumptions were based on London Accord literature wherever possible. The abatement costs are forecast 2030 incremental costs above the cost of capital for an assumed business-as-usual scenario. For example, the geothermal costs represent geothermal power infrastructure being built and operated instead of the reference mix of fossil-fuel fired power. The costs are based on replacing existing infrastructure at the end of its normal economic life, not early, which limits the potential of new energy infrastructure. For Scenario 1, the IPCC data is key. For Scenario B, Sarasin's solar estimates are the fundamental difference. For Scenario C, negative abatement costs are included. For Scenarios B and C where there is not a data difference the corresponding data point from Scenario 1 was used. The summary data table is reproduced below:

Investment	Abatement Cost (US$/tonne CO2e)									Abatement Potential Gt CO2e/year		
	Minimum			Maximum			Likely					
Scenario	1	2	3	1	2	3	1	2	3	1	2	3
Nuclear	1		-7	20			5.75		3.25	1.88		
Hydro	1		-1	50			11		10.1	0.87		
Wind	1		-1	50			12.1		11.4	0.93		
BioEnergy	1		-1	100			24		23.6	1.22		
Geothermal	1		-5	50			11.5		9.98	0.43		
Solar (PV + CSP)	50	-170		100	-113		94	-141		0.25	1.404	
CCS	20			100			50.2			0.81		
BioFuels	1		0	100			29		28.6	1.55		
Forestry	1			100			36.7			13.77		
Building Efficiency	1		-200	100			37.3		-75.2	1.1		6.1
Transport Efficiency	1		-10	100			33.7		29.1	1.02		
Industry Efficiency	1		-5	100			50.8		50.1	0.82		

Abatement by portfolio - The basic portfolio variables consist of an input cost, in this case an incremental investment above business-as-usual, and a benefit of annual GHG emissions abatement. In short:

input = annual incremental cost above cost of capital, in 2030 (in 2006 US$);

value = annual 2030 GHG emissions abatement (Gt).

Returns by Portfolio - A crude investment 'return' was derived by calculating the incremental income that would be generated from a carbon market with a CO_2 price ranging between $30/tonne and $40/tonne. This price range reflects a general consensus amongst participants in the London Accord of a realistic social and investment price level for mitigation. In the event, $30/tonne to $40/tonne also tended to be close to the breakeven point such that half of the portfolios were profitable and half were unprofitable. The return was calculated as the carbon value for each portfolio's abatement level as:

input = annual incremental cost above cost of capital, in 2030 (in 2006 US$);

value = annual carbon market returns in a $30/tonne to $40/tonne carbon market randomly selected (in 2006 US$).

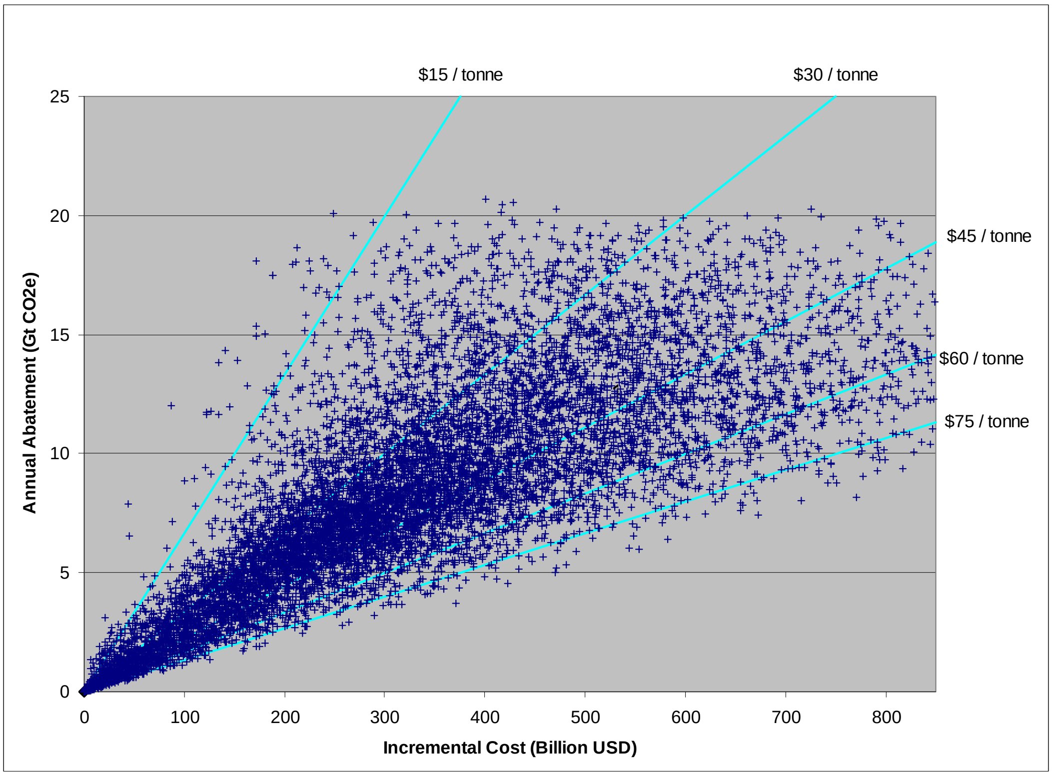
The IPPC report contains two quite different estimates of the abatement potential of forestry. In their consolidated portfolio model, they chose to use the lower more conservative estimate. In the spirit of modeling the full range of uncertainty, we have chosen numbers throughout the range of both estimates up to 13.77 $GtCO_2e$ (which is consistent with other estimates such as Vattenfall [2007]), but it is important to highlight the fact that forestry abatement potential is highly uncertain.

The IPCC's underlying abatement costs are based on relatively low energy prices, approximately $25 to $30/bbl oil. The IPCC points out that an additional cost of $50/bbl for oil is roughly equivalent to a $100/tonne abatement cost. As of 2007, oil prices are close to $100/bbl. With higher fossil fuel energy prices, renewables and efficiency look much more attractive, whereas forestry and CCS become less attractive abatement options. The London Accord Portfolio Model uses abatement costs expressed as costs over and above the use of fossil fuels, but with recent energy price changes and currency market movements a number of these assumptions bear re-examination.

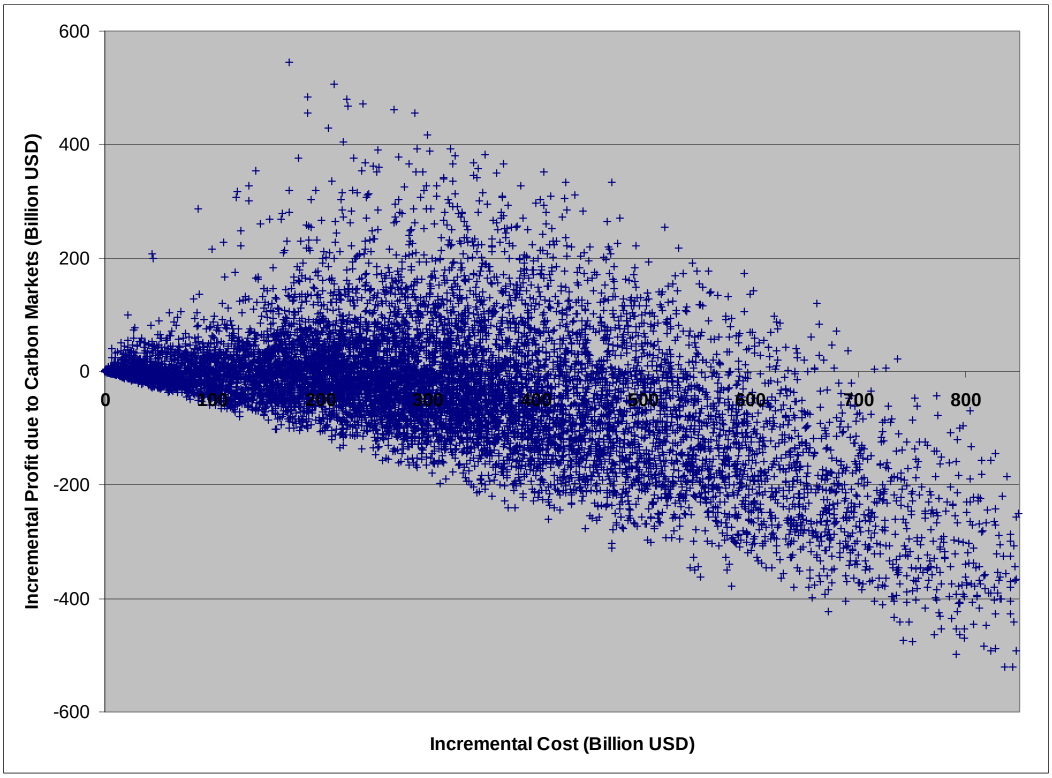
By the standards of some portfolio models, the London Accord Portfolio Model is simplistic, but it does illustrate the range of revenue that investors might achieve from technological options combined with carbon markets. Ideally, net investment returns would have been constructed from direct investments, rather than marginal, and contrasted with abatement value for each portfolio, taking into account 25 or more years of risk. The capital requirement, cashflows, discount rates, capital structure, long-term free risk rate and other risk factors will complicate future investment decisions, but this simple portfolio approach still provides a broad overview.

Scenario A – The Base Case

The following charts show the unfiltered portfolio distributions for the base case scenario. The abatement charts plot each portfolio's emissions reduction against the incremental cost of the portfolio. The radial lines on the abatement charts indicate an average cost of abatement for portfolios on those lines.



By inspection, it is clear that there are numerous potential portfolios that can achieve abatement up to about 15Gt along the $40/tonne radial line. When interpreting these graphs it is important to remember that the distributions model the range of possibilities. For example, the chart above suggests that it is possible to construct a portfolio that that *might* offset 10 Gt CO2e per year for less than $15/tonne, and a bit more likely from $15/tonne to $30/tonne, though a range of $30/tonne to $45/tonne is even more likely. The next chart illustrates the incremental revenue that could be generated for each portfolio in a world of $30 to $40/tonne CO_2e avoided.



As noted earlier, a $30/tonne to $40/tonne price for carbon seems to produce a balance of successful investment portfolios and unsuccessful investment portfolios. The portfolio distributions show a wide range of average abatement costs, indicating both uncertainty and the fact that it is possible to construct very bad portfolios. The large proportion of portfolios with negative incremental profits shows that it is rather easy to construct losing portfolios. The wide range of returns, many at significant cost, highlights the perils of policy-makers trying to pick winners rather than allowing markets to learn and 'evolve' towards efficient investment.

The efficient frontier for the base case touches $15/tonne, potentially indicating that estimates of marginal abatement costs could be on the high side, or more likely, there is a lot of money to be made by selecting an efficient portfolio given current uncertainties in the market. Some specific portfolios on the efficient frontier have been selected for further examination. The two charts below identify six portfolios and their placement on the efficient abatement frontier and on the efficient financial return frontier.

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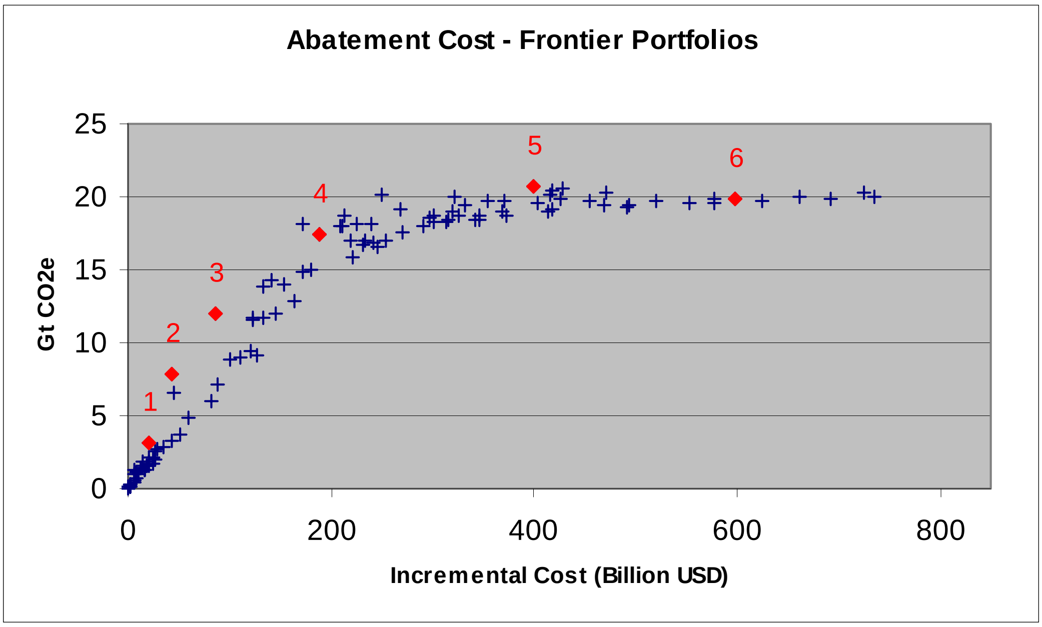
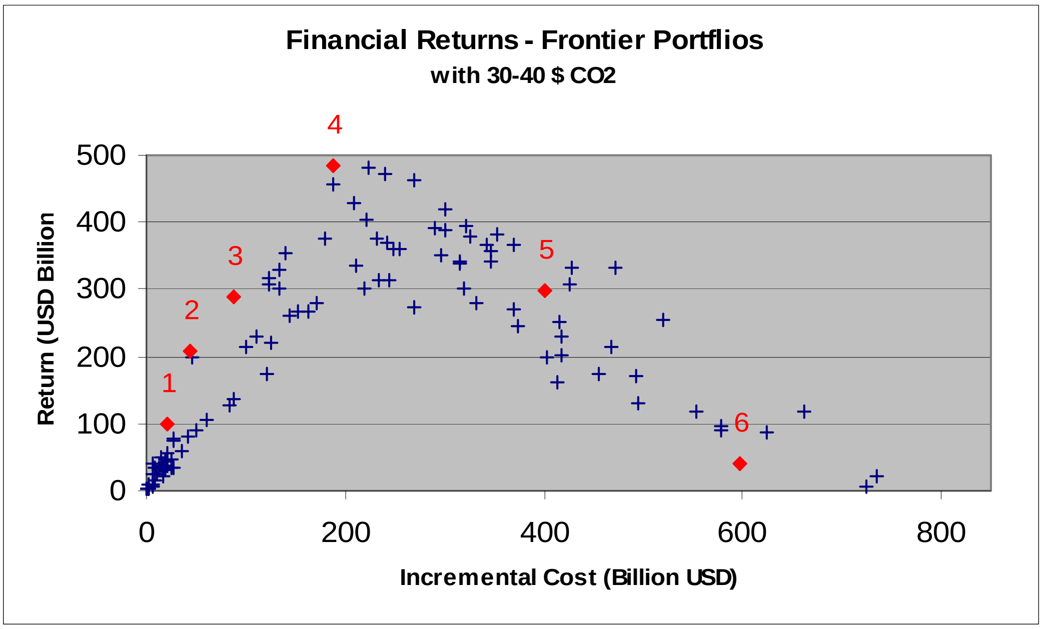


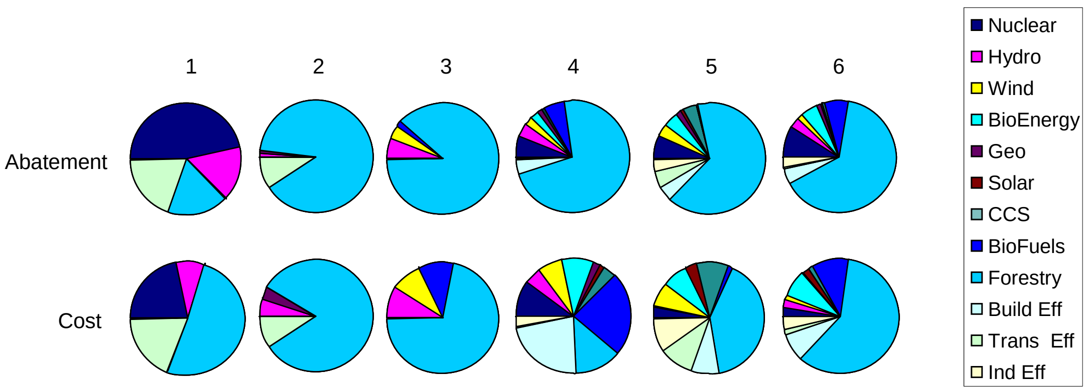
This second chart shows that marginal financial returns begin to decline after about $300 billion of incremental expenditure. Interestingly, the Stern [2006] estimates 1% of global GDP as the likely cost to avoid climate change, in a range –1% to +3.5%. With global GDP estimates of $350 billion to $450 billion, there already exist investment portfolios for private investment with sensible returns that begin to reach Stern's estimate. But all this depends on confidence that CO_2 emissions will be controlled to a level with a likely price of $30/tonne to $40/tonne.



Each of the selected portfolios has been broken down by investment type, and displayed by expenditure and contribution to abatement. Contrasting just two portfolios in the round, four and five, in the table below helps to illustrate how abatement and investment do not necessarily align:

Portfolio	Cost	Abatement	Returns	Largest Financial Components	Implied Marginal Return	Abatement Efficiency
4	$200bn	17.5 Gt	$500bn	biofuels/building efficiency	250%	$11/tonne
5	$400bn	21.0 Gt	$300bn	forestry	-25%	$19/tonne

The problem is that 'dream portfolios', such as Portfolio 4, are possible, but perhaps not probable. First, a large number of things must go right at once. Second, almost all of the dream portfolios rely on fantastic forestry investments for their superb returns. The next chart examines the proportion of major option in each of the six portfolios broken down by abatement and cost:



It can be seen by inspection that:

forestry is by far the most significant contributor to these portfolios, essentially because (although more uncertain than other options) forestry has the largest abatement potential. Forestry returns can be so dominant that other options, such as biofuels in Portfolio 4, can produce a marginal return and still help the portfolio perform well. Clearly, more definitive, perhaps urgent, research into forestry cost and abatement would help to produce better portfolio analysis;

nuclear is a proportionally big contributor in the smaller, efficient frontier portfolios, reflecting its cost parity with business-as-usual options; however its scale is limited in the IPCC data reflecting the difficulties associated with new nuclear facilities politically, including planning permission and long-term waste disposal risks;

solar, CCS, and geothermal are not big contributors in the frontier examples. IPCC forecasts are based on forecasts of their technology cost curves. If the technology cost curves change, (see the Santa Fe Institute contribution to the London Accord - E1: "The Dynamics Of Technological Development In The Energy Sector"), then their importance in an efficient climate change portfolio might alter markedly. Technology cost estimates significantly affect Scenario B;

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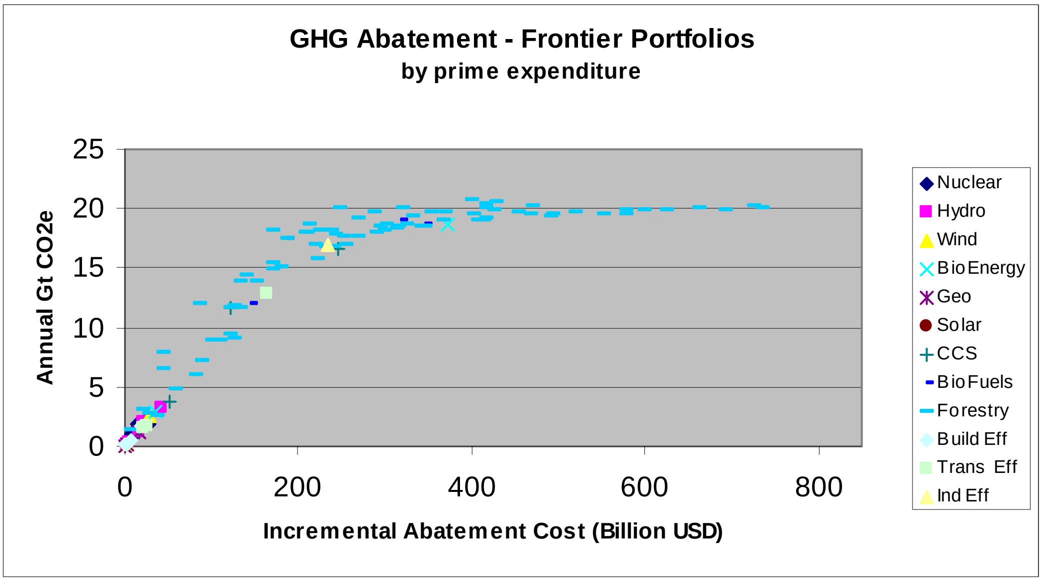
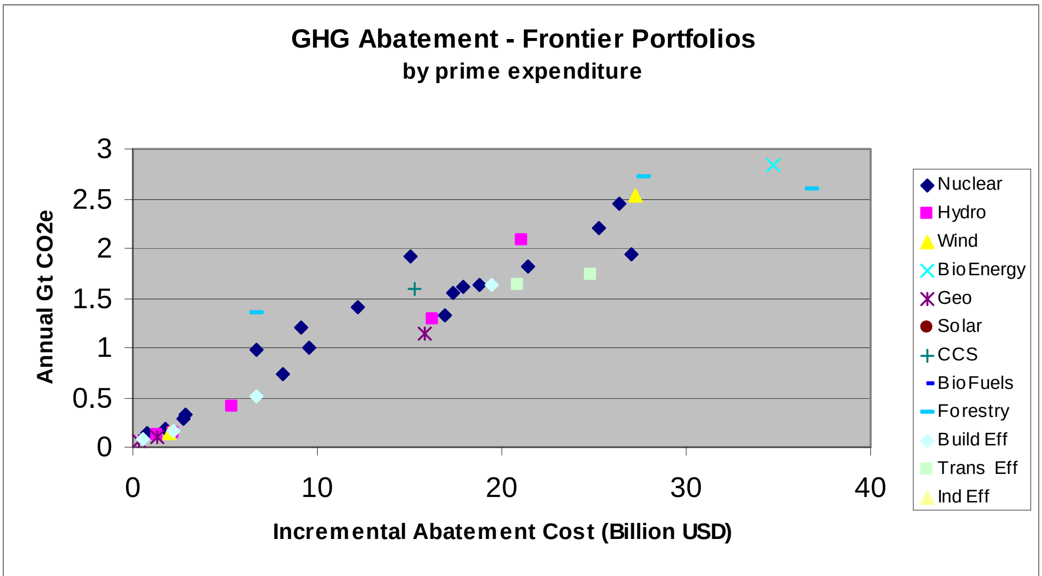
small abatement portfolios of three or four technologies can be financially rewarding, but achieving large emissions reductions requires a wide range of technologies – there is no silver bullet. Further, this analysis has not taken account of the risk of failing to find a portfolio of solutions for climate change. This risk decreases as the range of options in the portfolio increase.

The next chart demonstrates another method of viewing the efficient frontier. Each portfolio has been categorised by the investment option with the largest incremental expenditure in that portfolio. This again illustrates forestry's dominance.



Examining just the small portfolios more closely, abatement costs below $40bn/year, nuclear dominates, but forestry is key to any large portfolio.



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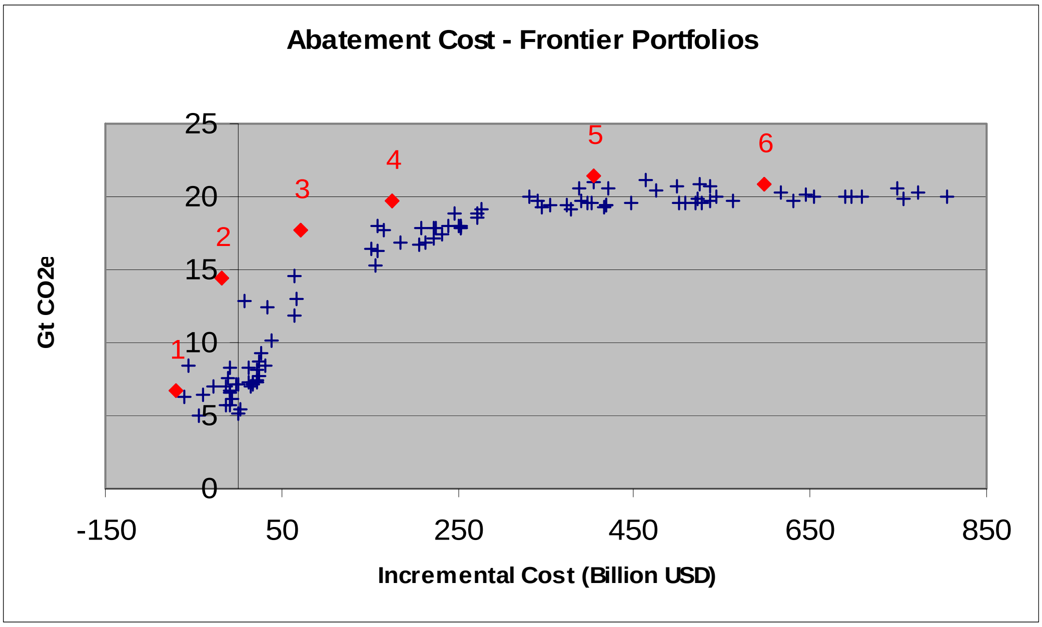
Scenario B- Sarasin's Views on Solar

Sarasin's more optimistic view of solar power predicts a CO_2 breakeven of less than minus $100/tonne for photovoltaics and CSP in 2030. This -$100/tonne is based on the cost of photovoltaics continuing to fall while energy prices remain at or above $100/bbl. The efficient frontier has shifted markedly to the left, with some portfolios being profitable in the absence of carbon pricing. This scenario demonstrates the importance of having a view on technology development, or alternatively, the importance of having a diversified portfolio to manage risk inherent in the development of low carbon technologies. In this case, a bullish view on just one technology has made a significant difference to the efficient frontier. Again, six portfolios on the efficient frontier of Scenario B have been chosen for closer inspection.



Two Scenario B portfolios (1 & 2) are attractive given negative abatement costs, i.e. they might work today without a price for greenhouse gas emissions.

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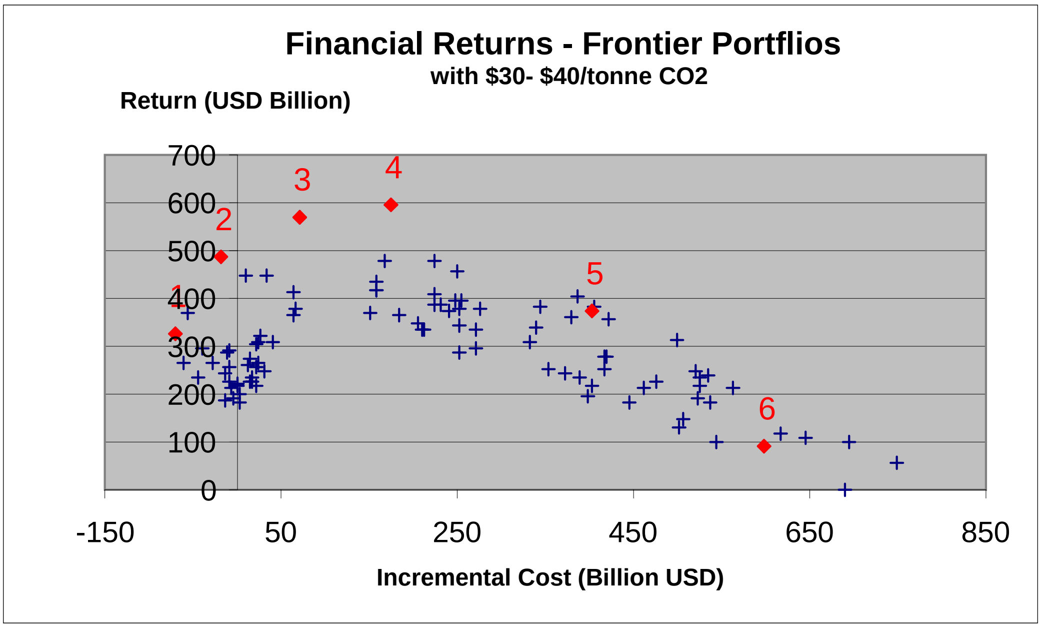
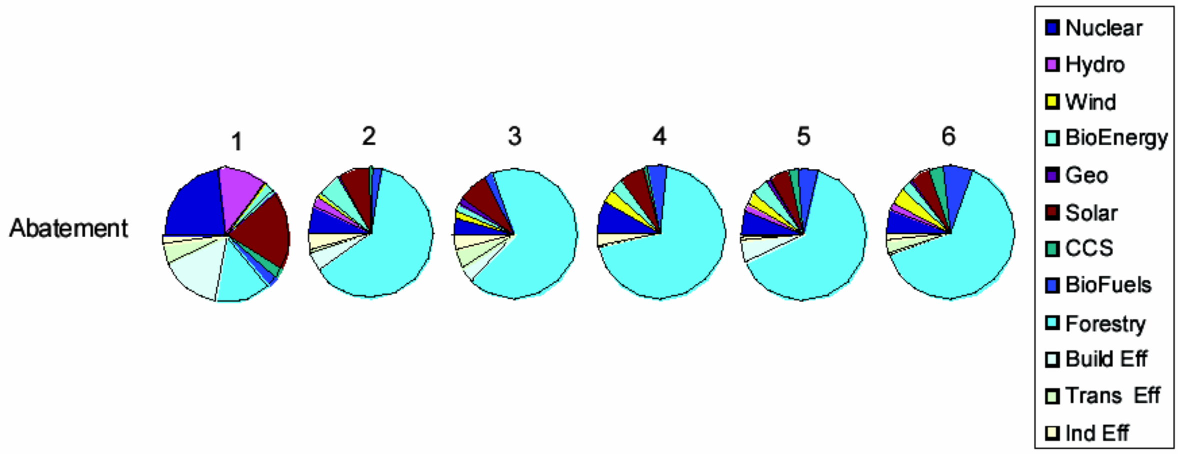
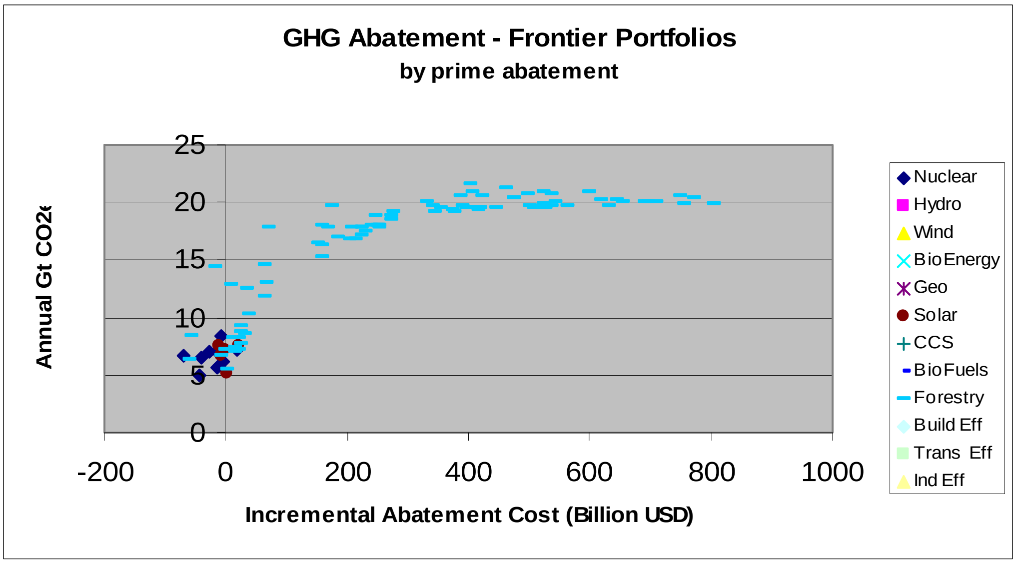


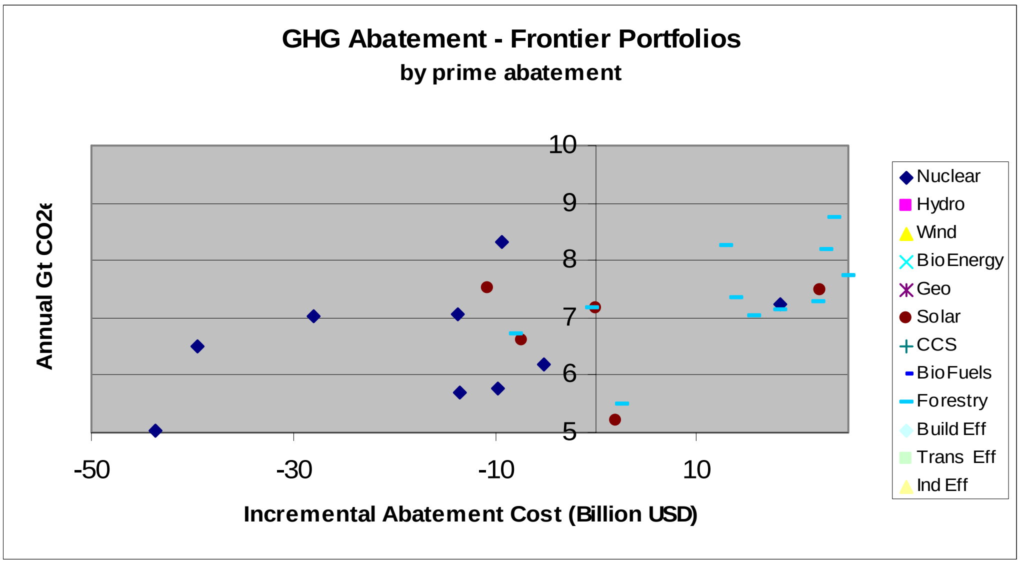
The portfolio breakdown for Scenario B again shows that forestry dominates larger portfolios but, as might be expected, solar power makes a much bigger contribution to abatement in the smaller portfolios.



Again, in the chart below the Scenario B frontier portfolios have been characterised by their prime abatement investment.

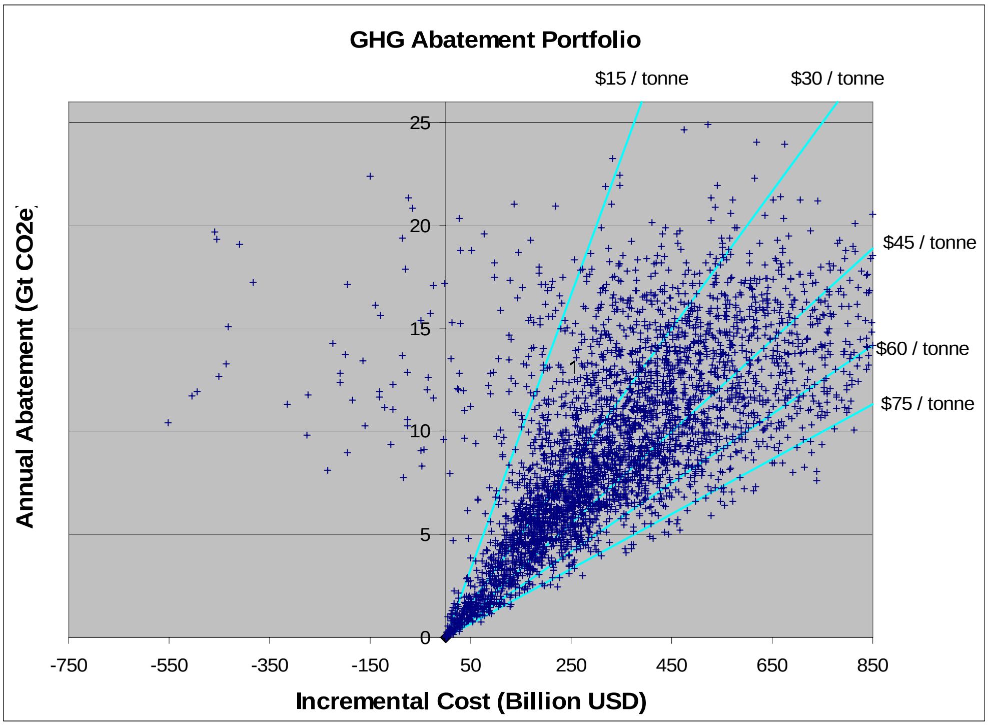


The following chart shows that if one wishes to spend nothing additional, solar and nuclear might lead to abatement of as much as 8Gt.

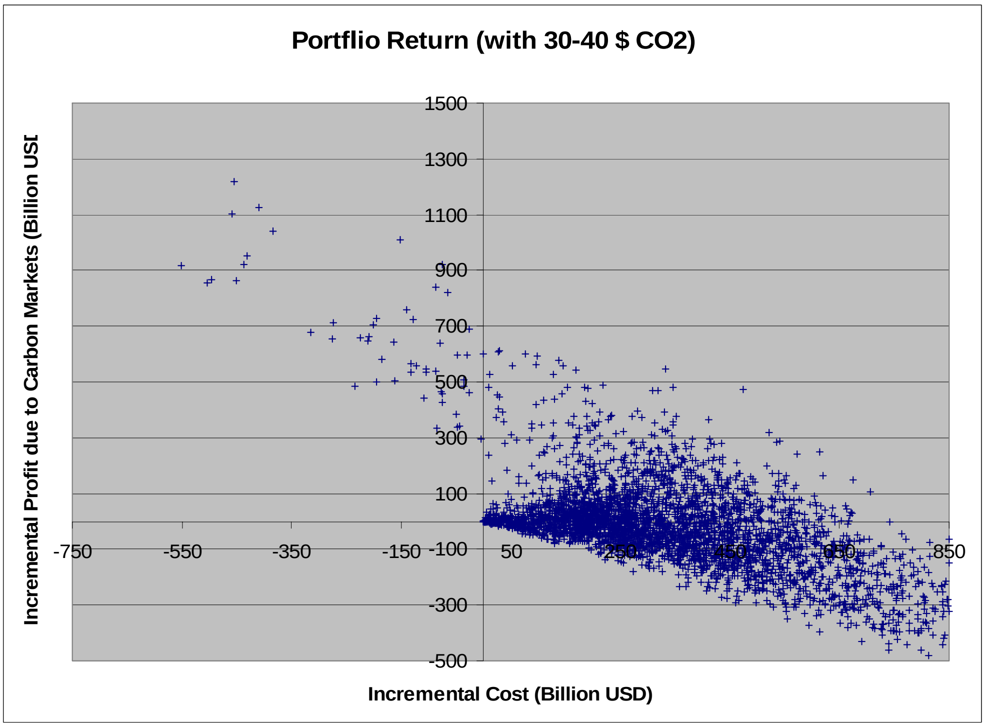


Scenario C - Including Negative Abatement Costs

Significant, profitable abatement potential is possible without carbon pricing in Scenario C. Forestry still dominates total abatement, but efficiency also becomes significant – in particular building efficiency. Building efficiency is a low risk investment strategy – it makes money without carbon pricing and benefits from high energy prices.



There is a small scattering of positive abatement and positive profit with no incremental cost, portfolios consisting predominately of building efficiency investment. However, it is not possible to construct a diversified portfolio with these characteristics.



Further examination of negative abatement proposals seems in order as it should be important to understand why these investments fail to be made under current financial conditions. Neglected

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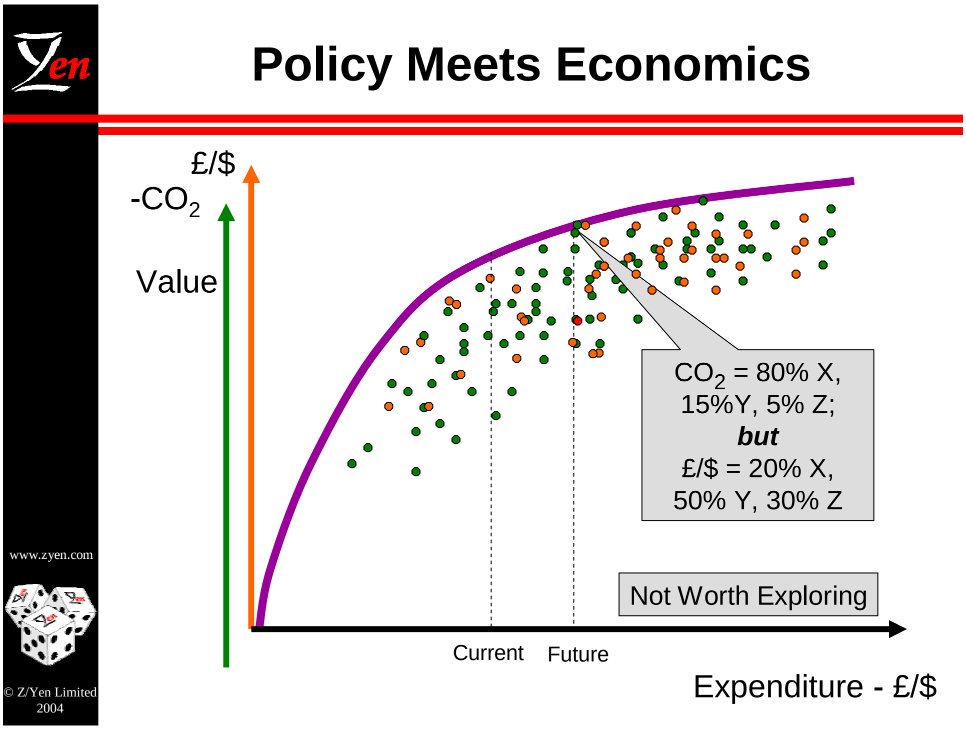
negative abatement may justify regulatory intervention by policy-makers, e.g. imposing minimum building or transportation efficiency requirements.

Conflicting Values – Policy Meets Finance

For most investors, the abatement realised from a low-carbon portfolio is less important than the return on investment of that portfolio. For most policy-makers, the investment community must invest in abatement, yet simultaneously create wealth. Investors undervalue externalities, by definition. Policy-makers undervalue investors' needs to generate returns within macro-economic and micro-economic frameworks. The London Accord Portfolio Model sets out a crude dual 'returns' approach that can highlight conflicts between abatement value and investment value. This tension may be particularly evident in markets where certain technologies enjoy direct subsidies in addition to a carbon price signal – these technologies are likely to be more attractive in terms of their investment returns than in terms of abatement. The following diagram illustrates the conflict that arises in having two output values:



The green axis and portfolios represent the emissions abatement of each portfolio, the orange portfolios and axis show the distribution of financial returns. For a number of portfolios near the combined efficient frontiers it may be that 80% of option X is crucial to reducing CO_2, while option X only forms 20% of investment returns against 50% of option Y and 30% of option Z. This example is an illustration only (the results are hypothetical), but it shows an effective way to visualise the outcome of two (or more) competing sources of value. In this context, what might be best for an investor may not result in the best outcome for the environment, and vice versa.

Critique Of This London Accord Portfolio Model

In summary, even this basic London Accord Portfolio Model analysis indicates that:

CO_2e avoided prices $30/tonne to $40/tonne seem to produce a reasonable number of portfolios that might lead to abatement up to 20Gt with positive investment returns in about half of the cases;

significant private-sector investment is possible given enough confidence in a carbon price, probably within a largely cap-and-trade system;

forestry might be the most significant part of any portfolio, investment or policy. If forestry's costs and benefits reflect a real opportunity, fantastic, but if they are illusory it is important to dispel that illusion rapidly;

policy-makers should examine some of the reasons for negative abatement opportunities not being seized in existing portfolios, with a view to considering new policies for abatement.

There are a large number of ways in which this model could be improved and extended. Many of the extensions would be technical, calculations of discount rates, cashflow estimation models, capital structures, asset life or underlying probability distribution work. Much work remains to be done on various volatility calculations. However, a few higher-level cautionary points are worth making in this short note. These comments provide a pathway for future development of the London Accord Portfolio Model:

aggregate limits - The IPCC makes it clear that the individual abatement potentials are often not additive. Specifically, there is a limit to the total amount of abatement that can be achieved from energy efficiency and clean energy sources in a given portfolio. If you have too much efficiency, then there is insufficient demand for new energy sources. For the purpose of the London Accord Portfolio Model, this issue as been ignored although it is clearly an area for future models. Similarly, the final output can be filtered to eliminate portfolios that fail other tests, for example as discussed in the Canaccord Adams contribution to the London Accord - C3: "Investing In Renewable Energy" - there are limits to the direct contributions of intermittent energy sources such wind and tidal to an energy grid in the absence of efficient electricity storage;

each option as a portfolio - This model grossly simplified cost and return estimates. Assigning a single cost distribution to each investment option ignores much of the heterogeneity within these investment options. There will be cheap and expensive projects within any given abatement potential. The model permits all the abatement potential for a given option to be achieved at the highest or lowest cost. Each set of options, such as biofuels, has its own diversification and concentration effects. In other words, as these options are examined more minutely, they become portfolios. Portfolio specific risk reduction effects will cluster returns and abatement more tightly than has been possible with simple triangular distributions of IPCC data. Future extensions to the model would provide much additional granularity for each investment option, turning each option into many sub-options. More granularity would quite likely 'tighten' the range of returns and abatement;

intra-portfolio correlations - Synergies between technologies could be modeled with a multiplicative approach using a 'benefit cross table', as shown in the portfolio algorithm diagram. As an example, intermittent power sources like wind power could be made to look more attractive with simultaneous investment in energy storage devices such as advanced batteries. This interaction could be modeled such that for every $ that is invested in battery technology, you get a multiplicative benefit for every $ invested in wind;

modeling expectations – The path chosen for particular investment trajectories can be crucial. Expectations about technological improvement (see the Santa Fe Institute contribution to the London Accord - E1: "The Dynamics Of Technological Development In The Energy Sector") materially affect investment, which in turn materially affects the prospects of success and deployment. Other expectations on topics as diverse as taxation and political will can be self-fulfilling. You can select an ideal technology, but if the market fails to follow then economies of scale and acceptance may never arrive. You may select a sub-optimal technology, but widespread acceptance may make it exceptional. However, modeling these expectations and their consequent 'network effects' is not straightforward and could form the basis of significant future research;

positive feedback and diversification – In real life, under conditions of uncertainty, investors should, and frequently do, spread their risks. However, herd behaviour can emerge from early successes or failures. People tend to follow the herd, investing in previous successes and avoiding previous failures. The positive feedback 'feeds forward', i.e. diversification narrows (again, see the Santa Fe Institute contribution to the London Accord - E1: "The Dynamics Of Technological Development In The Energy Sector"). This behaviour itself may be seen as rational. Investments increase in value with increasing liquidity and perception of attractiveness. Most investments are made with one eye on the potential for sale to the next investor, and then the one after that – a "Keynesian beauty contest". Modelling this evolution of the fitness landscape is difficult, but perhaps as important in climate change trends as in any other investment bubble, e.g. railways or the internet;

sensitivity - A more sophisticated approach would consider the impact of a number of key variables such as assumed energy prices or agreed international emissions targets. One could model the response of the portfolio to these external variables. Portfolio modelling could be performed over a wider range of scenarios so that portfolios can be tested for robustness.

Savvy investors realise that abatement options are not the only investment response to a changing climate. Adaptation projects or biases towards companies with low carbon exposure are also part of a mix. For savvy policy-makers, there may be a need to incorporate even broader measures of value in the portfolio analysis, beyond just returns and abatement. Forum for the Future's 'Five Capitals' model (see Forum for the Future's contribution to the London Accord - D3: "Investments To

Combat Climate Change: Exploring The Sustainable Solutions") might inform the valuation of portfolios in terms of sustainability.

Finally, portfolio analysis is not a static tool. Investors must constantly review their assumptions and forecasts – technology and regulation can change quickly.

Conclusion

This paper illustrates how a portfolio approach to climate change might extend the work of the London Accord. In the future, the data for this model could be drawn from the London Accord research papers (rather then the IPCC data), so that the portfolio model becomes a synthesis of all the London Accord research, offering even greater insight into climate change investment.

Portfolio analysis is already an important and powerful tool for investors. With the addition of an abatement axis, or perhaps additional sustainability axes, multi-value portfolio analysis can help to highlight contradictions between investment potential and policy. Thus, portfolio analysis should be as important a tool for policy-makers as it already is for investors.

Further Reading

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Further Surfing

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Thanks

Our thanks go to Ian Harris, Jan-Peter Onstwedder and Mark Yeandle who helped to develop the thinking behind this note and also provided assistance with building and analysing the London Accord Portfolio Model.