# The carbon market – A primer for actuaries

**John McManus and Nick Silver**

**FIRM 2009**

**Keywords**
Climate change, carbon trading, Clean Development Mechanism, insurance, emissions targets, basis risk

**Abstract**

The carbon market(s) transacted $126 billion in 2008 and are increasing in size at a considerable rate. Carbon is a regulatory derived commodity, which has been brought into existence to regulate greenhouse gas emissions, which cause anthropogenic climate change. This paper provides an introduction to the carbon markets for an actuary or investment consultant.

**Nick Silver, FIA Callund Consulting Limited**
nick.silver1@btinternet.com

**John McManus Union Investment**
John.McManus@union-investment.de

## Introduction

The threat of global warming is causing society to shift resources to mitigate the effects of global warming which has created a new market. The new market, often referred to as the carbon market, is regulatory driven and highly complex. This paper gives an overview of the market for the interested actuary. The paper also analyses the market fundamentals, the price drivers and how institutions can invest in the market.

This paper falls into 2 parts the first part gives an overview of the carbon market. The second part provides an analysis of the market.

## 1 The Carbon Market

The carbon markets are regulatory created markets, the aim of which are to facilitate efforts to mitigate anthropogenic climate change. The science of climate change and its effects have been dealt with in great detail elsewhere, I refer the interested reader to The International Panel on Climate Change (IPCC) AR4 synthesis report[1] or the HM Treasury's Stern review[2] for summaries of the science and economic implications. However, I will give the briefest of summaries as an introduction.

***Climate Change – a parsimonious introduction***

Climate scientists have noted that the average global temperature has increased by more than 0.6 degrees centigrade over pre-industrial levels, and predict that the world will get hotter, which will cause a number of malevolent affects, some of which could be potentially disastrous. The cause of this warming are so called greenhouse gasses (GHGs), mainly carbon dioxide, but also – and often forgotten a number of other gasses such as methane and nitrous oxide – which are produced mainly as a result of burning fossil fuels for energy, but also in other industrial processes and in agriculture[3]. The potentially malevolent affects include:

1. Hotter global temperatures – the increase will not be uniform, for example temperature increases at the poles are likely to be more extreme
2. Changed rainfall patterns which could lead to widespread drought and flooding
3. Increased salinity of oceans threatening marine wildlife and hence livelihoods
4. Melting of inland glaciers causing changes to alpine landscapes and river flooding followed by reduce flow of many major rivers
5. Increased risks and severity of severe weather events such as North Atlantic hurricanes
6. Sea level rises caused by expansion of oceans
7. Melting of Greenland and Antarctic glaciers causing potential catastrophic rise in sea level[4].

The higher the concentration of GHGs in the atmosphere, the higher the probability of positive feedback effects – for example the "albedo" flip (if the arctic ocean melts, the

[1] IPCC (2007), IPCC (2007a) and IPCC (2007b) – also see http://www.ipcc.ch/ for the other reports
[2] Stern (2006)
[3] IPCC (2007)
[4] IPCC (2007b)

sea absorbs heat rather than reflects it), the burning of tropical rainforests (reduced rainfall and higher temperatures increases could render tropical rainforests unsustainable; they will then burn releasing further carbon into the atmosphere) and the release of methane from permafrost (if the arctic permafrost melts, methane – a powerful greenhouse gas - will be released in large quantities into the atmosphere)[5].

***International abatement agreements***

In an attempt to avert the damaging consequences of climate change, many governments have agreed that there is a need for reduced GHG emissions. They have also recognised that developing countries are not the cause of global warming – but will suffer the brunt of the effects – for example many developing counties will face reduced rainfall & hence crop yields with potentially disastrous effects (whereas countries like Canada & Russia may benefit from increased crop yields.)[6]

However, it has been accepted that these countries must be allowed to develop, so two key concepts are enshrined in the negotiations, namely to divert carbon finance to developing countries – for example for sustainable energy projects, and to provide funds for adaptation[7].

In an effort to avoid the potential disastrous effects of global warming, practically all governments signed the United Nations Framework Convention on Climate Change (UNFCCC) in Rio de Janeiro in 1992. The UNFCCC is aimed at stabilizing greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

The signatories of the treaty (practically all countries) meet every year at an official meeting (called a conference of parties ("COP") or meeting of parties ("MOP")) with the aim of developed countries restoring their 1990 level of emissions, and helping developing countries with clean technology and adaptation. In 1997 the Kyoto protocol was signed – again by practically all countries in the world. This has now been ratified by 182 parties – notable exceptions being Turkey and the USA. Under the Kyoto protocol, developed countries agree to reduce their GHG emissions by 5.2% below 1990 levels by 2012. Developing countries have no obligations except to monitor emissions. Kyoto came into force in 2005 and runs until 2012.

Under the Kyoto protocol, although countries agree to reduce their GHG emissions, they are allowed to trade; if targets are not met, they can buy emissions reductions from others who have bettered their targets –so called flexible mechanisms. Emissions reductions can be traded at both the country level and company level; each country allocates emissions permits to companies within the country, who therefore have reduction targets. These companies can trade their permits.

***Country level units: AAUs***

Countries with commitments under the Kyoto Protocol (effectively "developed" countries) have accepted targets for limiting or reducing emissions. These targets are expressed as levels of allowed emissions, or "assigned amounts," over the 2008-2012

[5] See Hansen et al (2007) for further information on positive feedback
[6] IPCC (2007b)
[7] Stern (2006)

commitment period. The allowed emissions are divided into “assigned amount units” **(AAUs).**

Emissions trading, as set out in Article 17 of the Kyoto Protocol, allows countries that have emission units to spare - emissions permitted them but not "used" - to sell this excess capacity to countries that are over their targets.

***European Union Emission Trading System (EU ETS)***

The European Union Emission Trading System (EU ETS) is the largest company level trading scheme. This system is a cap and trade system[8]. The ETS currently covers more than 10,000 installations in the energy and industrial sectors which are collectively responsible for close to half of the EU's emissions of $CO_2$ and 40% of its total greenhouse gas emissions.

Under the EU ETS, large emitters of carbon dioxide within the EU must monitor and annually report their $CO_2$ emissions, and they are obliged every year to return an amount of emission allowances to the government that is equivalent to their $CO_2$ emissions in that year. In order to neutralise annual irregularities in $CO_2$-emission levels that may occur due to extreme weather events, emission allowances for any plant operator subject to the EU ETS are given out for a several years at once. Each such sequence of years is called a Trading Period. The 1st EU ETS Trading Period expired in December 2007; it had covered all EU ETS emissions since January 2005. With its termination, the 1st phase EU allowances became invalid. Since January 2008, the 2nd Trading Period is under way which will last until December 2012. Currently, the installations get the allowances for free from the EU member states' governments. Besides receiving this initial allocation on a plant-by-plant basis, an operator may purchase EU allowances from others (installations, traders, the government.) If an installation has received more free allowances than it needs, it may sell them to anybody.

In January 2008, the European Commission proposed a number of changes to the scheme, including centralized allocation (no more national allocation plans) by an EU authority, a turn to auctioning a greater share (60+ %) of permits rather than allocating freely, and inclusion of other greenhouse gases. These changes are still in a draft stage and are only likely to become effective from January 2013 onwards, i.e. in the 3rd Trading Period under the EU ETS. Also, the proposed caps for the 3rd Trading Period foresee an overall reduction of greenhouse gases for the sector of 21% in 2020 compared to 2005 emissions. The EU ETS has recently been extended to the airline industry as well, but these changes will not take place until 2012

[8] A central authority (usually a government or international body) sets a limit or *cap* on the amount of a pollutant that can be emitted. Companies or other groups are issued emission permits and are required to hold an equivalent number of *allowances* (or *credits*) which represent the right to emit a specific amount. The total amount of allowances and credits cannot exceed the cap, limiting total emissions to that level. Companies that need to increase their emissions must buy credits from those who pollute less. The transfer of allowances is referred to as a trade. In effect, the buyer is paying a charge for polluting, while the seller is being rewarded for having reduced emissions by more than was needed. Thus, in theory, those that can easily reduce emissions most cheaply will do so, achieving the pollution reduction at the lowest possible cost to society (Montgomery (1972))

***Clean Development Mechanism (CDM) and Joint Implementation (JI)***
The other system instigated by the Kyoto Protocol is a baseline and credit regime. Developing countries (non Annex 1 countries) have no mandatory target, so the only way of getting carbon finance to them is on a project basis. A project has to demonstrate that it produces emissions reductions from what would have happened anyway. There are two kinds of projects – Clean Development Mechanisms (CDMs) and Joint Implementation (JIs). JIs are in Annex 1 (normally but not exclusively former Soviet Bloc countries), CDMs are in other developing countries. JIs and CDMs are for all intents and purpose the same, albeit with different compliance frameworks. The units of carbon produce by JIs are called Emissions Reductions Units (ERUs) and CDMs Certified Emissions Reductions (CERs). CERs/ERUs and EUAs are different currencies - like the pound or dollar - denominated in tonnes of CO2 equivalent[9].

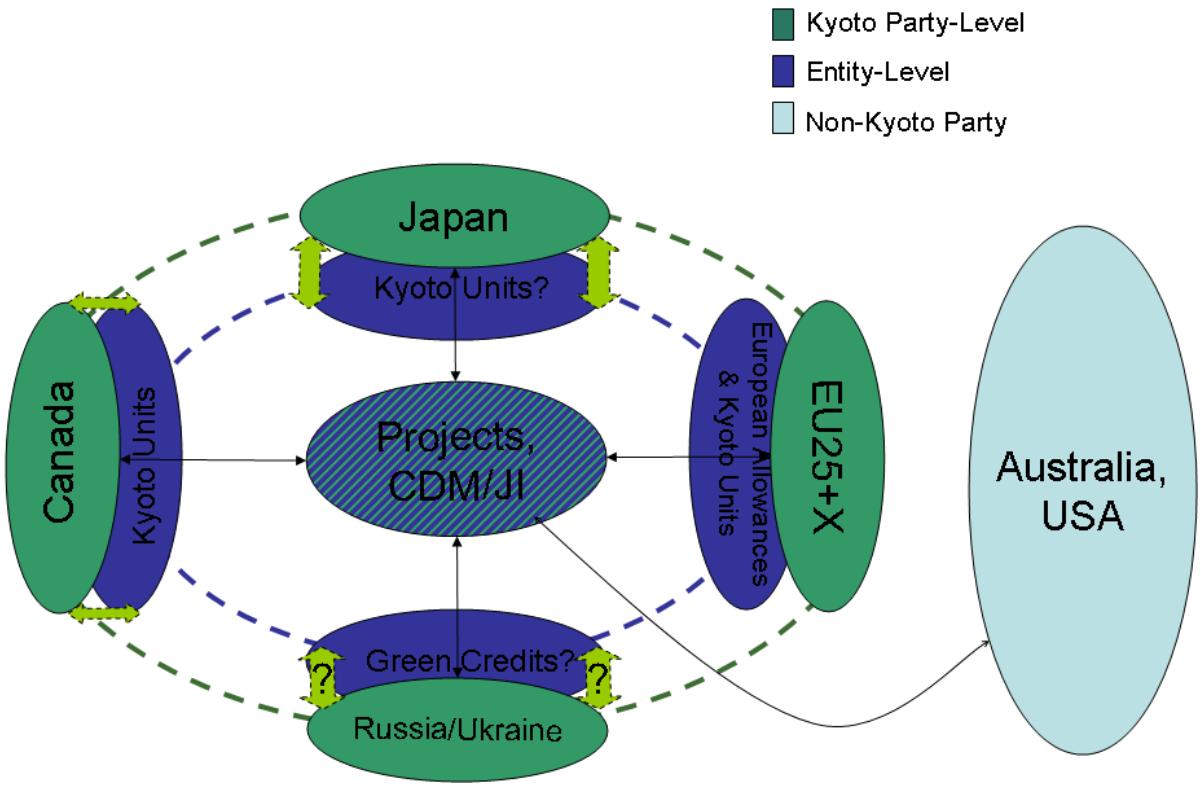
The key concept is that GHG emissions are reduced in one country to permit an equivalent quantity of GHG emissions in another country without changing the global emissions balance. As has already been mentioned, the CDM is a baseline and credit trade mechanism. The idea behind CDMs are that reductions are cheaper in developing countries, and it will encourage clean technology investment and technical expertise in these countries, helping them to leapfrog carbon intensive development.

Emissions reductions under CDMs and JIs must demonstratably create real, measureable and long term benefits to the mitigation of climate change and be additional to any that would occur in the absence of certified project activity[10].

The "official" carbon market described above is totally different to the "voluntary" market, which has received a lot of bad publicity. Figure 1 illustrates how the different trading systems all fit together.

[9] IPCC (2007c)
[10] United Nations (1998)

**Figure 1 Global GHG Market**[11]




***The CDM/JI Market***

Figure 2 shows where the projects are being set up and which countries are buying credits from them. This shows that almost 2/3rds of projects (by volume) are in China. This is because of the size of the market, but also because China has been very efficient in setting up a carbon infrastructure. Also surprising is the small number of projects in India – although this is rapidly changing. Brazil is another big growth area. The pie on the right shows the buying market, with the UK a clear leader. This reflects that London is the centre of the carbon finance market. Maybe the most important country in this chart is the USA – along with China the world's largest emitter is absent. But the new administration has signalled its intention to join the mechanism at some point, so we could see exponential growth in CDMs.

[11] From www.ieta.org

**Figure 2 Distribution of projects by buyer and seller**[12]

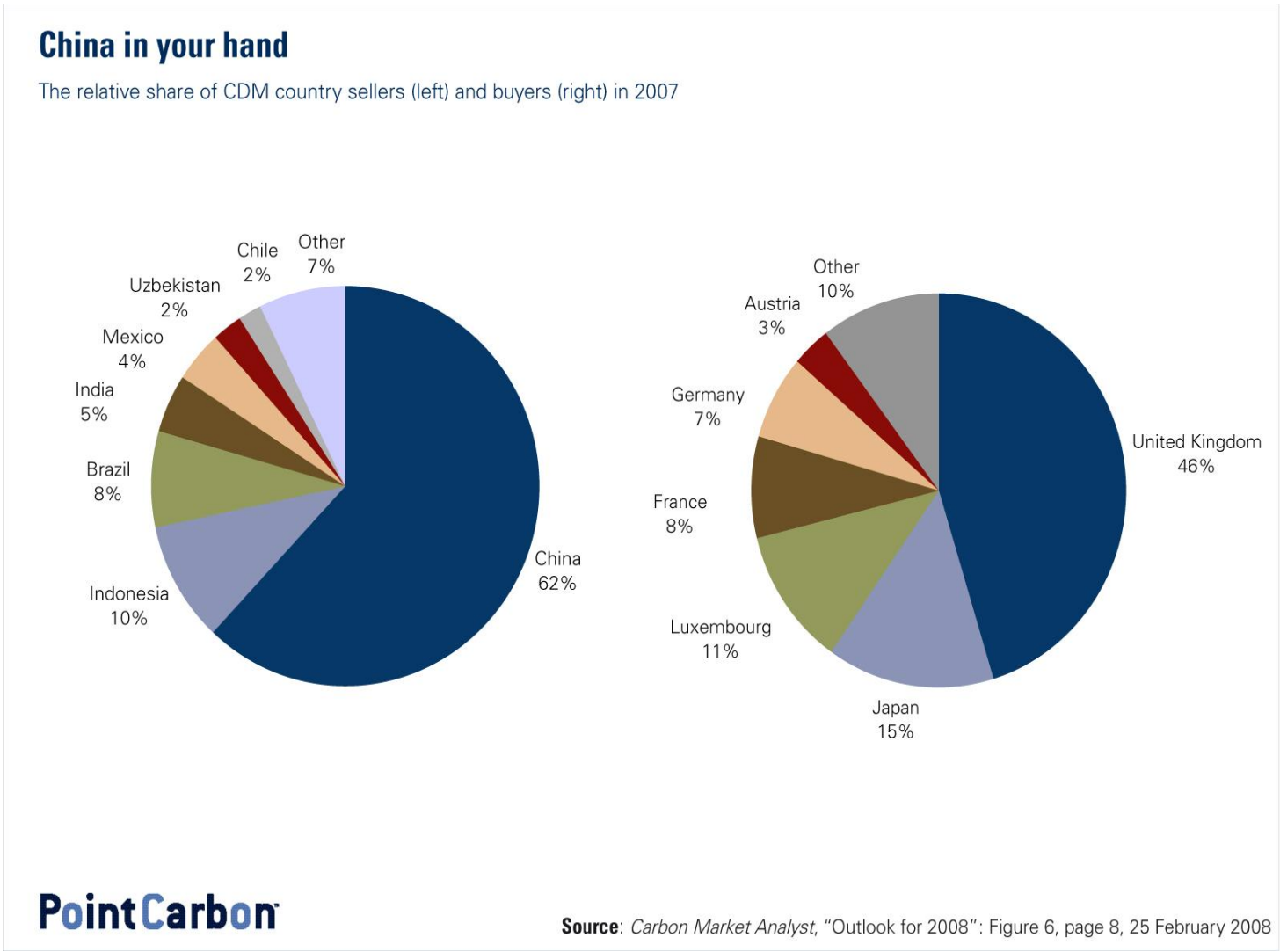



Figure 3 shows the massive growth in the market rising to a projected 2,600 million tonnes of CO2 equivalent in 2008 (at €20 per tonne – the size of the market is apprximately €50bn.)

Figure 4 shows the make up of CDM projects by type. The biggest group, as might be expect are energy generation projects. These are mostly traditional technology such as combined cycle gas power station or hydro-electricity. Fugitive emissions are projects using fossil fuels, such as gas capture and flaring. Waste handling and disposal tend to be much smaller scale such as composting or methane flaring from landfill sites. Only 1 project registered so far is in forestry – this reflects the difficulty of the procedure. It is s expected that the successor to Kyoto will include some kind of finance for forestry – this could be a potential area for future insurance, there are a few companies looking at this.

[12] Point Carbon (2008)

**Figure 3 Growth in CDM Market**[13]

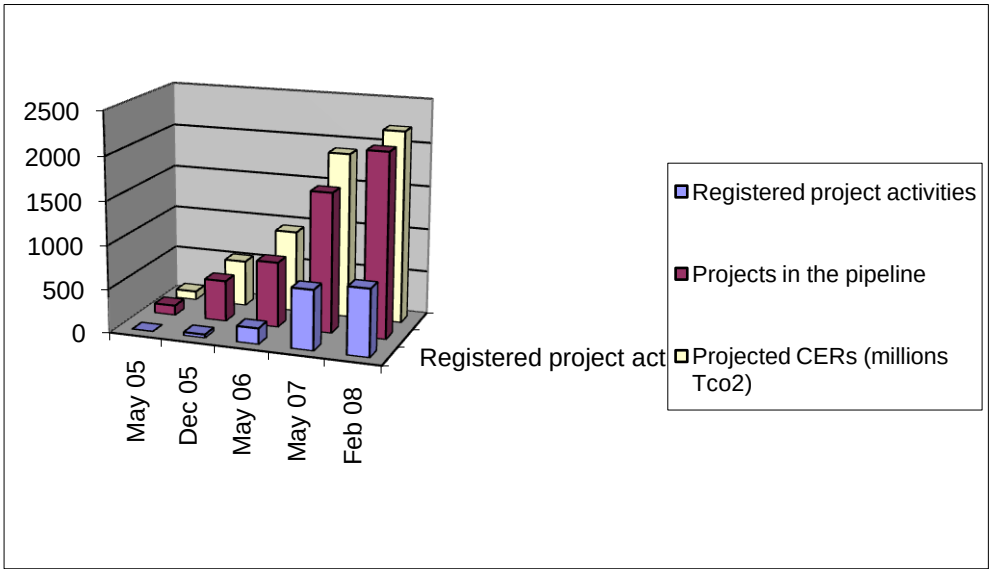
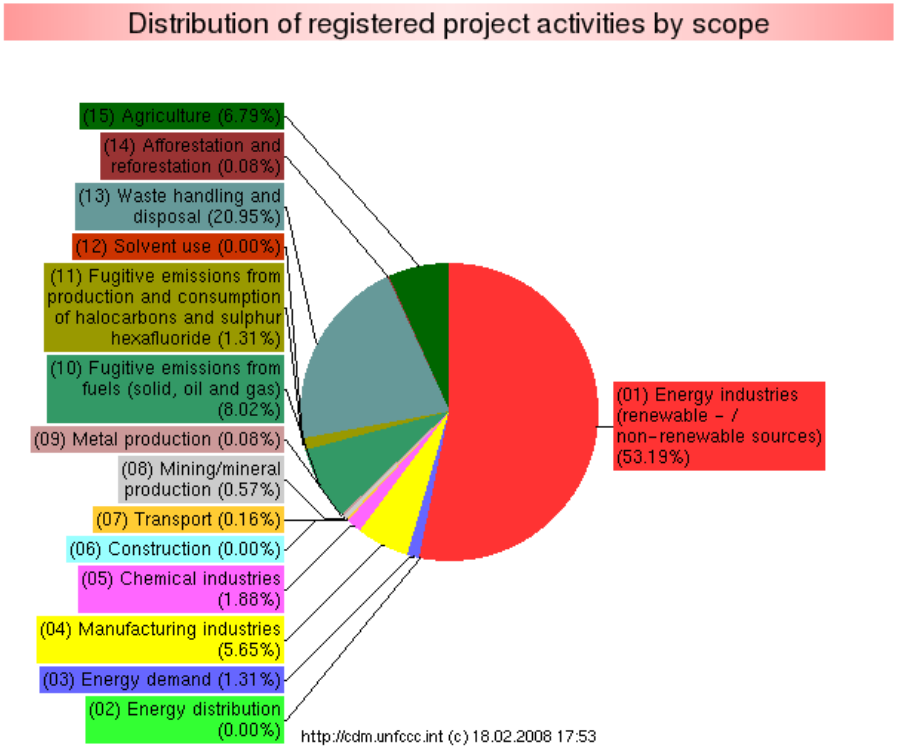



**Figure 4 CDM projects by type**[14]




| Sectoral Scope* | Registered Projects |
|---|---|
| (01) Energy industries (renewable - / non-renewable sources) | 650 |
| (02) Energy distribution | 0 |
| (03) Energy demand | 16 |
| (04) Manufacturing industries | 69 |
| (05) Chemical industries | 23 |
| (06) Construction | 0 |
| (07) Transport | 2 |
| (08) Mining/mineral production | 7 |
| (09) Metal production | 1 |
| (10) Fugitive emissions from fuels (solid, oil and gas) | 98 |
| (11) Fugitive emissions from production and consumption of halocarbons and sulphur hexafluoride | 16 |
| (12) Solvent use | 0 |
| (13) Waste handling and disposal | 256 |
| (14) Afforestation and reforestation | 1 |
| (15) Agriculture | 83 |

* Note that a project activity can be linked to more than one sectoral scope

[13] Source www.unfccc.int
[14] ibid

To qualify as a CDM, a project has to pass strict requirements, including the following:

1. Commercially viable technology
2. Adequate ERs volume
3. The ER volume must be big enough to make a project viable under the CDM -- for example, a small-scale project should generate a minimum threshold of 30,000 tonnes CO2/year.
4. Demonstration of additionality and determination of baseline Scenario and Emission Reductions
5. Competent Project participants and clear institutional arrangement with technically experienced and sound project developers with clear division of functions.
6. Viable business and operation model that help reduce transaction costs
7. Sound financing structure
8. Ratification of Kyoto Protocol by the Host Country
9. Environment impact and sustainability of the project
10. Contribution to Sustainable Development

Once the project is up and running, emissions reductions have to be validated by an independent approved private sector organisation to meet the appropriate criteria.

**Future developments**

Despite the economic downturn, the carbon market has continued to grow – the total value transacted in 2008 was $126 billion – twice its level in 2007[15]. However a number of political developments are likely to determine the future of the markets:

- USA: The Waxman-Markley bill has now reached the House of Representatives. This will legislate for the first time binding national emissions caps in the USA – 17% below 2005 levels by 2020 is proposed, and will establish a national cap and trade system. The bill does not automatically accept all CDM-certified credits, however provides generous allowable limits of two billion tons annually from domestic and international offsets, and international allowance trading[16].
- EU Climate and Energy Package in 2008: this makes carbon market continuity beyond 2012 more concrete. The EU ETS is to be expanded and the objectives of the Package are to reduce overall GHG emissions to 20% below 1990 levels by 2020, to increase the share of renewable energy sources to 20% by 2020; and to improve energy efficiency by 20% by 2020[17].
- EUETS Phase III: A single EU-wide cap will be implemented. The cap on emissions is expected to decrease at 1.74% per year rate with the 2010 allocation as a reference. As a whole, it is estimated that about half of allowances will be auctioned, increasing with time until70-80% are auctioned by 2020, which (compared to 4-5% during Phase II). The EU ETS could see an average 1.3 billion EUAs being auctioned each year, potentially raising €25-40 billion annually, part of which will be to be used for low-carbon and climate-resilient growth, both within and outside the EU[18].

[15] Kapoor and Ambrosi (2009)
[16] ibid
[17] ibid
[18] ibid

- International agreement: The successor to the Kyoto Protocol is due to be negotiated at COP 15 in Copenhagen in December. The agreement is expected to commence from 2013 and will determine the future of the international carbon market.

## Part 2 – Market Analysis

### 1) Commodities: A distinct Asset Class

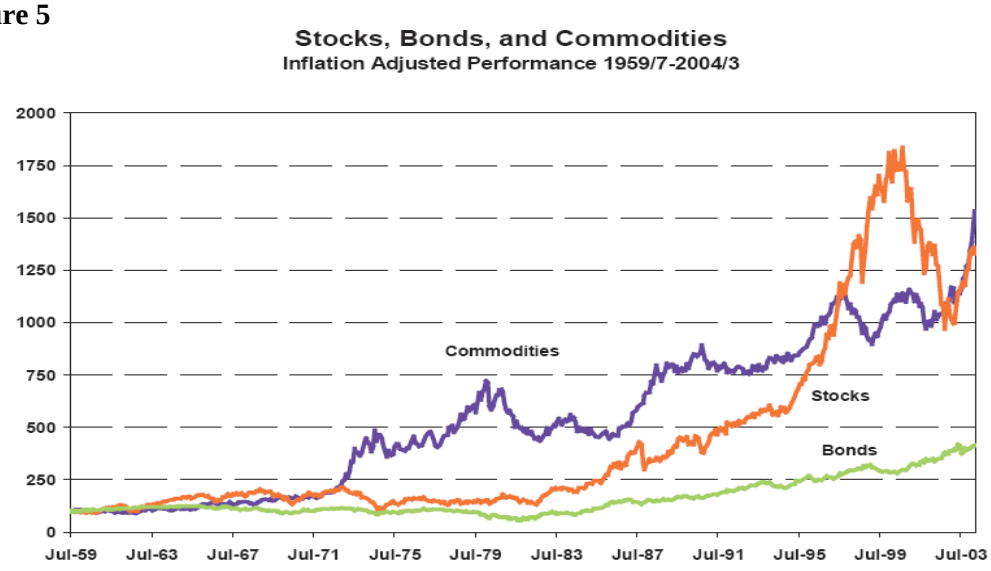
Expected Asset Returns are simply the sum of the risk-free rate plus the risk premium (compensation) for purchasing the specific risky asset. Ordering traditional assets in terms of risk, one will observe that the risk premia are cumulative in nature (Table 1 below) with the exception of commodities which clearly buck the trend. For this reason, many extreme event or shocks, the traditional assets will tend to be highly correlated while commodities would offer diversification benefits.

**Table 1 – Ranking of traditional assets by risk**

| Asset Class | Risk Premium |
|---|---|
| Cash | Zero |
| Inflation-Linked Bond | Liquidity Premium |
| Government Bond | Liquidity +Inflation Premium |
| Corporate Bond | Liquidity +Inflation +Default Premium |
| Equities | Liquidity +Inflation +Default +Equity Risk Premium |
| Commodities | Commodity Premium |

In "Facts and fantasies about Commodity Futures", Gorton & Rouwenhorst[19] estimate that the historical annualised risk premium on a diversified basket of commodity Futures to be approximately 5% , based on the period 1959-2004 period (see figure 5). This is similar in magnitude to the risk premium that they calculated for the S&P500 with both asset classes experiencing similar volatility levels. They also determined that commodities have historically had negative correlations to bond and equities, with the magnitude increasing with the duration of the investment (figure 6). The positive risk premium coupled with the favourable correlation characterises places commodities firmly on the efficient frontier of a mean-variance 2 factor analysis.

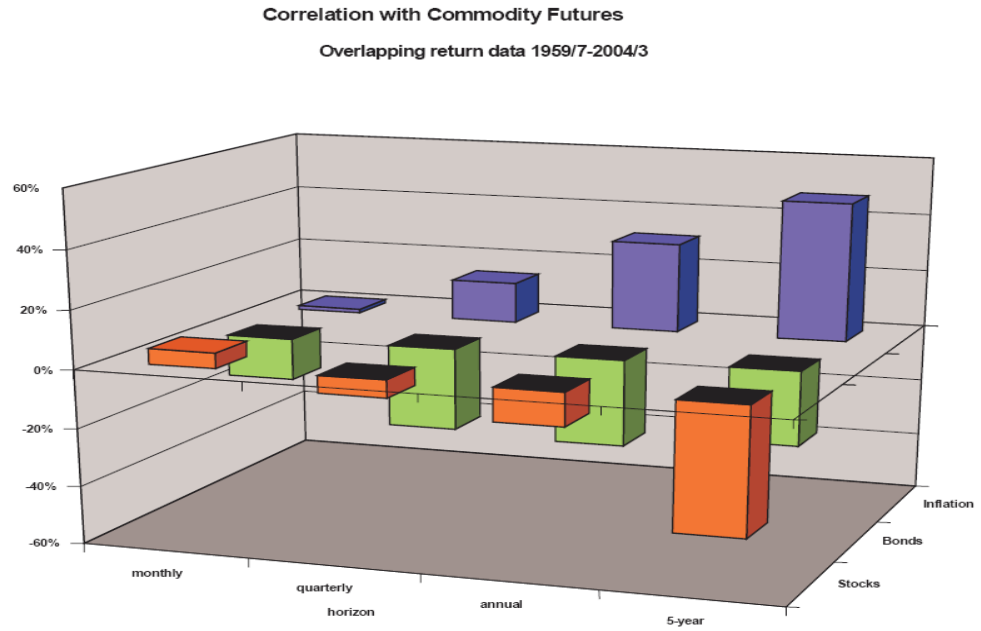
**Figure 5**




*Source: Yale Working Paper "Facts and fantasies about Commodity Futures"*

[19] Gorton & Rouwenhorst (2005)

**Figure 6**




*Source: Yale Working Paper "Facts and fantasies about Commodity Futures*"

The distinct risk-return profile of commodities is not unexpected when one examines the valuation and price drivers of commodities. The price of a traditional asset such as a bond or share is a function of the net present values of the expected future cash flows. The expected dividend / coupon payments and the prevailing interest rates are crucial inputs in the valuation process. The valuation of commodities is entirely different. Commodities are either consumable or transferable and thereby do not have claims to a defined or expected cash flows. Commodity prices are determined by global demand and supply and hence their returns are expected to differ from those of traditional asset classes (which are forward looking) along the different stages of a business cycle. Several commodities also experience a seasonality in both prices and volatilities.

## 2) Carbon: Price Drivers

**Demand Side Factors:**

- Weather:
  The prevailing temperature will impact the demand for electricity, especially during winter months when the electricity demand is most sensitive to weather conditions. A relatively mild winter will reduce the overall demand for electricity while colder temperatures will increase overall demand. Above-average temperatures in summer will lead to higher electricity demand and vice-versa. Above-average temperatures in summer will lead to increase demand for electricity in order to satisfy air-conditioning use.

  Coal and gas power stations meet the marginal demand in many countries in Europe such as Germany (with coal power stations satisfies marginal demand during off-peak hours and gas meeting demand during peak demand). Nuclear and hydro are generally used to meet the base load. Therefore, the change in electricity demand as a result changes of abnormal temperatures will result in changes in carbon emissions and thereby the demand for carbon credits.

- Economics of coal versus natural gas
  A coal plant produces approximately 1 kg C02 /KWH[20] whereas a gas power plant produces 0.5kg CO2 / KWH. Therefore, running a power plant on gas oppose to coal is an immediate option to abate carbon emissions. However only power plants that have the technology to run on either coal or gas will be able to make the switch. Furthermore, any decision will be based on the economics of the two options which will depend on the prevailing coal gas and carbon prices.

- Alternative Electricity Generating Sources (Hydro, Wind, Solar, Nuclear)
  - Impact of Weather on Non-Carbon Emitting Power Sources:

  Wind, rainfall, direct sunlight levels will impact the supply of electricity generated from hydro, wind and solar. Weather conditions which reduce the electricity produced from these sources will result in an increased use of carbon-emitting power generation from coal and gas. Precipitation is one of the most influential factor affecting hydroelectric production.

  - Relative Pricing:

  Technical advances and government subsidies have resulted in a significant increase in the use of wind and solar generated electricity.

- Economic Growth / Industrial Activity:
  As industrial activity increases, there will be more demand for the world's limited energy sources. While increased industrial activity is been partly offset in the OECD countries by improved energy efficient and strong political support for renewable energies, the pace of economic growth of countries in emerging markets such as the BRIC[21] Countries and the energy policy they adopt will have a major impact on carbon emission prices

- Financial Flows / Investor interest

[20] KWH is an abbreviation for Kilowatt hour, which measures the energy content of the electricity produced.
[21] Brazil-Russia-India-China

**Supply-Side Factor**

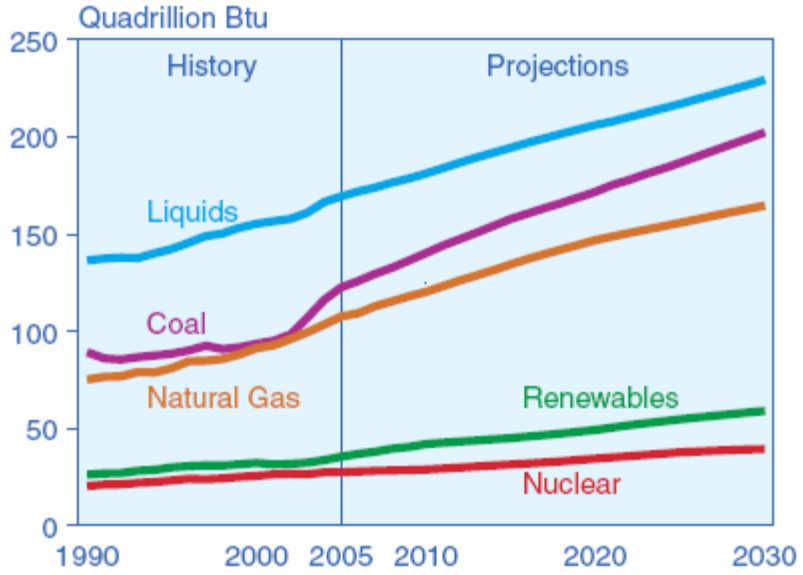
- Structural Factors in Developed Countries:

The EU is currently targeting a 20% reduction in carbon emissions by the year 2020 (from the 1990 levels). Therefore further emissions cuts will be necessary in Phase III. Additionally, many market participants are expecting that other industries such as the petrochemical and chemicals will be added to the scheme in Phase III.

- Structural Factors in Developing Countries:

The EIA forecasts that the growth in electricity demand over the next 20 years will be meet predominately by growth in coal-generated supply, and whereby China will be the world's largest consumer of coal. There will be increasing pressure on countries such as China and India to contribute to the goal of reducing carbon emissions globally.

**Figure 12. World Marketed Energy Use by Fuel Type, 1990-2030**



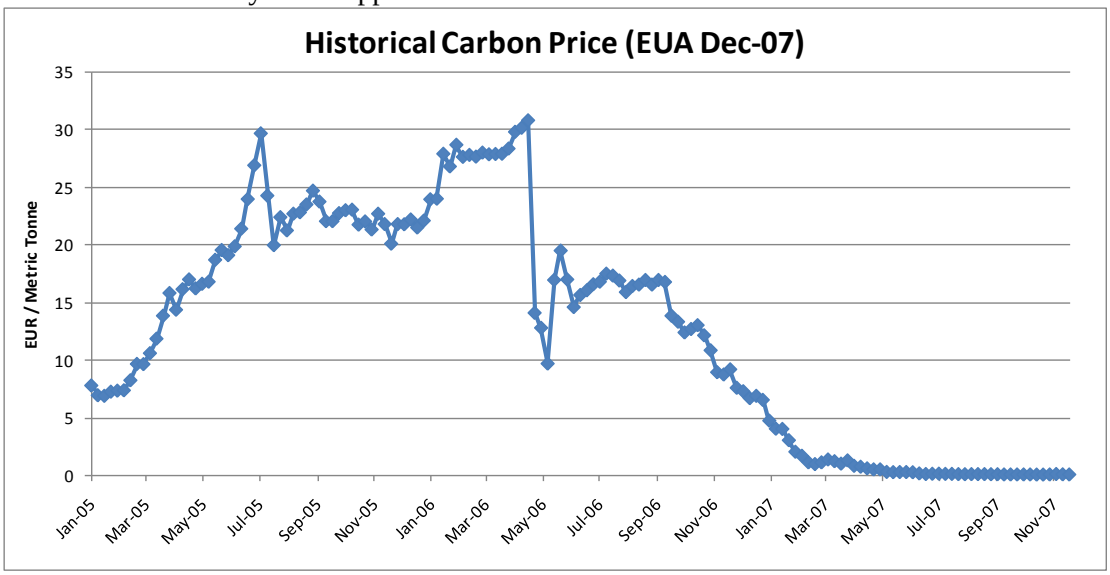

Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2005* (June-October 2007), web site www.eia.doe.gov/iea. **Projections:** EIA, World Energy Projections Plus (2008).

- Allocation of allowances

  While the overall number of emission allowances will have a significant impact of prices, the allocation between power producers and the industrial sector will also impact prices. Historically power plants have been subjected to the tightest allocation.

- Publication of Emissions Reports

**Phase I (2005-2007): Test Phase**
Phase I of the EU ETS started off well as "favourable" weather conditions and utility companies hedging activity supported prices. However, governments were forced to rely on industrial estimates of emissions due to a lack of historical emissions data. Additionally policy makers tried to avoid overly-burdening industry during the test phase. The net effect was a significant over-allocation Phase I. The price collapsed in April 2006 once the emissions figures for 2005 were released and finally converged to 0 as investors realised that the market was clearly over-supplied.



Source: Bloomberg

**Phase II (2008 – 2012**) The second phase (2008-12) expands the scope significantly:

- CDM and JI credits are introduced in second phase through the EU's 'Linking Directive',
- Aviation emissions are expected to be included from 2012.
- 3 non-EU members, Norway, Iceland, and Liechtenstein join the scheme.

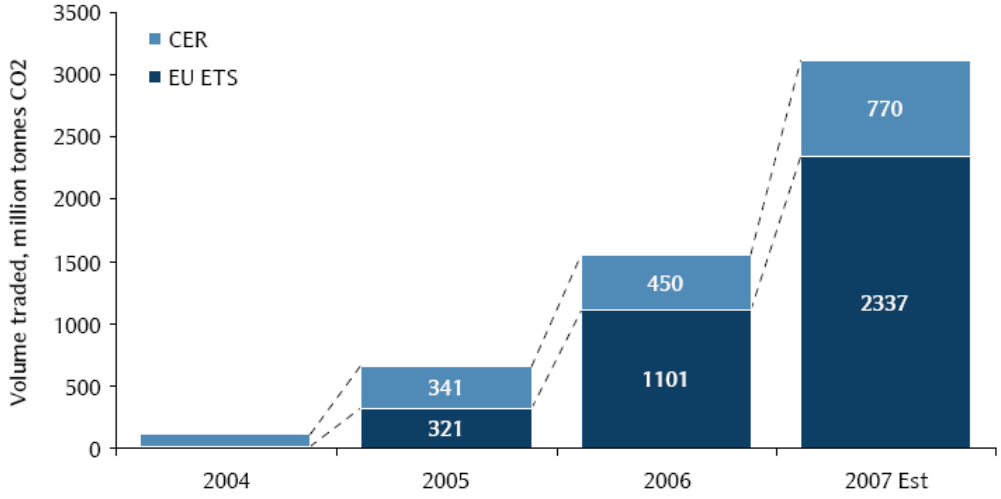
The inclusion of aviation is a move considered important due to the large and rapidly growing emissions of the sector. The inclusion of aviation is estimated to lead to an increase in demand of allowances about 10-12 million tonnes of $CO_2$ per year in phase two. This in turn is expected to lead to an increased use of JI credits from projects in Russia and Ukraine, which would offset the increase in prices and eventually result in no discernible impact on average annual $CO_2$ prices.

Ultimately, the Commission wishes the post-2012 ETS to include all greenhouse gases and all sectors, including aviation, maritime transport and forestry. For the transport sector, the large number of individual users adds complexities, but might be implemented either as a cap-and-trade system for fuel suppliers or a baseline-and-credit system for car manufacturers.

## 3) Investment Products - how to gain exposure

***Carbon is a traded Commodity.***

*Direct Investment:*
While all the main carbon credits described in this paper (AAs, EUAs, CERs, ERUs) are tradable, CERs and in particular EUAs are by far the most liquid. EUAs are traded both on exchanges and through the OTC market. Exchange activity is currently confined to spot and future transactions, but options on EUAs are expected to be launched in the future.



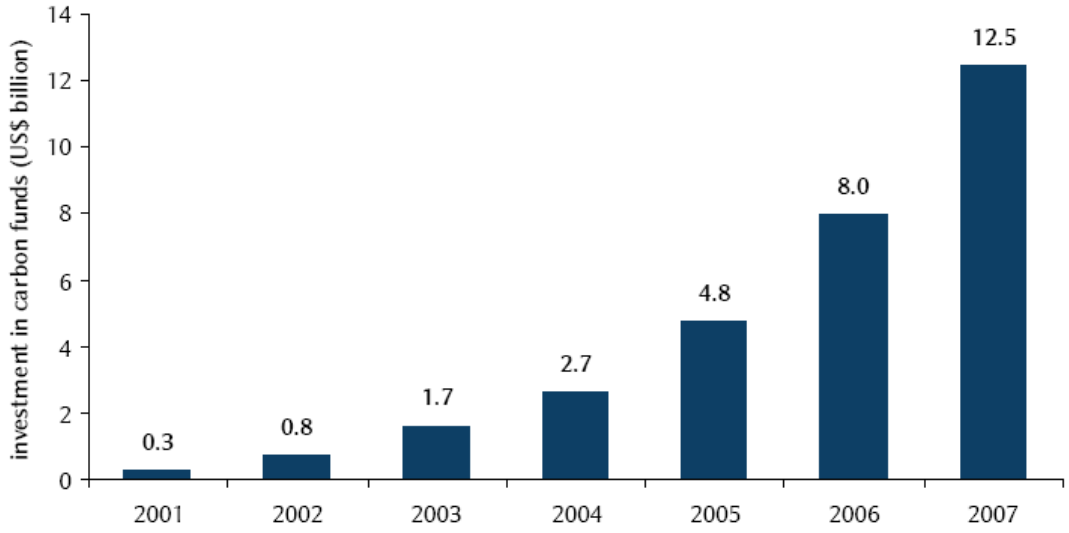

*Note: CER volume includes primary and secondary volume*
*Source: World Bank, New Carbon Finance, Barclays Capital*

Most EUA exchange trading occurs on the European Climate Exchange with European Energy Exchange, Nord Pool, Powernext having lower activity.

While there is no specific plan currently in place, several industry participants envisage an international trading scheme could be created in the future (incorporating for example California, Australia, New Zealand ) with a common carbon price. New Carbon Finance estimates that the global carbon market could increase to $700billion by 2020.

*Indirect Investment:*

- Funds: While considerably smaller than direct investments, investment in Carbon Funds has grown significantly in recent years.




*Source: New Carbon Finance*

- Indices:

A number of investment banks and exchanges have creating indices based on carbon credit prices, ranging from products that cover one type of carbon credit to products which incorporate several different types of credit (eg combining EUAs with CERs). Indices based on the equity prices of carbon-related companies have also been developed.

Swap and Options with a carbon index as the underlying are among the most common techniques that investors are currently gaining exposure to the market.

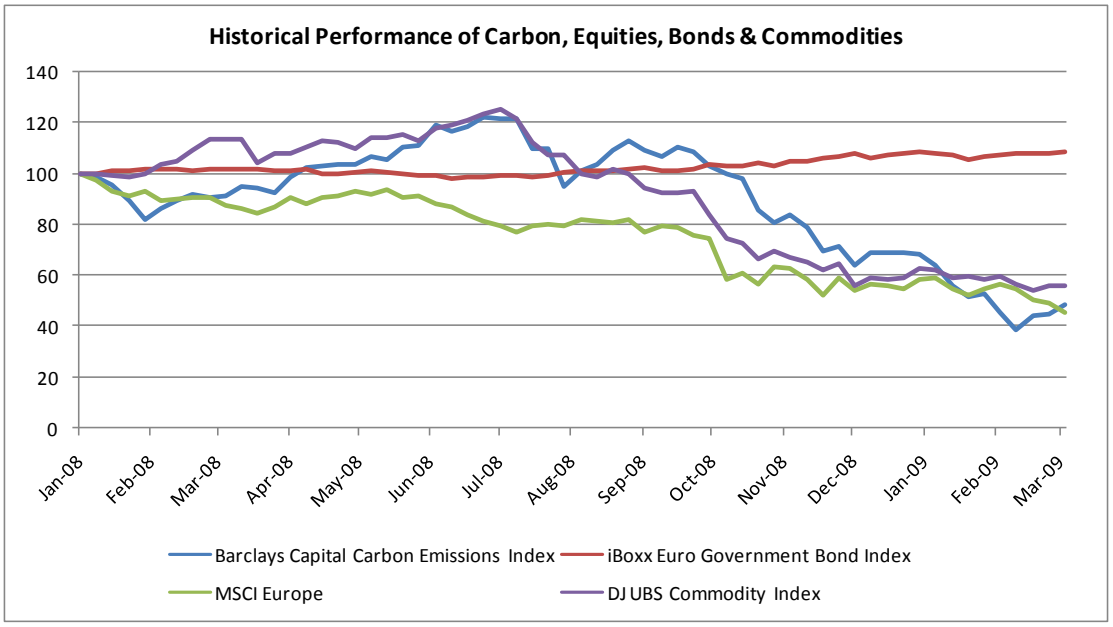
*Who are the Players in the Market?*

- Governments with an AAU shortfall / surplus
- Companies which are incorporated in the EU ETS
- Investors to whom carbon emissions appear as an attractive investment
- Green Players (Socially responsible investors)

## 4) Analysis of Carbon Investments in a Diversified Portfolio

Carbon has only been traded since the EU ETS was established in January '05 and was operating in a test environment for the first couple of years. Therefore there is limited data available which limits the ability to carry out any meaningful historical analysis.

One should also note that the price collapse in Phase I, as discusses above, was due to events that are unlikely to be repeated in the future. Furthermore, the period from 2008 incorporates one of the most severe economic / financial crisis in history and was marked by a sell-off in all risky assets as investors sought safe-haven investments.




Source: Bloomberg

## 5) Market Outlook

As discussed above, the EU ETS Phase III is expected to be more stringent than Phase II and thereby provide a positive headwind to prices. A return to trend global economic growth rate coupled by active support by the US for the global carbon global market will support carbon prices in the years ahead.

**References**


Beinhocker, E (2007) *The origin of wealth* Business Books

Bruce, N Cernesson, C Connell, R Fulcher, G Gardner, L Hawellek, D Herweijer, C Jewson, S Masi, L Maynard T, Mistry, V Rochester, D Silver, N Smith, L and Stainforth, D (2007) *The impact of climate change on non-life insurance* GIRO

Capoor, K and Ambrosi, P *State and Trends of The Carbon Market 2009* The World Bank

Farmer, D (2001) *Toward agent-based models for investment* Association for Investment Management and Research

Gorton, G and Rouwenhorst, G (2005) *Facts and Fantasies about Commodity Futures* Yale Working Paper

Hansen, J., Mki. Sato, R. Ruedy, P. Kharecha, A. Lacis, R.L. Miller, L. Nazarenko, K. Lo, G.A. Schmidt, G. Russell, I. Aleinov, S. Bauer, E. Baum, B. Cairns, V. Canuto, M. Chandler, Y. Cheng, A. Cohen, A. Del Genio, G. Faluvegi, E. Fleming, A. Friend, T. Hall, C. Jackman, J. Jonas, M. Kelley, N.Y. Kiang, D. Koch, G. Labow, J. Lerner, S. Menon, T. Novakov, V. Oinas, Ja. Perlwitz, Ju. Perlwitz, D. Rind, A. Romanou, R. Schmunk, D. Shindell, P. Stone, S. Sun, D. Streets, N. Tausnev, D. Thresher, N. Unger, M. Yao, and S. Zhang (2007*), Dangerous human-made interference with climate: A GISS modelE study*, *Atmos. Chem. Phys., 7*, 2287-2312.

Hansen, J., Mki. Sato, R. Kharecha, Beerling, D Berner, R Masson-Delmotte, V Mark Pagani, M Raymo, M Royer, D and Zachos, J (2008) *Target atmospheric CO2: where should humanity aim?* Godard Institute for Space Studies

IPCC (2007) *AR4 Synthesis report* IPCC

IPCC (2007a) *IPCC Fourth assessment report – Working Group 1: The physical basis of climate change* IPCC

IPCC (2007b) *IPCC Fourth assessment report – Working Group 2: Impacts, Adaptation and Vulnerability* IPCC

IPCC (2007c) *IPCC Fourth assessment report – Working Group 3:Mitigation of climate change* IPCC

King, D (2008) *Hot topics* Bloomsbury

Mandelbbrot, B and Hudson R (2006) *The (mis)behaviour of markets* Profile Books

Miller, J and Page, S (2007) *Complex adaptive systems* Princeton Paperbacks

Mills, E and Lecomte, E (2006) *From risk to opportunity: how insurers can proactively and profitably manage climate change* CERES

Monbiot, G (2006) *Heat* Penguin

Montgomery, W.D. (1972) *Markets in Licenses and Efficient Pollution Control Programs* Journal of Economic Theory 5:395-418

Muir-Wood, R (2005) *The future of the insurance industry under climate change* ABI Conference 29 June 2005

Myles, G (1995) *Public Economics* Cambridge University Press

Palin, J Silver, N, Slater, A and Smith, A (2008) *Complexity economics: application and relevance to actuarial work* FIRM

Point Carbon (2008) *Outlook for 2008* Point Carbon Carbon Market Analyst

Stern, N (2006) *Stern review on the economics of climate change* HM Treasury

Stern, N (2008) *Key elements of a global deal on climate change* LSE

United Nations (1998) *Kyoto Protocol* United Nations

**Websites**

http://climatechange.pbwiki.com

www.ipcc.ch

www.pointcarbon.com

www.ieta.org

www.unfccc.int