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ECG Bulletin – July 2008

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A glimpse of the interior of a rainforest on the Tutoko River Track, Fiordland National Park, New Zealand. *The protection of rainforests through the financial incentives offered by carbon trading schemes was described in this year's ECG DGL 'The Science of Carbon Trading' pp 2-18.*

Sir Frank Fraser Darling, ecologist, 1903-1979

'Wilderness and Plenty', The Reith Lectures 1969. Published by the British Broadcasting Corporation, 1970.

"Now, there is a much greater change to which we are contributing, this time in the planetary atmosphere … I am alluding to the rise of carbon dioxide in the atmosphere … There is a carbon dioxide cycle which naturally keeps levels right. It is a system of great age and stability which we are now taxing with the immense amounts of carbon dioxide we are adding from the fuel we burn. Vegetation is a great buffer: the forested wilderness removes a great deal of the carbon dioxide … sequesters it, giving out oxygen in exchange … But unfortunately we are cutting the virgin wildernesses all the time and reducing tree cover in so many places … the activities of industrial and technological man in our day are adding carbon dioxide and also injuring the capacity of the biosphere to redress the balance."

These prescient and compelling words are from the transcript of one of Dr Frank Fraser Darling's BBC Reith Lectures delivered nearly 40 years ago. He went on to foresee the effects of global warming on the oceans and on marine fauna, and the consequences for the polar icecaps. At the time, Fraser Darling wrote that 'the carbon dioxide problem is as yet remote', but scorned those who said the 'posterity must look after itself', instead 'we should be delving ecologically into the future'.

Now 40 years on the carbon dioxide problem is very real, and commands the attention of politicians, economists as well as scientists. This year's ECG DGL and symposium 'The Science of Carbon Trading' addressed a few of the issues raised by Fraser Darling. In the main lecture, economist **Terry Barker** explained the financial leverage exerted by carbon trading as a way of reducing overall CO_2 emissions. Preservation of tropical rainforests was the concern of two of the speakers in the supporting symposium, **Jon Lovett** and **Matthew Owen**. While the vexed question of whether the use of biofuels can reduce the levels of greenhouse gases was tackled in the remaining talk by **Nigel Mortimer**.

In 1969, Fraser Darling thought that 'not nearly enough data are being gathered' about the effects of global warming. That, at least, is no longer the case, and **Stephen Ball** analyses a recent article in *Nature* on the impact on physical and biological systems due to anthropogenic climate change.

RUPERT PURCHASE

Achieving the European Union's 2 °C target through carbon trading

***Dr Terry Barker**, University of Cambridge, UK*

ECG Distinguished Guest Lecturer 2008

Introduction

The climate-change problem

The climate-change problem is essentially one of accumulating stocks of greenhouse gases (GHG) in the atmosphere. Economic behaviour and the availability of fossil fuels have led to greatly increased greenhouse gas emissions from human activity, and the unrestrained future increase in emissions is likely to end in dangerous climate change.

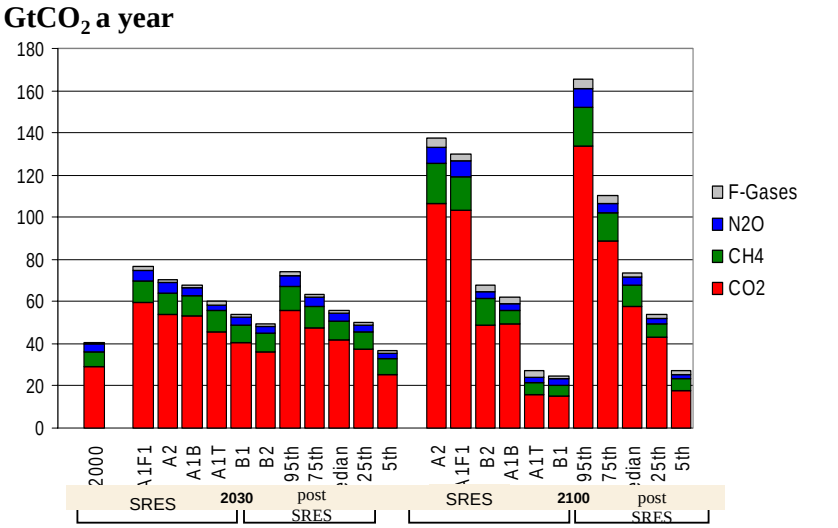
Figure 1 shows the expected increases in GHG emissions from a wide range of Intergovernmental Panel on Climate Change (IPCC) scenarios. The reason to be pessimistic about future emissions (IPCC 2007c, Fourth Assessment Report, AR4) is that there are very substantial reserves of fossil fuels, especially coal, available at prices that make them economic for power generation, even more so with the higher levels of gas prices seen in recent years, gas being one of the main alternative fuels.

Adding to the economic pressure to use coal, there is a political pressure for countries that might otherwise be importing gas, to use domestic coal to maintain or increase energy security. Deforestation also contributes to the emissions, but the motivations and institutional behaviours here are more complicated. There is a very long-term global trend in the loss of virgin forests and grasslands, also arising from their availability as common resources, so that their destruction for land or timber benefits individuals but the loss of the resource and the climate-change costs are collective.

Impacts of climate change

Knowledge about the potential impacts of climate change is provided by both *The Stern Review* (2007) and the IPCC 2007 Working Group 2 (IPCC, 2007b) Report. The first impacts of anthropogenic climate change appear to be already evident in the European heat wave of 2003, the Katrina hurricane of 2005, and the widespread fires in Greece and California in 2007 – although variation in weather events makes attribution difficult. These events are all consistent with higher average temperatures and more energy in the atmosphere as a result of higher greenhouse gas (GHG) concentrations.

Figure 1: Global GHG emissions for 2000 and projected baseline emissions for 2030 and 2100 from IPCC Special Report on Emissions Scenarios (SRES) and post-SRES literature



The attribution of such extreme events to global warming is supported by the unexpectedly high increase in CO_2 concentrations reported by Raupach *et al*, 2007, in turn attributed to faster-than-expected global economic growth and the increased use of coal in China and other developing countries for electricity generation.

The important feature of future climate change that leads to the damages is the expected increase in frequency and severity of extreme climatic events over the next millennium at least. The average temperatures and sea level rises should be seen as indicators of the risks of such events, rather than as widespread small and gradual changes. What may appear to be a favourable outcome, e.g. a milder climate in northern Europe, may turn out to be more variable winters and summers, with more floods and droughts. As the temperatures go up, the frequency and severity of the extreme events seems likely to rise too. The problem of scientific reticence (Hansen *et al*, 2007) means that the underlying situation may be much more serious that portrayed in the last IPCC Report. The economics of the problem suggest that the risks to human life and health, along with the escalating value of the net loss of life and health without discounting, imply unbounded costs of business as usual.

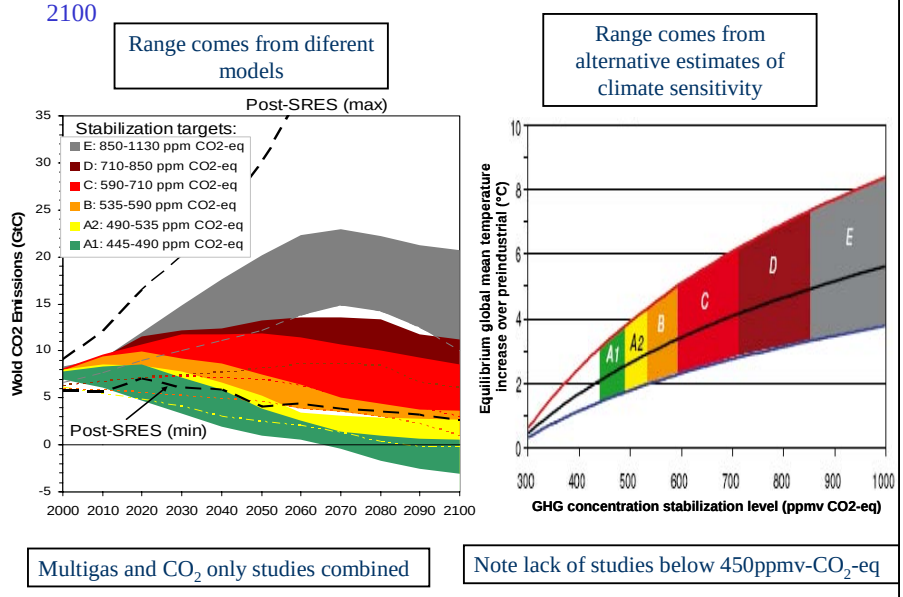
The IPCC Fourth Assessment Report (AR4) WG3 Summary for Policymakers (2007a) gives an indication of just how deep the cuts will have to be to avoid risks of catastrophe. It presents six scenarios from the literature on the scale of action required. For a chance less than 50:50 that the target will be met, the scenarios suggest that global CO_2 emissions will have to be between 50% to 85% below 2000 levels by 2050, and becoming negative (through sequestration and storage) by 2070 and beyond.

Therefore to be reasonably sure of avoiding dangerous climate change defined as a 2 °C rise or less, the world should be aiming for complete decarbonisation by 2050 or earlier. All sectors in all countries should be aiming to stop emitting GHG into the atmosphere as soon as possible without excessive cost. We should be considering just how fast economies can reduced their emissions without any serious damage to government, business and household finances. **Figure 2** from the Report shows the ranges from assumptions about climate sensitivity in converting from temperatures to GHG concentrations, and the implications of the concentrations for the GHG emission trajectories 2000-2100, with the range coming from the different models' estimates. The link between the two charts in **Figure 2** comes through the colour coding for groups of scenarios. Note that there are no estimates below about 450ppm CO_2-eq, because there were too few studies in the literature for a reliable estimate.

The economics of dangerous climate change

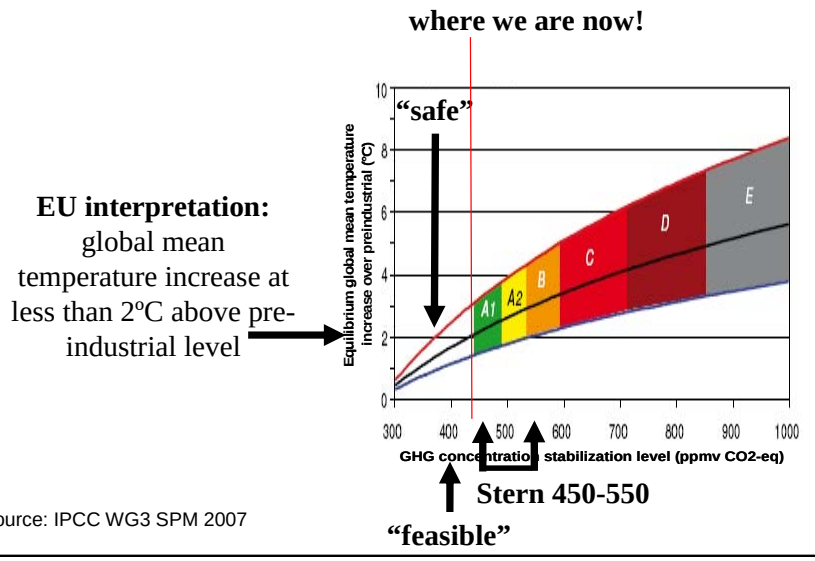
In the traditional Cost-Benefit Analysis (CBA) of climate change (reviewed by van den Bergh, 2004 and Barker, 2008), the damages to human life and health are usually discounted at rates many times the 0.1%pa taken by Stern as the pure rate of time preference. This is a very odd ethical position because it implies that human lives and health of people living, say, 20 years ahead, are valued at a fraction of those living today. Since this feature is hidden in the mathematics (including those of *The Stern Review*), it has not

Figure 2: Average global temperatures, GHG concentrations and emissions 2000-2100



Source: IPCC WG3 SPM 2007

Figure 3: EU temperature target, Stern's concentration range and "safe" and "feasible" concentration targets



Source: IPCC WG3 SPM 2007

been recognised that a more consistent and indeed in my mind a more ethical treatment would yield the overwhelming costs I have mentioned.

This is obvious intuitively if we postulate that:

1. Business as usual emissions are likely to lead to concentrations above 750ppmvCO_2-eq, and
2. The damages are likely to rise steeply as average temperatures rise over the next century.

The costs rise as the damages to life and health increase for the rich, who can afford to protect themselves, and far more so for the poor. The CBA solution in this case is one of costs so high that immediate and instantaneous elimination of all GHG emissions is justified as well as the use of all our resources in a massive programme to remove CO_2 from the air. This of course in not going to happen and I agree with Marty Weitzman (2008) that this makes CBA meaningless and useless.

Figure 3 shows various targets for climate stabilisation in terms of temperature increases above pre-industrial levels, and GHG concentrations in the atmosphere in CO_2-equivalent parts per million (ppm). The current level is about 430ppm CO_2-eq, but this is affected by SO_2 and other non-GHG emissions that have a net cooling effect. *The Stern Review* range is 450-550ppm CO_2-eq, but a feasible level for scientific study is assumed to be 400ppm CO_2-eq, whilst the safe level for the 2 °C target, allowing for climate sensitivity, would be more like 380ppm CO_2-eq (Hansen *et al*, 2008).

The central question for climate policy

So we must re-direct our economic thinking towards a risk assessment. The central question for climate policy is how to reduce all damaging emissions from human activity as soon as possible, recognising the risks and uncertainties and the opportunities for improving human well-being.

In the atmospheric emissions with GHGs, I include soot, other fine particles, SO_2 and the chemical surfaces of the particles (as well as the chemical soup cooked up by the sun and weather) as an inherent part of the problem and their reduction as an inherent part of the solution. Luckily for us, the biosphere appears to absorb about half our current GHG emissions, so if we stop emissions altogether (very unlikely, but an iconic target) then concentrations will fall. However, this feature of the carbon cycle is weakened by the higher temperatures, ocean and forest acidification and pollution, so we risk damaging this natural service as well, making the problem worse. The reduction in other pollutants associated with GHG emissions is important because the literature suggests that this side benefit of GHG mitigation may be substantial, indeed comparable with the direct costs of the mitigation (Barker *et al*, 2007, section 11.8). Fortunately these do not accumulate, but get washed out of the air much sooner than GHGs, so that abatement has immediate benefits in terms of improved air quality.

Table 1 shows the reductions in emissions required for the different target ranges. For the most stringent range shown of 445-490ppm CO_2-eq, GHG emissions have to be at least 50% below 1990 levels by 2050, preferably much more and much earlier, and emissions have to peak before 2015.

Table 1: Long-term mitigation

Stabilization level (ppm CO_2-eq)	Global Mean temp. increase at equilibrium (ºC)	Year CO_2 needs to peak	% reduction in 2050 compared to 2000
445 – 490	2.0 – 2.4	2000 - 2015	-85 to -50
490 – 535	2.4 – 2.8	2000 - 2020	-60 to -30
535 – 590	2.8 – 3.2	2010 - 2030	-30 to +5
590 – 710	3.2 – 4.0	2020 - 2060	+10 to +60
710 – 855	4.0 – 4.9	2050 - 2080	+25 to +85
855 – 1130	4.9 – 6.1	2060 - 2090	+90 to +140

Source: IPCC WG3 SPM 2007

The costs and benefits of accelerated decarbonisation

We need short-term modelling to explore the costs and benefits of accelerated decarbonisation of the global economy, so I am very taken with Klaus Hasselmann's call for an international forum to be established to provide information and help to explore details of the economic solutions (Hasselmann and Barker, 2008). Carbon trading is one of the critical policy instruments in that solution, which brings me to the main theme of my talk.

Political economy has been portrayed by Thomas Carlyle as the dismal science, but on the contrary, I am heartened by the fact that a new understanding of the economy leads me to assert that it need not cost much, and if we choose a good mix of policies such action will benefit economic performance and improve human well being.

Just as Malthus was wrong (so far!) in his predictions of population growth leading to economic collapse (Trewavas, 2002), so I think traditional economists are wrong in arguing that rapid decarbonisation will ruin our economies, and for much the same reasons: technological change, but with a twist. In addition to food-producing technologies to feed us ("the green revolution"), we now need GHG-reducing technologies with carbon trading and carbon taxes "to save the earth", by which I mean initially the coral reefs and tropical forests, these treasures of biodiversity evolved over millions of years of climate stability, but ultimately the favourable climatic conditions that have allowed life to flourish on earth.

Of course this depends on the mix of policies available, but we can find a clue to the scale of feasible reductions from the studies of the costs of ratifying the Kyoto Protocol for the USA. These postulated a 30% reduction in CO_2 emissions below business as usual over a 3 to 4 year period. With US emissions more or less static, this in turn implies a reduction of some 7% a year (Barker and Ekins, 2004). I shall discuss later how much this might cost.

Carbon trading and other policies for mitigation

The major problem for climate policy is that the atmosphere is a common resource, which makes the problem almost intractable and the outlook for effective action bleak. As Stern says, *the use of the atmosphere for waste disposal represents the greatest market failure the world has ever known.* In the economic behaviour underlying economic growth and development, no government, business or household has a direct self-interest in reducing emissions. Each has an interest in using the atmosphere as disposal of the waste gases of combustion, but action by any single group in reducing its waste, even the USA, will have a very small effect on the global stock. Cooperation with others is necessary to reduce costs and achieve substantial reductions.

Figure 4 shows the carbon prices as they have emerged in the scheme over the three years 2005-2007 covering Phase 1 of the ETS. It shows the actual prices of Phase 1 and the future prices for use of allowances in 2008 and 2011 during Phase 2. The future prices move together and have averaged between €20 and €25 per tonne of CO_2.

It is in this context that I should like to consider **carbon trading**.

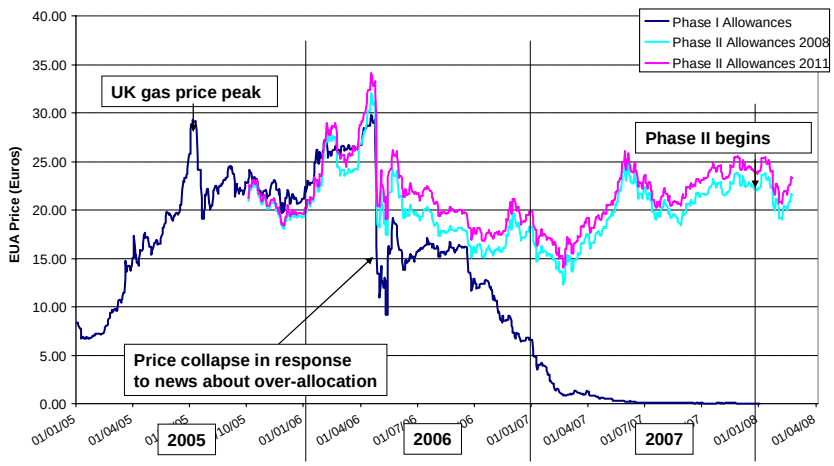
The European Union's Emission Trading Scheme (EU ETS) for CO_2 emissions

The European Union's Emission Trading Scheme (EU ETS) for CO_2 emissions is by far the largest and most comprehensive action yet taken in mitigation policy. It has the potential to achieve the 2 °C target, but it will have to become global and incorporated within national policy portfolios including regulation and perhaps ecotax reform if it is to be effective, efficient and equitable in doing so.

The role of the carbon price generated through trading is pivotal in realising the mitigation potential in all sectors. The carbon price re-enforces the effects of regulations improving efficiency standards in vehicles, appliances and buildings. It suggests the appropriate levels of carbon taxation for the non-traded sectors in an environmental fiscal reform. It induces technological change, because investment in low-carbon technologies is increased and costs fall as their scale rises, leading to more take-up of the technologies.

Finally, at a global scale, it offsets the cheapening effect of increasing energy efficiency on the real costs of using energy, and so offsets any potential rebound effects (Sorrell, 2007). The earlier and stronger the actions to make the future carbon prices sufficiently high and reliable, then the higher are the investments and the lower the eventual costs.

Figure 4: EU Emission Allowance Prices: January 2005 to February 2008 in €/tCO_2



Source: European Energy Exchange (EEX, 2008)

Figure kindly provided by Aoife Brophy, Electricity Policy Research Group, University of Cambridge

Why a carbon price is essential

The impact of carbon pricing

The main reason why technology alone is very unlikely to solve the mitigation problem is this "rebound effect" (Sorrell 2007). This effect comes about through improvements in energy efficiency leading to reductions in costs of a technology, which then leads to higher use, so that the energy-saving from the technological improvement if offset by increased demand for energy. Therefore any technological breakthrough without a carbon price to deter extra use of carbon will lead to higher incomes and more use of energy in general, weakening the effect in reducing GHG emissions especially at a global level. A carbon-price signal is needed to provide a pervasive and long-term signal for investment decisions so that low-GHG options are chosen. Most important, the R&D decisions would also be influenced by the expected carbon price.

Basically the low-cost trajectories towards stabilization in the literature involve the strong expectation that carbon prices will rise to very high levels, so that new investments (supplying energy in the form of power plants and demanding energy for power, comfort, light and transportation) are designed, deployed and installed as low-GHG depending on their lifetime. The low carbon price in the near term reduces the cost of premature obsolescence; the expectation that they will be high later encourages R&D and investment in long-lived low-GHG capital, and reduces risks of lock-in. The outcome should be seen in terms of rapid adaptation of the energy system to low or negative GHG emissions without excessive costs and making the most of the no-regrets technical (e.g. in dwellings) and institutional (environmental tax reform) opportunities and the potential for induced technological change. If the policy is successful eventually no sector will need to pay for carbon because the emissions will cease, but the price signal must be credible and should escalate to give time for adjustment.

Carbon prices are social prices with their levels generated by policy through two main market-based instruments to manage the climate problem: carbon taxes and emission-permit schemes. A carbon tax is a highly specific and targeted way of tackling the global warming problem: the necessary fiscal system is already largely in place, the administrative and compliance costs are exceptionally low compared with those of many other taxes, the tax revenues will tend to grow with incomes, and the expected responses to higher prices are such that revenues will continue to rise even as there is substantial erosion of the tax base as emissions decline. However taxes are disliked, particularly by the energy industries.

In contrast, the externality can also be managed by creating a market in legally enforceable rights to emit GHGs, such as the EU ETS and then restricting those rights, and auctioning all or part of them. The rights or allowances can be given to the emitters as an incentive to participate, as in Phases 1 and 2 of the EU ETS, a crucial advantage compared to taxes. The schemes, in contrast to carbon taxes, provoke an institutional response in that a new market is created, and companies tend to seek out new ways of reducing emissions. However, there are several objections to such schemes: they acknowledge rights that may not have existed up to that point, no actual monetary compensation is normally provided for those who will suffer damage from future pollution, the schemes are open to abuse by collusion, and transactions costs can be high, especially for small non-business sectors. So far the schemes have been confined to cover large fixed business uses of carbon, predominantly power generation.

Level of long-term carbon prices

This brings me to the issue of what level of long-term carbon prices is needed to decarbonise the global economy. This question cannot be answered with any certainty because the underlying literature is insufficient in quantity and quality. In any case we should refer to a range of prices to achieve a quantitative target, which itself is chosen by taking into account the risks and uncertainties of not achieving the target. And, crucially, we should keep in mind that business as usual is the most dangerous and risky of the options available in the literature.

There are prices around. The most recent results for the UK, are given in a report for the 2007 Energy White Paper (Strachan *et al*, 2007). The Shadow Price of Carbon from this report to achieve a 60% reduction in CO_2 by 2050 below the year 2000 levels is £65 to £176/tCO_2 (year 2000 prices) by 2050 with a central estimate of £105. At year 2000 exchange rates the range converts to $98 to 267 with a central estimate of $159 for 2050. As an aside, contrast this price with that proposed by Defra (Price *et al*, 2007), converted to the same basis, of $76 (£50)/t$CO_2$ by 2050. The Defra price was chosen not on the basis of achieving the 60% target, let alone the 2˚C target, but from a cost-benefit analysis with an outdated estimate of the costs of climate change that substantially discounts the value of health and lives of future generations and ignores the significant risks of catastrophe. Although no one pays the shadow price, it does enter the cost-benefit analyses of major projects, such as the third runway at Heathrow airport, and may affect planning decisions, such as those for the proposed coal-fired power station at Kingsnorth on the Thames estuary. The current Defra price of half or less than the one from more relevant modelling seems likely to undermine the achievement of UK CO_2 targets.

The global carbon prices required to reach the 2 °C target

The global carbon prices required to reach the 2 °C target are not in the literature, but we can extrapolate from what is available at least at ranges that may achieve the 450ppm CO_2-eq, the most stringent level recommended in the Stern Review. Barker and Jenkins (2007) estimate a range of $24 to 173/t$CO_2$-eq year 2000 prices by 2030, depending on the treatment of technological change in the models, with the lower value assuming a technological break-though in the form of a low-cost, low-carbon source of energy in unlimited supply (a "back-stop" technology).

As a rule of thumb, given all the uncertainties and a precautionary approach, a carbon price rising to $100/t$CO_2$-eq by 2020 for OECD countries seems to be a good starting point. This could emerge from emission trading schemes for the energy sector with a stringent GHG

reduction target by 2020 of at least 30% below 1990 levels by 2020. Such a carbon price is a market price similar to the world oil price, but applying mainly to CO_2 emissions from electricity generation. It converts to $45/barrel of oil and would be paid on CO_2 emissions from burning coal and gas (the electricity sector does not use much oil for generation), essentially raising electricity prices (by 70% in the US on year 2005 fossil-fuel use). However, there is a the crucial difference compared to 2007-2008 oil-price increases on a similar scale: the increase in carbon prices would be spread over several years and the revenues from auctioning the emission allowances would accrue to the countries regulating the emissions, not to the oil producers, and so they can be used to compensate those who lose employment and to provide incentives for low-carbon alternative sources of energy. If the energy sector responds rapidly and switches to renewables, nuclear and other low-carbon sources, then the CO_2 allowance costs will fall rapidly. However, emission trading schemes are less suitable for other sectors, especially for emissions from transportation and buildings, and wider portfolios of policies, in which institutional and technical barriers to change are addressed, are more appropriate.

Portfolios of economic instruments for mitigation: carbon prices, low-GHG incentives and regulation

The literature on mitigation is concerned mainly with quantitative GHG targets, as required by any stabilization target, which has to be absolute in relation to the prospective stocks of GHGs in the atmosphere. However, the economic system driving the emissions is market-based, in which prices play a critical role in allocating resources and encouraging technological change. The low-cost policies all require the use of market instruments via carbon prices, combined in portfolios with regulation and subsidies targeted at clear market failures, most critically the pervasive general market failure in innovation and the specific market failures in the energy markets (e.g. achieving more rapid penetration of hybrid and plug-in vehicles, or exploiting no-regrets options in buildings). The market failure in innovation comes about because those doing the investment, even allowing for patents, are unable to capture all the benefits, which accrue to all those able to copy and exploit the innovation. In consequence not enough innovation is done in a market system (Jaffe *et al*, 2005).

Governments usually have a wide range of policy instruments at their disposal to achieve their targets for climate policy. Indeed, the focus of the IPCC WG3 Report is on the sectoral options for mitigation (7 out of 13 chapters), providing a rich source of detail on the economic potential for mitigation at different carbon prices in energy, transport, buildings, industry, agriculture, forestry and waste management. Good policy portfolios for GHG mitigation will be specific to each country depending on their political systems, the available renewable and other energy resources and the energy efficiency of the stocks of buildings and equipment. Such portfolios will combine policies and measures to produce outcomes that are effective at achieving the main objective, efficient with low costs, or even benefits, as regards effects on GDP, and equitable in that the most vulnerable groups affected will be most likely to benefit. Most important for policies to achieve a wide social consensus, they should also address other potential social benefits, such as improvements in air quality with the associated better human health and higher crop productivity, the increased comfort from better insulated buildings, or reductions in traffic-related pollution.

It is a great advantage that climate policies, both for adaptation and mitigation, are inherently *equitable*. This is because mitigation has its main and central benefit the avoided costs of climate change and adaptation also avoids the effects of climate change. The climate change damages are focused on those who cannot re-locate or otherwise protect themselves against climate-related damages, i.e. those on low incomes, especially in developing countries with relatively large agricultural sectors in flood plains or drought-prone regions. However, there are major exceptions, e.g. energy use per capita may be particularly high in low-quality dwellings occupied by low-income households. In such cases the portfolio should include measures to improve the energy efficiency of dwellings.

One complement to the market-based carbon prices is the use of the traditional regulatory command-and-control approach, which involves agencies (such as Pollution Inspectorates) fixing and forcing energy and GHG standards. Climate, air quality and energy-security objectives are all served by technology-forcing policies of the sort pioneered in California over the past 15 years (Jänicke and Jacob, 2004). The main objection has been their potential inefficiency, but they can be targeted to correct market failures and support investments that are profitable given social as opposed to private costs and discount rates.

The potential for environmental tax reform

There is one particular benefit that may be important for economies with chronic problems of unemployment or underinvestment: the potential use of the revenues to reduce taxes that bear on employment and investment. The distortions of the current tax system may be so great that a large number of jobs could be created, at no net fiscal cost and at little risk to inflation, by a reform of the tax system (Patuelli *et al*, 2005). This is feasible because a 60 percent cut in emissions is only 2.3 percent a year over 40 years. If the price incentives are in place, especially if they can be anticipated, the economy can move gradually and efficiently towards a sustainable level of emissions without sacrificing economic welfare. However, this requires the use of efficient instruments such as the carbon tax, and it also requires social acceptance of long-term radical change, in which people with a preference for carbon-intensive lifestyles are liable to lose out.

The costs of achieving the 2 °C target

Before I finish, I would like to give an estimate as to how much this will cost. This is a surprisingly difficult and controversial issue because economists are by no means agreed on how to represent and model these costs.

The energy system costs

We can find one estimate of these sectoral costs from the price of the allowances times their number, since this is what has to be paid to achieve a target if all the allowances are auctioned. Thus if we expect total UK CO_2 emissions to be 30% below 2000 levels by 2020, the revenue (assuming prices of £66/tCO_2 converted from \$100/tCO_2) would be £25bn in 2000 prices. It is important to put this into perspective. Total UK environmental taxes were £35bn in 2005, current prices, representing 7.7% of total tax and social security revenues[1]. In other words, the revenues from CO_2 emission trading are likely to be less than 10% of total tax revenues, even at the \$100 carbon price for 2020. However, these costs are one-sided and partial. They show what the system is projected to pay for the rights to emit CO_2, but do not take into account the wider picture. These costs are also simultaneously revenues for the government that can be used to support alternative low-GHG technologies or to reduce burdensome taxes. A more complete assessment of costs is given by a macroeconomic analysis.[1]

The macroeconomic costs

To give a flavour of the likely costs, we can look at the studies of the costs of the US ratification of the Kyoto Protocol (Barker and Ekins, 2004). The US government published a study for the US reducing CO_2 emissions by 30% over 3 to 4 years, and reported costs of about 1% of GDP under Kyoto trading. Other studies showed benefits, especially if the reductions in air pollution are included. Furthermore I expect that technological change will accelerate and costs fall sharply as the scale of effort moves towards 100% reduction. The traditional, equilibrium thinking arguing that GDP costs will rise as the scale of effort rises does not take induced technological change and developing countries' underemployment into account.

Conclusions

Although mitigation can reduce climate change and the need to adapt, the inertia in the climate system, as a result of the long lifetime of CO_2 (the main greenhouse gas) and the slow response of the oceans, means that adaptation will be necessary. There is also a risk that the international co-operation required for successful mitigation will not be achieved.

The Stern Review and the IPCC Reports in 2007, together with the experiences of early pilot mitigation policies in the European Union and its Member States, have provided the information and analysis sufficient for global policies to be developed. And the reception of the reports suggests that the seriousness and magnitude of the problem is recognized and that the key messages have been understood more generally. However, effective action requires an unprecedented co-operation of policies by the very large emitters involving many governments world-wide acting urgently. This is almost unprecedented, with the success of the Montreal Protocol on ozone depletion giving the best indication of the way forward.

The most effective policies appear to be those that combine:

- the carbon-price signal,
- environmental tax reform for small and mobile domestic sources,
- and emission trading schemes for large fixed and international sources of GHGs;

with:

- direct incentives for low-GHG innovation,
- and R&D funded from tax revenues and emission permit auctions.

Such portfolios of market-based instruments can be made even more effective if complemented by technological forcing via standards, such as a requirement for carbon capture and storage by a specified date on all new coal plant.

There is also evidence from energy-efficiency studies that many sectors, particularly buildings, have substantial opportunities for no-regrets mitigation, requiring tailored policies to reduce or remove barriers, with the policies often led by higher enforced standards on energy efficiency. Carbon trading has a crucial role to play in these portfolios by establishing market prices for CO_2 emissions to achieve CO_2 reduction targets. These prices can provide the signals for the scale of action required in the whole economy.

The way forward is in international agreement to establish a global carbon market, with the ultimate aim of decarbonising the global economy. A good starting point is a scheme covering international activities such as aviation and shipping, with a cap-and-trade scheme to achieve zero net emissions by 2050, and auctioning of revenues to support low-carbon alternatives to fossil fuels in developing countries through a greatly expanded clean development mechanism. Such a scheme, if well managed, could provide a strong, rising and predictable carbon price to provide the signal for more general national and international action.

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Cambridge Centre for Climate Change Mitigation Research (4CMR)

The Centre's objectives are 'to foresee strategies, policies and processes to mitigate human-induced climate change which are effective, efficient and equitable, including understanding and modelling transitions to low-carbon energy-environment-economy systems.' The Centre aims to be at the forefront of research in the area of climate-change mitigation through technological change induced by use of economic instruments, such as the EU's emission trading scheme, applying a multi-disciplinary approach and informing national and international policy-making. The research is organised around energy-environment-economy (E3) econometric and simulation modelling at UK, European and global levels.

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This article is based on a presentation by Dr Barker at the ECG's 2008 Distinguished Guest Lecture and Symposium 'The Science of Carbon Trading'.

Having our climate cake and eating it: reduced emissions from deforestation

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Introduction

The chemistry behind reduced emissions from deforestation is straightforward. Plants sequester atmospheric carbon through photosynthesis and this is released when forests are degraded or cleared. Carbon dioxide is a greenhouse gas and so policies that limit the level of deforestation will help meet the ultimate objective of the 1992 United Nations Framework Convention on Climate Change (UNFCCC) for "stabilization of greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system."

Following the 2007 Intergovernmental Panel on Climate Change (IPCC)'s 4th Assessment Report, there is now increased certainty that observed changes in the Earth's climate can be attributed to human activities. This has given rise to much concern and there appears to be strong political will to deal with human-induced climate change, for example, the then British premier Tony Blair said when he took up the presidency of the G8 at Gleneagles in 2005 that climate change is "probably, long-term the single most important issue we face as a global community".

However, the politics of climate change are far from clear cut. The current British prime minister, Gordon Brown, in a speech two weeks before the 2007 UNFCCC meeting in Bali – the first since the IPCC report – said that "… the role of government from now on is transformed. Once government objectives were economic growth and social cohesion. Now they are prosperity, fairness and environmental care." It is important to note that environmental care is linked with two other governmental objectives: prosperity and fairness.

Byrd-Hagel Resolution

Resolved: That it is the sense of the Senate that –

(1) The United States should not be a signatory to any protocol to, or other agreement regarding, the United Nations Framework Convention on Climate Change of 1992, at negotiations in Kyoto in December 1997, or thereafter, which would –

(A) mandate new commitments to limit or reduce greenhouse gas emissions for the Annex I Parties, unless the protocol or other agreement also mandates new specific scheduled commitments to limit or reduce greenhouse gas emissions for Developing Country Parties within the same compliance period, or

(B) result in serious harm to the economy of the United States; and

(2) Any such protocol or other agreement which would require the advice and consent of the Senate to ratification should be accompanied by a detailed explanation of any legislation or regulatory actions that may be required to implement the protocol or other agreement and

should also be accompanied by an analysis of the detailed financial costs and other impacts on the economy of the United States which would be incurred by the implementation of the protocol or other agreement.

***Box 1:** Byrd-Hagel Resolution from the 1st Session of the 105th Congress of the United States of America expressing the sense of the Senate regarding the conditions for the United States becoming a signatory to any international agreement on greenhouse gas emissions under the United Nations (Passed by the Senate 95-0).*

Similar concerns can be seen in the famous Byrd-Hagel resolution of 1997 in which the United States Senate voted unanimously not to be a signatory in any agreement that contained the principle of 'common but differentiated responsibilities' in which developed countries bore the burden of mitigating climate change or which might harm the economy (Box 1) [1]. The Senate thus considered the Kyoto Protocol to be both unfair and damaging to prosperity. As the USA was at this time the major emitter of greenhouse gases, from this point on the Kyoto Protocol was irreparably wounded.

Nonetheless, other countries, which had ratified the Kyoto Protocol, continued to implement policy aimed at meeting their Kyoto commitments. In 2003 the European Union passed the European Parliament Directive 2003/30/EC which promoted greater use of biofuels for transport as "part of the package of measures needed to comply with the Kyoto Protocol…".

But, as with other climate change policies, Kyoto was only one of three major policy objectives in the directive. The other two were creating new opportunities for rural development and the strategic need to reduce energy import dependency. The example of the biofuels directive neatly illustrates the fact that policy-makers are keen to have their climate cake (Kyoto compliance) and eat it too (multiple additional policy objectives). The same is true for reduced emissions from deforestation, a policy that was a major topic of discussion at the UNFCCC Bali meeting and which we now cover in more detail.

Reduced Emissions from Deforestation in Developing countries (REDD)

The recent Stern Review on the economics of climate change [2] points out that 20-25% of global green house gas emissions are from tropical deforestation and suggests that reducing deforestation emissions is a cost-efficient mitigation option. Putting in place policy measures to reduce tropical deforestation also potentially meets two other major objectives. Firstly, about a billion people are dependent on forests in the tropics. Many of these are the poorest of the poor and helping them to improve their livelihoods could help to meet the Millennium Development Goal of poverty alleviation. Secondly, much of the world's terrestrial biodiversity is

found in tropical forests. Protecting these forests will go a long way towards fulfilling the objectives of the Convention on Biological Diversity.

Analysis of country-level emissions with and without forestry shows both the magnitude of forest-related emissions and their spatial distribution (Table 1). When forestry is included then developing countries with high deforestation rates have per capita emissions comparable to, or exceeding those of developed nations. Under the Kyoto Protocol Clean Development Mechanism (CDM) it is possible to obtain funds for afforestation and reforestation by planting new forests to act as new carbon sinks. These funds are for new plantations in areas not covered by forest in 1990 and come with many restrictions and high transaction costs. So far only one project has been approved, in China, and in no way does this process counter the problem of deforestation.

Table 1: *Estimates of country emissions per capita per year with and without forestry [3] based on UNFCCC and World Resources Institute sources*

Country	Emissions per capita/year without forestry	Emissions per capita/year with forestry
USA	23.91	21.06
Netherlands	13.31	13.48
Malaysia	7.20	37.30
Brazil	4.90	13.00
Indonesia	2.40	14.80
Nepal	1.30	6.70

In contrast, the policy of Reduced Emissions from Deforestation in Developing Countries (REDD), which was introduced by Papua New Guinea and Costa Rica in 2005 [4] and which is currently under discussion by the UNFCCC [5,6] includes deforestation, degradation and sustainable management. The option being considered is that a reference scenario for national rate of deforestation is established for each country participating. Then, over the commitment period, the actual rate of deforestation is monitored and compared to the reference scenario. Improvements in deforestation rate are translated into tonnes carbon equivalent and some form of compensation will be paid. The scheme would be entirely voluntary and the payments would be made on a national basis, rather than for a specific project as in the case of the current clean development mechanism. Use of the carbon payments would be a matter of national sovereignty to be used however the government sees fit.

This proposal is contentious. A country, such as India, which has historically looked after its forests, will have a lower rate of deforestation as a reference scenario than a country such as Brazil, which has a high rate of deforestation. Brazil thus stands to gain more through changes in its deforestation rate. The proposed national-level scheme of payments is designed to prevent a country lowering deforestation in one part of the country whilst stepping it up elsewhere. This kind of safeguard is necessary for the integrity of the policy. However, this means that if some stakeholders work hard to reduce deforestation in one area while others continue to destroy forests elsewhere, there will be no overall gain and therefore no financial payment, which means that setting up an internal payment system to encourage actors such as community groups to maintain their forest, is rather complicated.

There is also disagreement internationally about how the funding would work. Some Parties to the UNFCCC support a market based system with credits to trade against emission reduction targets of the industrialised countries, while others, such as Brazil, would prefer the establishment of an internationally managed fund to help counter deforestation.

There are also concerns about the rights of people traditionally dependent on forests. Local people could be alienated from forests in the name of “conservation” and carbon funds might be used to enforce restrictive laws without consideration of local needs. This rises of the question of who owns the carbon. One may assume that where forest land is held privately, the carbon savings are the property of the land-owner, but in cases where local communities live in, and have for generations utilised forest that is nominally state owned, the situation is not so clear. Furthermore, the biodiversity conservation objective may also need value attached to it. In the rest of the article we will focus on community forestry and discuss the possibility of local communities carrying out their own inventories and monitoring of their carbon stocks.

Community forestry

Large scale logging and land clearance generally requires capital for the equipment needed; almost by definition, this does not involve poor people. However, when forests are used by local people for their subsistence needs (for firewood, grazing or low level shifting cultivation) they can lose carbon through degradation. Until recently very little attention has been paid to the methodology of measuring this type of degradation, though it has certainly been grossly underestimated. The potential for avoiding loss of carbon through degradation is the linking factor between REDD compensation policy and poverty alleviation. Implementing community forest management with funding from REDD could form the basis for large-scale involvement and empowerment of forest dependent people in combating carbon emissions.

The numbers are compelling. If we take the example of seven dry forest countries in southern and eastern Africa where there is no primary undisturbed forest remaining, and where we estimate off-take of products through community use to result in a net annual reduction of biomass stock of 0.9-2.3 tons/ha/year, then the total carbon emissions due just to this degradation is on the order of 178m tons CO_2/year for the seven countries. Payments based on opportunity costs needed to prevent degradation are \$0.7-\$1.8 per ton CO_2 [7], so if we take a relatively low value of \$10/ton for compensation of avoided CO_2 emissions, then REDD could generate around \$1424 million/year for poverty alleviation through community forestry in the seven countries.

Community forest management is a well development instrument and institution in many countries including Tanzania, Nepal, Philippines and Mexico. Under most CFM arrangements the rights and responsibilities with regard to natural forest management are vested in local communities, including rights to products in kind and income from sales of timber and non-timber forest products.

Management is usually administered by a local committee through by-laws on off-take, plus protective measures such as fire prevention and patrols against unauthorised exploitation. Rewards may be distributed in different ways, often through a village fund. Thus developing a REDD policy which includes opportunities for community forest management to receive financial rewards also helps over come some of the equity concerns associated with national-level payments mentioned earlier.

A REDD policy based on community forest would be building on a well established model, about 17% of the world's forest is under community control and the proportion is increasing, though not all of this is managed sustainably or in a 'planned' way. Much of this area involves poor communities. If it where possible for there to be community measurement of the forest carbon stock, then there could be grounds for a local 'claim' on the carbon and the communities would be empowered to manage their forests. Moreover, local measurement would be cheaper than professional forest inventories and so reduce the transaction costs of implementing the policy.

Kyoto: Think Global Act Local project

The Kyoto: Think Global Act Local (K:TGAL) project is currently working on 25 sites in seven countries (Senegal, Mali, Guinea Bissau, Tanzania, Nepal, India and Papua New Guinea) with four regional teams. The project trains people to measure the carbon stock changes in their forest and assesses the carbon impact of community forest management together with quantifying the transaction costs of carbon credits and potential social benefit of carbon credits.

The results are encouraging. Villagers with 4-7 years primary education can handle mapping and inventory with only limited support necessary, especially for maintenance of computers. The community forests assessed are accumulating carbon at 5-10 tons CO_2 /ha/year, not including an allowance for degradation avoided. Transaction costs are highly subject to economies of scale related to supervision costs.

Conclusion

REDD policy is still under discussion by the UNFCCC and is not without problems. Some environmental lobbies oppose it on the grounds that emissions from forests are not of the same nature as emissions from fossil fuels. However, it has been give a very favourable review at the Bali conference and a wide range of different Parties are agreed that some policy in this area is needed.

The discussion at the moment is on the details:

- Will only the carbon emissions avoided by stopping deforestation be rewarded, or will emissions from reducing degradation rates also be included?
- What about the additional carbon that is sequestered when forests stop degrading and start to return to their original healthy state?
- How will changes in deforestation and degradation rates be measured and verified?
- Will the money come from carbon credits or from a fund managed by an international panel?

Debates in the coming months will be crucial to resolving these issues and to formulating a policy which is effective from a carbon point of view, straight forward to implement, and of benefit to millions of forest-dependent people.

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‘Cool Earth’

Cool Earth is a UK based charity launched in 2007 to fund the conservation of rainforests as a means of tackling climate change. *Cool Earth* currently has 20,000 members, who have funded the conservation of over 9 million tonnes of CO_2 stored in endangered tropical rainforests. **Matthew Owen** from Cornwall College outlines the significance of tropical rainforests in balancing the global carbon budget.

Why conserve tropical rainforests?

The atmospheric CO_2 concentration is currently growing at a rate 1.9 ppm/yr [1]. This increase is primarily through fossil fuel use and land-use change, roughly 80% and 20% respectively, with tropical deforestation and degradation accounting for 96% of land-use emissions [2].

The role of tropical forest is nonetheless understated. If left undisturbed, tropical forests are estimated to sequester 4.4 $GtCO_2e/yr$ (15% of all anthropogenic emissions) [1]. Reducing deforestation and degradation therefore not only decreases the release of CO_2 emissions but also moderates the effects of emissions by preserving a sink.

Pristine tropical forests also provide many other varied services at the local to global scales. Rainfall generated from the Amazon supplies the Rio Plata basin, which generates 70% of the GDP of southern South America. Deforestation of the Congo basin has been linked to reduced precipitation by 5-15% less in the US Great Lakes and 25% less in the region north of the Black Sea [3]. Once rainforests are removed, replanting may not restore these complex global weather patterns.

The variety of tropical forests means they occupy different positions on the marginal cost abatement curve, with estimates varying by location and land-use from under \$1 to \$2000 /tCO_2 [4]. We nonetheless estimate that at least half of deforestation emissions could be prevented through investments equivalent to less than \$5 per tonnes of CO_2e.

Rainforests and carbon trading

The UNFCCC/Kyoto agreement established a partial global carbon market infrastructure, but explicitly barred trade in abatement through reduced deforestation. As a result, forest carbon in developing countries is not currently priced. This makes global mitigation unnecessarily expensive, and discriminates against developing countries, who are not able to realise the global market value of their natural carbon assets. But developed (Annex I) countries are allowed to set off their carbon targets against their domestic forest sinks. This disparity is unethical, economically inefficient, and environmentally dangerous.

Only the carbon market can deliver the required scale of abatement through reduced deforestation. In a perfect market each unit of carbon – sunk, emitted or avoided – would be accounted for globally and floated to achieve a global market-clearing carbon price equilibrium.

However, carbon price stability is crucial during the transition period to a low carbon global economy. Jon Lovett has described the Reduced Emissions from Deforestation in Developing Countries (REDD) scheme, which promotes carbon trading as a means to reduce deforestation (see accompanying article). Compensation under the REDD scheme could perhaps be further exploited to decrease the global emissions cap to a level needed for a 2 °C stabilisation. In this way the cost of global mitigation can be reduced, while maintaining the stable carbon price essential to drive technological transformation.

The earliest that barriers to global trade in deforestation carbon abatement can be dismantled is 2012. A hiatus in significant abatement of deforestation until then is untenable. Urgent action is required by the UK and like-minded partners to guarantee the future redeemability of forward investments. This will unlock the potential for rapid growth in finance flows for cost effective abatement through reduced deforestation in developing countries.

How can tropical rainforests be protected?

Cool Earth has achieved much through public support for targeted conservation of endangered forest. To scale-up the efforts of the NGO community, national level governance and leadership is critical.

Forest protection considerations need to be fully integrated into national poverty reduction and growth plans. A range of schemes to support this are being established, such as the World Bank’s Forest Carbon Partnership Facility (FCPF) – which will help countries prepare to take advantage of future REDD benefits and provide a limited fund which will purchase credits from successful emissions reductions programmes. The Congo Basin Forest Initiative and GEF will also offer assistance to developing nations.

The specificities of forest types, communities and opportunities means that forest protection will ultimately be secured through projects – ideally, but not necessarily, fitting into a coherent national programme. From the wealth of experience and lessons available, certain principles for successful projects are clear:

1. Finance mechanisms are needed that promote new forest business models that will provide local and global ecosystem services, and support communities who depend on forests for their livelihoods.
2. Forests can be fenced. Protected area programmes can work, but they need to integrate poverty reduction and alternative livelihoods elements and address tenure/rights issues.

3. Sustainable Forest Management, developed with and for communities, will often be the best way to prevent deforestation and at the same time contribute to poverty reduction objectives. Forest communities know best how to protect their forests assets. Carbon finance will often work best as a supplement to other forest-derived income streams.
4. Successful projects need to employ sophisticated monitoring and verification techniques to ensure the market credibility of their carbon assets.

In order to obtain sufficient finance (particularly from the private sector) for the establishment of large-scale forest protection schemes, successful projects need to generate desirable and credible forest assets. These assets are likely to incorporate carbon and non-carbon elements and should be capable of being integrated into the future carbon market.

What financing mechanisms are appropriate?

There are various options for attracting institutional investment to the protection of rainforests. These range from the securitisation of mixed incomes generated from pooled projects, to taking equity control over forest-derived carbon assets. But the success of any of these financial tools depends upon establishing a fundable carbon credit scheme.

Capital markets have little experience of investing in forest product derivatives. The international timber trade is dominated by Swiss, Chinese and Lichtenstein registered producers. Domestic trades are similarly opaque and account for up to 80% of demand in nations such as Brazil.

As such, it is doubtful that the potential volatility in carbon pricing could be accommodated in a fixed income instrument. This leaves an equity mechanism as the more likely way of securing funding.

The Kyoto Protocol's Joint Implementation mechanism offers the best chance of success since it would allow forest-derived credits without affecting price stability. However, in order to attract the scale of investment needed, some level of precedent-setting investment by a developed nation would be required, ideally for a duration greater than 15 years.

Cool Earth is working to develop a better understanding of these opportunities on the part of capital markets. Ultimately, a global carbon price will stabilise around the lowest cost of emission mitigation. Avoided deforestation is the most likely supplier of such mitigation and it will have to play a central role in future negotiations concerning the post-2012 carbon market.

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Web links

Cool Earth: http://www.coolearth.org/

Stern Review on the Economics of Climate Change:
http://www.occ.gov.uk/activities/stern.htm

Rainforest Protection Organisations

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Conservation International www.conservation.org
Fauna & Flora International www.fauna-flora.org
Friends of the Earth www.foe.org
Forest Stewardship Council www.fscoax.org
Global Forest Watch www.globalforestwatch.org
Greenpeace International www.greenpeace.org
IUCN: The World Conservation Union www.iucn.org
Native Forest Network www.nfn.org.au
Rainforest Action Network www.ran.org
Rainforest Alliance www.rainforest-alliance.org
Rainforest Foundation UK www.rainforestfoundationuk.org
Rainforest Information Centre www.forests.org/ric
Rainforest Rescue www.arborday.org
Tourism Concern www.tourismconcern.org.uk
The Nature Conservancy www.nature.org/rainforests/
World Rainforest Movement www.wrm.org.uy
World Wide Fund for Nature www.wwf.org

Accounting for biofuels: green, black or shades of grey?

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Current controversy

"Biofuel" is a term which covers a range of liquid of gaseous fuels which are produced from organic materials and can be used as alternatives to conventional transport fuels, such as diesel and petrol that are derived from fossil fuels. Since these organic materials, or biomass feedstocks, absorb the same amount of carbon dioxide (CO_2) as they release subsequently when the biofuels is burnt, they offer apparent prospects of being "carbon neutral".

However, the actual benefits of biofuels, as potential means of assisting the mitigation of global climate change, depend on many factors and complex interactions. In particular, it is necessary to determine the total greenhouse gas (GHG) emissions associated with their production and use. In addition to CO_2, other GHG emissions, such as methane (CH_4) and nitrous oxide (N_2O), have to be taken into account.

Depending on the biomass feedstock and its original source, how and where it is cultivated or otherwise derived, and how it is converted into a biofuels, total GHG emissions can vary from a very low, or, indeed, negative, value to very high values that exceed those from the production and use of conventional transport fuels. Whilst such results have been interpreted in different ways by people with different perspectives, the Biofuels Working Group of the Royal Society concluded that "each biofuels option needs to be assessed individually on its own merits" (Royal Society, 2008).

Life cycle assessment

The necessary scientific approach to resolving the current controversy over biofuels involves the application of life cycle assessment (LCA). This established technique consists of evaluating the full process chain of any biofuels, including cultivating, harvesting and transporting or otherwise collecting the biomass feedstock, preparing it for processing by drying or other pre-treatment, converting it to a biofuels and then distributing it to eventual consumers. Examples of current biofuels and their biomass feedstocks are summarised in **Table 1**.

***Table 1:** Current biofuels and biomass feedstocks*

Biofuel	Biomass feedstock
Biodiesel	Recycled vegetable oil Tallow Jatropha Oilseed rape Oil palm Soy bean
Bioethanol	Maize/corn Sugar beet Sugar cane Wheat

***Table 2:** Main differences between accounting methodologies*

Accounting method-ology	Co-product allocation	Reference land use
RFA Technical Guidance	Substitution credits	No reference land use
BSI PAS 2050	Price	Direct land use change
EC Renewable Energy Directive	Energy content	Direct land use change

Various considerations throughout the full process chain have to be accommodated and the details of how this is achieved are governed by accounting rules or methodologies. There are a number of different methodologies which are proposed and these have different approaches to two essential aspects of the LCA of biofuels. One aspect concerns "co-product allocation" which determines how GHG emissions are divided between the different outputs that can arise during the production of certain biofuels.

The second aspect addresses "reference land use" which is a means for incorporating the GHG emissions effects of alternative uses of the land for growing biomass feedstocks. At the moment, there are at least three possible methodologies for assessing the total GHG emissions associated with biofuels production. These consist of the Renewable Fuels Agency (RFA) Technical Guidance (RFA, 2008), the British Standards Institution (BSI) PAS 2050 (BSI, 2008), and the European Commission (EC) Draft Renewable Energy Directive (EC, 2008). The differences between these accounting methodologies, with regard to co-product allocation and reference land use, are summarised in **Table 2**.

Methodological effects

Differences between accounting methodologies can cause significant differences in estimates of the total GHG emissions associated with biofuels. Relevant and subsequent results have been derived from the Biomass Environmental Assessment Tool (BEAT) which has been produced for the Department for Environment, Food and Rural Affairs (DEFRA) and the Environment Agency in the United Kingdom (DEFRA, 2008).

In particular, BEAT has been used to estimate the net GHG emissions savings of biofuels which measures the percentage reduction in total GHG emissions from any given biofuel relative to those of the conventional transport fuel which it replaces. Examples of the effect of applying different co-product allocation procedures to the production of bioethanol from wheat are shown in **Figure 1**. The main co-product of bioethanol production from wheat is distillers' dark grains and soluble (DDGS) which is normally sold as animal feed. In this case, using substitution credits which subtract GHG emissions associated with soy meal animal feed that is displaced by DDGS generated the lowest net GHG emissions savings. Whilst co-product allocation by price produces intermediate net GHG emissions savings, using the energy content of the bioethanol and DDGS results in the highest net GHG emissions savings.

Although the current version of the RFA Technical Guidance excludes reference land use, this is being re-considered in the light of the United Kingdom review of the Renewable

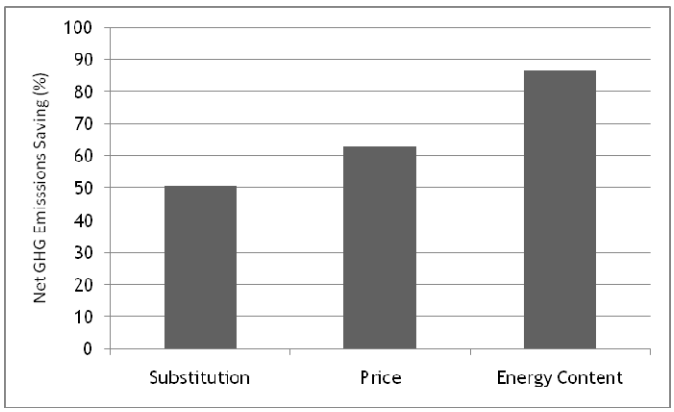

Figure 1: *Effect of co-product allocation procedures on net greenhouse gas emissions savings of bioethanol production from wheat*

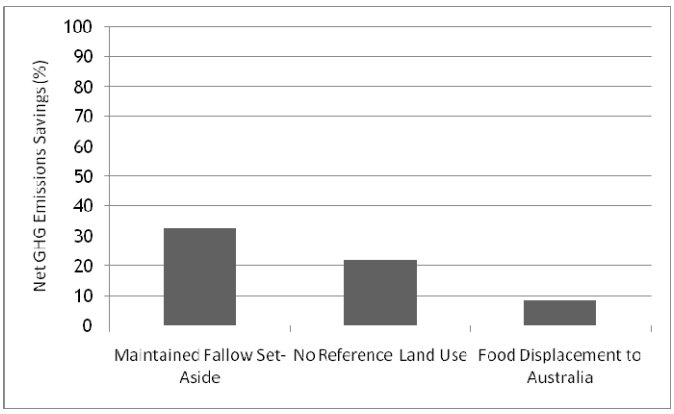

Figure 2: *Effect on net GHG emissions savings for biodiesel production from oilseed rape of reference land use*

Transport Fuels Obligation (RTFO). It is possible that all accounting methodologies will be modified to include the effects of direct and indirect land use change (LUC). It is relatively easy to accommodate the GHG emissions effects when alternative land uses do not involve the creation of a useful product such as food.

However, when food or other production is displaced by the cultivation of a biomass feedstock, it is necessary to determine the nature of the displacement and its effects on total GHG emissions. Deciding the location and implications of alternative production is not simple but the consequences for on GHG emissions can be dramatic as shown in **Figure 2**. This illustrates the effect of net GHG emissions savings for biodiesel production from oilseed rape in the United Kingdom with no reference land use, with cultivation on maintained fallow land and with cultivation on land used to grow oilseed rape for food which is now switched, for example, to Australia (Mortimer, 2006).

Technological effects

Before considering the important issue of indirect or displaced land use further, it is necessary to address the effects of technological choices on the total GHG emissions of biofuels production. These can have a significant influence on net GHG emissions savings as demonstrated in **Figure 3** and **Figure 4** for biodiesel production from oilseed rape and bioethanol production from wheat, respectively.

There are many different technological choices in the design of biofuels process chains including different agricultural practices, different means of providing heat and electricity for processing and different uses for the co-products. It can be seen from **Figures 3** and **4** that the use of combined heat and power and co-products for fuels can improve net GHG emissions savings substantially.

Displaced land use

The issue of displaced land use is currently the most controversial consideration for biofuels production. The basis of this issue is quite simple. It is possible that biomass feedstocks grown on land for biofuels may displace the cultivation of other crops, especially for food production, into other areas of the world leading to the damage or destruction stocks or sinks of carbon in the soil and vegetation. This could result in the release of substantial quantities of GHG emissions that would equal or exceed the net GHG emissions savings of the original biofuels.

Potentially, this amounts to a powerful case against biofuels production as a means of mitigating global climate change (Fargione *et al*, 2008; Searchinger *et al*, 2008). This concern is a major focus of the RTFO review in the United Kingdom. Thorough analysis is required to form robust conclusions and subsequent policy. However, it is clear that the outcomes from any rigorous analysis will always be heavily qualified. In particular, given the existing state of knowledge, it

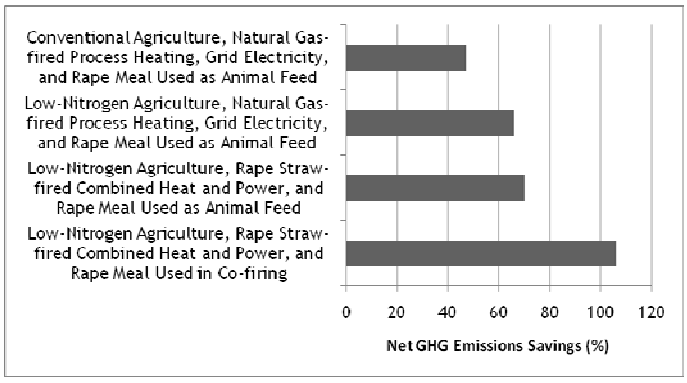

Figure 3: *Effect of technological choices on net GHG emissions savings for biodiesel production from oilseed rape*

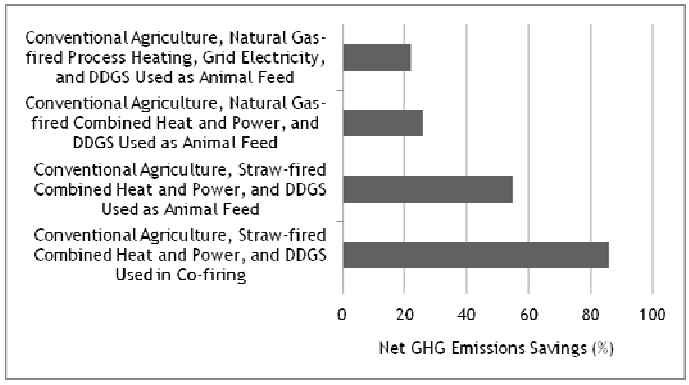

Figure 4: *Effect of technological choices on net GHG emissions savings for bioethanol production from wheat*

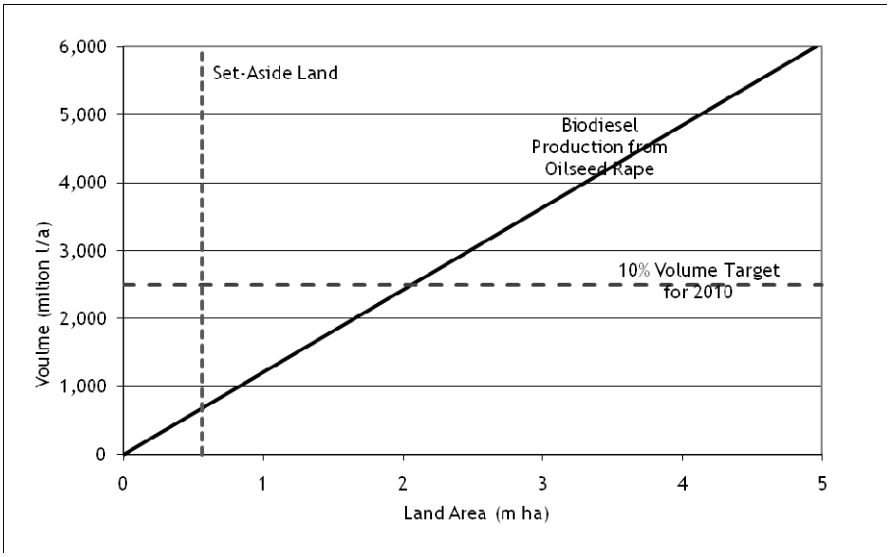

Figure 5: *Potential biodiesel production in the United Kingdom*

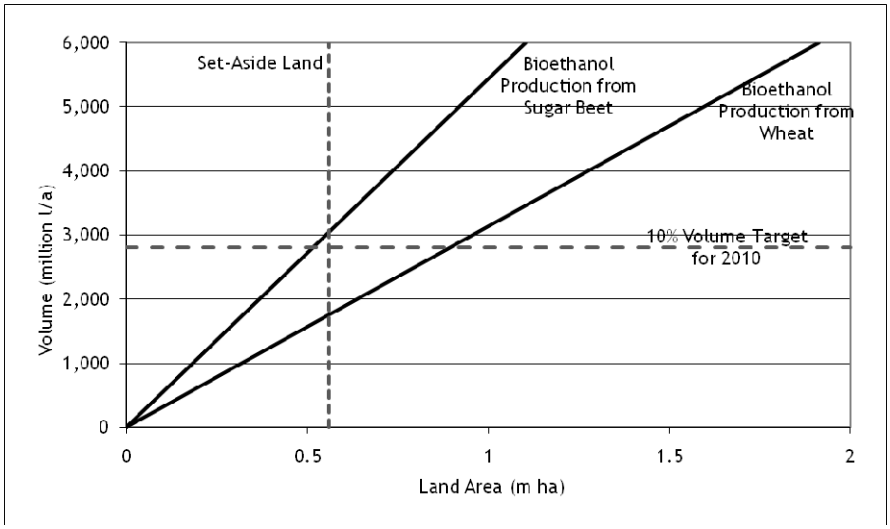

Figure 6: *Potential bioethanol production in the United Kingdom*

is impossible to be totally confident over the precise and complete chain of land displacement that potentially link the cultivation of any given crop to indirect and remote GHG emissions. Greater understanding which enables this issue to be resolved will only emerge over time. Despite this, broad guidelines can be established. In particular, the destruction of any significant carbon stores, such as continuously grown forest, wetlands, peatlands and permanent grasslands, should be avoided anywhere for any purpose as this is directly responsible, as an act in itself, for global climate change. Hence, emphasis should be placed on growing biomass feedstocks for current biofuels in areas which does not result in land displacement.

Within the United Kingdom, this would consist of agricultural land, such as set-aside, which is not currently used for productive purposes. This has implications for the total amount of biofuels which can be grown, as suggested by **Figures 5** and **6**. These indicate the net amount of biodiesel and bioethanol, respectively, that can be obtained from set-aside land in the United Kingdom in comparison with proposed targets for production in 2010. Whilst the existing target cannot be achieved with biodiesel production from oilseed rape, it is more attainable with bioethanol production from wheat and, particularly, sugar beet. This demonstrates that target setting is quite complex and requires qualification to realise real GHG emissions savings. Apart from anything else, the type of biofuels, its biomass feedstock and where this is produced has to be accommodated within essential target-driven policies. As well as avoiding the worst consequences of direct and indirect land use change, the development and commercialisation of future biofuel technologies which may result in very high net GHG emissions savings need to be encouraged.

Conclusions

A number of important conclusions can be drawn from this brief examination of biofuels. There is a need to harmonise accounting methodologies for the evaluation of total GHG emissions associated with biofuels production and, indeed, all proposed measures for mitigating global climate change to ensure consistency and clarity with results. Such results should form the basis for science-based policies which incorporate targets for net GHG emissions savings. These policies will require sound methods of accreditation for their implementation. Additionally, these policies should promote good technological choices for current biofuels production and encourage the realisation of new biofuels technologies. Above all, land use displacement and the destruction of carbon stores, globally, should be avoided. This is a conclusion which not only affects biofuels production but also has serious implications for the agricultural industry, generally, along with rural and urban development and, ultimately, future human behaviour and lifestyles.

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Biographical details

Nigel Mortimer is one of the founding directors of North Energy Associates Ltd. This consultancy company has been involved in the practical implementation of sustainable energy development since 1991. Nigel has a BSc in Physics and a PhD in Energy Technology. Nigel formerly held the Chair of Sustainable Energy Development at Sheffield Hallam University where he was the Head of the Resources Research Unit. His specific expertise within North Energy includes life cycle assessment. He has managed and undertaken research and consultancy contract work on a broad range of projects in the United Kingdom and elsewhere. His current work involves the evaluation of primary energy inputs and greenhouse gas emissions associated with biomass energy technologies, biomaterials and biochemicals. Clients for this work include the European Commission, the Department for the Environment, Food and Rural Affairs, the Department of Business, Enterprise and Regulatory Reform, the Environment Agency, British Sugar plc, Biofuels Corporation plc and the Northeast Biofuels Consortium. Nigel is a member of the Royal Society's Biofuels Working Group which recently published "Sustainable Biofuels: Prospects and Challenges.

This article is based on a presentation by Dr Mortimer at the ECG's 2008 Distinguished Guest Lecture and Symposium 'The Science of Carbon Trading'.

Biophysical remediation of petroleum hydrocarbon contaminated soil in Yorkshire

Our industrial past has left us with a large number of brownfield sites, many of which contain elevated concentrations of contaminants in the soil and groundwater. These substances pose potentially significant human health risks as well as impacting on groundwater, surface water, and flora and fauna.

ECG committee member **James Lymer** from the engineering and environmental consultancy firm, Wardell Armstrong LLP, describes some of the regulatory and practical considerations of cleaning-up contaminated land in the UK.

Contaminated land legislation

In the UK, new policy initiatives and various pieces of specific legislation for dealing with contaminated land have been introduced since the 1990 Environmental Protection Act.

Part II(a) of the Environmental Protection Act 1990 Part II(a) of the Environmental Protection Act 1990 was introduced under Section 57 of the Environment Act 1995 and came into effect in England and Scotland in 2000 and Wales in 2001.

Under Part II(a), the statutory definition of contaminated land is:

- land which appears to the Local Authority in whose area it is situated to be in such a condition, by reason of substances in, on or under the land, that:
  a. significant harm is being caused or there is a significant possibility of such harm being caused; or
  b. pollution of controlled waters is being, or is likely to be, caused.

Part II(a) was extended in 2006 to include radioactivity in England and Wales, but this currently only applies to human exposure to radioactivity.

Local Authorities Local Authorities are responsible for the inspection of contaminated land and for ensuring remediation is undertaken where necessary. Local Authorities also maintain a Public Register detailing the regulatory actions that they have implemented. **The Environment Agency** has a complementary role with specific responsibilities such as acting as the enforcing Authority for designated special sites.

Planning Contaminated land is also a consideration within the **Local Authority** planning system. When planning permission is sought for the development of a site that is considered to be potentially contaminated, the local planning authority will take this into

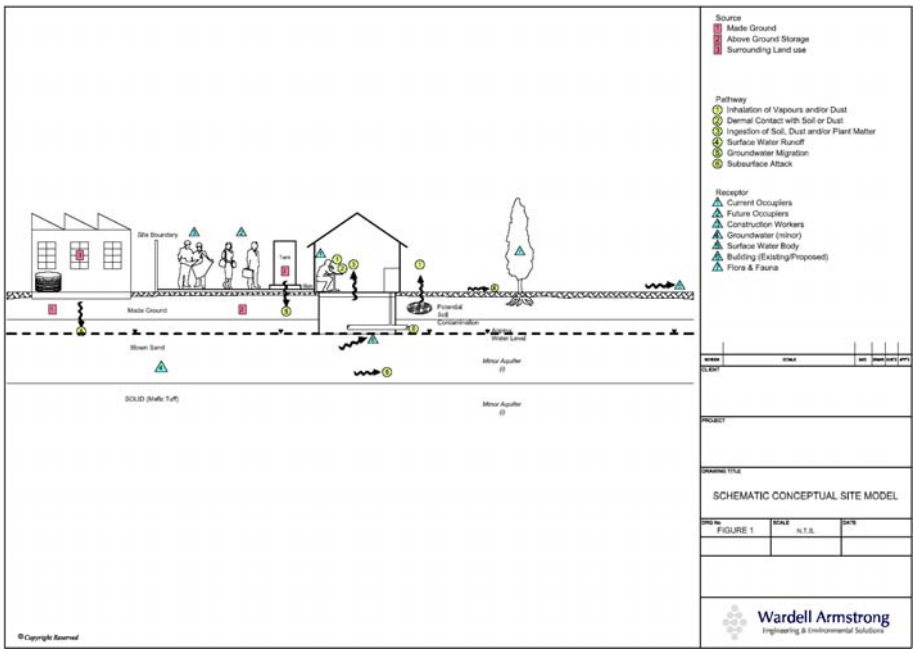

Figure 1: *Conceptual model of source-pathway-receptor linkages used in risk assessment of contaminated land. Diagram courtesy of Wardell Armstrong LLP.*

account and may require investigative work to be completed by the applicant.

Developers (applicants) often commission specialist environmental consultants to conduct contaminated land investigations on their behalf. The resulting assessment of these investigations can then be submitted with the planning application to the Local Authority for approval that the site is suitable for the proposed use.

Planning permission may be granted on condition that the site is remediated to the satisfaction of the Local Authority depending on the results of any investigation. New planning guidance (**PPS23**) was launched in November 2004, and this includes an Annex 2 which gives more detailed guidance about development on land affected by contamination.

The main difference between Part II(a) and PPS23 is that under the planning system, risks have to be assessed based upon the new or intended use of the land, rather than on the existing use, which was a criterion in the Part II(a) regime. For more information on the regulation of contaminated land, refer to Defra Circular 01/2006 and Planning Policy Statement 23 (see references for details).

Contaminated land investigation

Source-pathway-receptor models A key tool in the investigation and assessment of potentially contaminated land is deriving and updating a conceptual model through various phases of work. A risk assessment of the source-pathway-receptor linkages identified in the conceptual model can then be performed. A typical conceptual model is shown in **Figure 1**.

Regulation of contaminated land sites An important factor for safeguarding human health is the proposed use of the brownfield site. The redevelopment of land for residential purposes is more sensitive than development for commercial use. Local Authorities have regulatory responsibility for the protection of human health from exposure to possible contaminated land sites. The Environment Agency is responsible for the regulation of groundwater and surface water protection by ensuring that there are no discharges of contaminants into groundwater or surface water.

The risk assessment process A Phase I (Desk Study) involves the identification of potential sources of contamination, pathways and receptors by assessment of desk based information such as historical plans, geological maps and industrial profiles. A qualitative risk assessment is then performed for the site based on the conceptual model.

Where the Phase I Desk Study identifies potentially significant source-pathway-receptor linkages, then a Phase II (Site Investigation) may be carried out to provide quantitative information on the contaminant source, to assess pathways and the risk to the receptors as part of a Generic Quantitative Risk Assessment (GQRA). Phase II involves obtaining soil and/or groundwater samples and submitting them for chemical analysis. Soil and rock samples are obtained by the drilling or excavation of the ground.

Contaminant concentrations in soil and groundwater are compared with available generic assessment criteria and if concentrations are particularly elevated, then a Detailed Quantitative Risk Assessment (DQRA) can be performed. A DQRA involves the use of computer models to derive site specific assessment criteria for comparison with contaminant concentrations.

Remediation

Remediation is usually required when the results of the GQRA or DQRA indicate that contaminant concentrations pose a significant risk to critical receptors.

Remediation may involve:

- Contaminant source removal, destruction or conversion to less mobile or toxic forms;
- Blocking the pathway between the source and receptors;
- Changing the receptor, e.g. from residential to commercial land use.

Plates 1 and **2** illustrate a contaminated land site, which is currently undergoing remediation.

Petroleum hydrocarbons

In the UK, oil or petroleum hydrocarbons are considered to be significant contaminants in soil and groundwater systems, particularly as elevated concentrations may pose a risk to human health and the environment. Hydrocarbon contamination is

◀ ***Plate 1** and* ▲***Plate 2:***
A contaminated land site undergoing remediation. Photograph courtesy of Wardell Armstrong LLP.

frequently encountered in site investigations at brownfield locations.

Petroleum hydrocarbons (or TPH as they are commonly referred to) comprise a range of organic compounds (alkenes, alkanes, BTEX and PAHs). With this complexity, several methods of classification of TPH in groundwater and soil have been developed.

The Total Petroleum Hydrocarbon Criteria Working Group (TPHCWG) approach derived during the 1990s is a commonly used classification method for TPH. In this approach, petroleum hydrocarbons are divided into aromatic and aliphatic hydrocarbon fractions between C5-C35 and then further divided into a total of 13 fractions. The fractions are based on the fate and transport properties of the compounds which differ for aromatic and aliphatic compounds.

An example of an assessment and the remediation of a brownfield site

Assessment Wardell Armstrong LLP in Sheffield was commissioned to assess TPH contamination in soil and groundwater at a site in North Yorkshire. It was discovered that a significant spill of TPH had occurred in the past and was most likely sourced from on-site storage containers. Samples obtained from the site indicated elevated concentrations of TPH of aromatic fraction C21-C35; up to 35,000mg/kg in soil and 21,000mg/l in groundwater. As these concentrations were considered to pose a risk to human health, a remedial target of 9,000mg/kg for aromatic C21-C35 in soil was generated. A Detailed Quantitative Risk Assessment revealed no significant risk to groundwater but there was a potential risk to human health.

Remediation: soil

Ex situ bioremediation was considered a cost-effective and appropriate measure to reduce the TPH soil concentration and also the risk to any future occupiers of the proposed land use. *Ex situ* biophysical remediation is a commonly used technique in the UK, and in this case windrow turning was employed to meet the remedial target of 9,000mg/kg.

Windrow turning (a term borrowed from a composting technique in agriculture) involves the mechanical excavation of TPH-contaminated soil and placement into thick layers or heaps. Regular mechanical turning and tilling of the heaps is then carried out to improve the aeration of the soil. Naturally occurring micro-organisms in the soil facilitate biodegradation of the petroleum hydrocarbons and thereby reduce the source concentrations to a site specific remedial target.

Remediation: groundwater

Groundwater samples containing significantly elevated concentrations of TPH were considered to contain mainly free product. It was agreed that as part of the proposed remedial work, any TPH free product and groundwater encountered was to be pumped out of the excavation and treated by passing the mixture through an oil/water separator followed by a granular activated carbon filter. The separated TPH free product was disposed off site at a suitable facility.

Summary The site was found to be contaminated with aromatic hydrocarbon fraction C21-35 in soil and groundwater. Results from the DQRA indicated that the elevated concentrations posed a risk to human health. A remedial target of 9,000mg/kg was agreed and then achieved within 3 months using *ex situ* bioremediation with windrow turning.

Soil and groundwater samples taken during the remediation period were used to validate that the remedial target had been met as part of a validation report which was agreed by the Local Authority. The Planning Condition was then discharged for the commercial development.

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ECG or other RSC members who are interested in attending a future meeting on contaminant fate and environmental and health issues associated with contaminated land and groundwater, please contact James Lymer jlymer@wardell-armstrong.com.

The National Centre for Atmospheric Science Graduate Summer School in Atmospheric Measurement

The National Centre for Atmospheric Science (NCAS) Graduate Summer School in Atmospheric Measurement is an annual two-week field course for atmospheric science PhD students beginning their second year of research. Cambridge University student, **Ailsa Benton**, reports on her time at the 2007 Summer School.

(NCAS) Graduate Summer School in AtmosphericMeasurement 2007. One of the meteorological challenges we encountered!

In September 2007, I joined around twenty other early-stage Ph.D. students on the Isle of Arran, Scotland to participate in the second NCAS summer school on atmospheric measurement. The ten-day period started at the tranquil Kildonan hotel on the south of the island, where we had lectures on all aspects of the atmosphere, ranging from chemistry, to meteorology, to the atmospheric structures of other planets.

It was eye-opening to realise just how broad a subject it is and to see what different educational backgrounds brought people into studying the fascinating topic of our planetary atmospheres. The setting provided an ideal opportunity to discuss with our peers the challenges we had so far found in our post-graduate studies. We were also fortunate enough to gain a wide overview of the subject from experts in the specific fields – an experience that cannot be gained simply from undergraduate courses.

The course wasn't just limited to theoretical lectures. We also travelled to the north of the island to a field centre used by students of many ages and academic disciplines to carry out a number of field studies including:

- tracking sondes
- measuring the carbon monoxide concentration of air in different regions
- calculating back-trajectories for air packets
- deducing boundary layer profiles from meteorological data.

The scope for applying these skills coming to our Ph.D. studies was evident. For my work, the application of meteorological data to chemical species measurement is invaluable in making sense of data and its origins. Teamwork and planning for extreme weather (see photograph), particularly when climbing a mountain such as Goat Fell are essential skills for application to my varied work on research ships, in remote locations and even in urban areas!

The summer school finished with the participants having the opportunity to present some of their own work, and to plan future field campaigns with mythical budgets. I hope that some of these will be realised in the near future!

AILSA BENTON

2nd Year NERC studentship Ph.D. Student,

University of Cambridge

NOTE: The National Centre for Atmospheric Science (NCAS) Graduate Summer School in Atmospheric Measurement is an annual two-week field course, aimed at atmospheric science PhD students who are about to start their second year of research. The course comprises a week of lecture-based presentations outlining aspects of atmospheric science (e.g. Atmospheric Chemistry & Field Measurements; Synoptic Meteorology; Atmospheric Aerosols), delivered by experts drawn from the UK Universities and Research Institutes. The second week involves practical exercises in Atmospheric Measurements, including weather forecasting, measurement of pollutants and use of radiosondes. The course is based upon the island of Arran, and is held in September every year. Bursaries are available for NERC-funded PhD students. Further details are obtainable from the course website, http://ncasweb.leeds.ac.uk/summerschool2008/ .

Other web link: The National Centre for Atmospheric Science http://www.ncas.ac.uk/

Meeting report: 2008 Environmental Chemistry Group Distinguished Guest Lecture and Symposium

The Science of Carbon Trading

The 35th RSC Environmental Chemistry Group Distinguished Guest Lecture and Symposium took place in the Council Room of Burlington House on Wednesday March 12th 2008. An enthusiastic and well-informed audience heard four talks on carbon trading and related topics. The quality of the presentations was matched by the range of questions from those attending, reflecting the scientific, political, commercial, and economic aspects of this year's chosen subject.

Jon Lovett (University of York and University of Twente) commenced the symposium by discussing the key environmental milestones which have influenced policy responses to deforestation and degradation:

1. The 1992 UN Framework convention on Climate Change (which recognised the need to stabilise greenhouse gas (GHG) concentrations);
2. The oppositional 1997 Byrd-Hagel Resolution (which states the US position of not ratifying the Kyoto Protocol until developing countries also did and until it was clear that no serious harm would come to the US economy).

Kyoto requires the first world to take the main responsibility for GHG emission reductions until such time as the emissions of sovereign states converged. But the Byrd-Hagel Resolution effectively removed the US from the Kyoto process.

It is in this context that the 2003 European Parliament Biofuels Directive 2003/30/EC was formulated to ensure EC support and compliance for Kyoto. However, its policy thrust was layered first by the inclusion of collateral economic policy statements about supporting sustainable, harmonised, rural development (e.g. in Bulgaria and Rumania) and secondly by including statements about the policy's support for European energy security.

In spite of the policy focus on GHG emission reduction and the introduction of support for biofuel use, there was and is little recognition of the need for a policy response to deal with the 20-25% of global GHG emissions which are consequent on tropical deforestation. Reducing deforestation-linked emissions is a demonstrably cost-effective mitigation option with the added collateral advantages of targeting poverty alleviation for a billion people in the tropics and protection for forest biodiversity.

The Kyoto Protocol offers some support for afforestation/reforestation (new forests as carbon sinks) but this support is heavily restrained. It applies only to areas not covered by forests in 1990, only to the planting of new trees, has high transaction costs and in no way acts to counter deforestation.

A new policy (Reduced Emissions from Deforestation in Developing Countries (REDD)) was first proposed by Costa Rica and Papua New Guinea in 2005 and its adoption would imply the creation of a reference scenario for the national rate of deforestation for each country – for each country, any future improvements in lowering the deforestation rate are compensated *via* carbon credit funding.

What is important for the effectiveness of REDD compensation is that the income to the sovereign government should be targeted for the local communities who manage the forest resource – 17% of the world's forests are under community control and this is increasingly managed in a sustainable fashion (www.communitycarbonforestry.org).

Jon Lovett's lecture discussed the ways in which the difficulties in engendering local community action can be overcome by identifying local communities as the financial beneficiaries of REDD income and by developing their role as custodians of forests.

Matthew Owen (Cornwall College) continued this theme in his paper "REDD Bull: What can rainforest protection do to halt climate change?"

Matthew argued that the problems inhibiting the universal success of schemes such as those funded *via* REDD are often linked to issues within the community (e.g. tenancy). Such issues need to be reconciled before the creation of a community asset class associated with communal forestry management.

Matthew also argued that deforestation is easy to monitor (as shown by the satellite mages in his talk) and much cheaper than other carbon reduction interventions. However, the global requirement to bring 3.8 million hectares of land into production each year (a response to 'Appetite Growth') and the high value of timber as an asset class compete against REDD targets – and governance and transaction costs for REDD (e.g. establishing clear legal ownership of the land) are high.

As with many foresight environmental programmes difficulties arise with the implementation of REDD because associated market systems are not in place. For instance, although the carbon market itself seems to be shifting from a nascent to a fledgling state, it is still the least significant financial market.

It is still true for instance that most transactions are linked to companies alleviating their corporate-social responsibilities rather than genuine demand for carbon as an asset class. Additionally REDD is excluded from the market (but aforestation and reforestation are not).

Even though deforestation accounts for 25% of carbon emissions globally, there is no scope for its inclusion in the market prior to 2012 (and probably not until 2010 when it will be traded in a segregated market). Coincidentally, the March 13th edition of *Nature* (Issue Number 7184) has two articles on precisely the themes promulgated in Jon and Matthew's talks – albeit with slightly different points of view: "Race against time to save the Amazon rainforest" pp 134-138).

Nigel Mortimer (North Energy Associates Ltd) followed these two presentations with a discussion on the accounting of biofuels. His paper

focused on the ways in which Life Cycle Analysis (LCA) could bring a perspective to the current differing views around biofuels. These range from ‘ . . . there is no such thing as a sustainable biofuel’ (George Monbiot) to ‘assess each biofuel on its own merits ‘ (Sustainable Biofuels: Prospects and Challenges” The Royal Society, January 2008).

When LCA is applied to biofuels for GHGs, co-product allocations (all biofuels have side and waste products) and land use has considered and there are competing accounting methodologies by which these can be evaluated. The Renewable Fuels Agency Technical Guidance, BSI PAS2050 and the European Commission Renewable Energy Directive all use different approaches to accounting for land use and GHG consequences. Harmonisation of accounting processes is needed, GHG emission savings need to be accurately calculated (as do displaced foods and carbon store destruction), and good (and new) technological choices have to be made.

The **ECG 2008 Distinguished Guest Lecture** examined the way in which carbon trading could achieve the EU 2 °C target. **Dr Terry Barker** (4CMR, Dept. of Land Economy, University of Cambridge) began by noting the 70% increase in greenhouse gas (GHG) emissions which occurred between 1970 and 2004. He suggested that the existence of good fossil fuel reserves combined with strong demands for energy security will further increase GHG emissions; as will the long term trends in grassland and virgin forest removal – generally consequent on the desire for private gain at the expense of public loss.

The 2 °C (above pre-industrial) target is set by the EU as one for which serious anthropological climate change can be avoided and it is recognised that GHG emissions have to start being reduced as soon as possible (the 2 °C target is effectively equivalent to stabilising carbon dioxide in the range 445-490 ppm (*cf.* Stern: 450-550 ppm)). All countries and sectors will have to decarbonise to restrain climate change even though it is the industrialised countries which are currently responsible for the forcing inputs.

Having identified a scenario target, Terry Barker went on to develop the symposium theme that the achievement of the target depended on the critical policy instruments which drive decarbonisation and GHG removal technologies. The EU Emissions Trading scheme is the largest mitigation policy action and carbon ‘taxation’ is its driver. And he cautioned that simple increases in energy efficiency tend to lead to increased energy use unless the carbon price remains high enough to act as an incentive for decarbonisation.

In order for the policy instruments to act effectively carbon trading has to have credibility and currently its credibility resides in its creation as a government policy instrument with two strands: a carbon tax and an emission permit scheme. Such schemes are open to collusion and transaction costs are high, but

> “Policies that provide a real or implicit price of carbon could create incentives for producers and consumers to invest significantly in low-GHG products and technologies.”

There are difficulties in policy implementation:

- How can the market potential be estimated in relation to private costs?
- How can the economic potential be weighed against the social costs?
- And how can the discrepancies between the government target carbon dioxide price ($30 per tonne) be balanced against that obtained by projecting current prices to 2010 ($70 per tonne)?

But data show that the cost of stringent mitigation measures introduced now (i.e. sufficient to achieve the 2 °C target) would have a 3% impact on global GDP by 2030 (for the US, -0.7% by 2010 and zero % by 2020) – a negligible macro-economic cost for global GDP.

In the UK an effective policy needs several strands:

- A rising real carbon price ($100 per tonne by 2030) guaranteed by government to reduce the risks of investment in low GHG technology
- The introduction of supporting policies (regulation, eco-taxes, reform etc.).
- And the use of fiscal instruments to encourage all sectors to progress the planned phasing out of GHG emissions and decarbonisation.

The symposium ended with questions which emphasised both the importance of policy interventions and the lack of global political will to operate them. The future operation of carbon trading, its success, the difficulties in extending it across sectors, and the uncertainties involved were clearly enunciated and – to a certain extent – agreed.

However, although the symposium did pose many unanswered questions it does seem certain that there is little time left for continued inaction. If putting into practice the various forms of carbon trading is indeed the only viable solution, then it’s time the market began in earnest.

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‘Attributing physical and biological impacts to anthropogenic climate change’

In the May 15th 2008 issue of *Nature*, a group of scientists from the USA, Australia, China, the West Indies, and countries in Europe and in South America analysed the scientific evidence which links the IPCC’s conclusions on climate change with the modifications that are occurring in physical and biological systems on all continents and in most of the oceans of our planet. Atmospheric chemist and ECG committee member **Stephen Ball** provides a commentary on the methodology and the conclusions of the *Nature* article.

‘Attributing physical and biological impacts to anthropogenic climate change’, Cynthia Rosenzweig [+13 co-authors], *Nature*, 2008, **453**, pp 353-357.

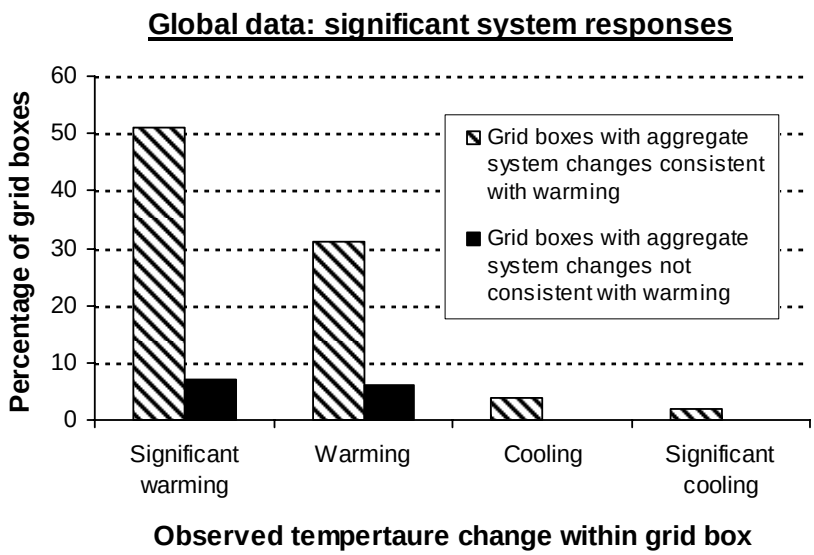
Natural systems respond – have always responded – to variations in climate. Thus a warm spring might prompt the early return of migratory birds or advance the flowering of certain plants [1]. Many physical systems also respond to climate: the advance/retreat of glaciers, the timing of peak flows in streams and the springtime thawing of sea ice or frozen rivers [2]. In Europe in particular [3], there has been a history of making observations of the timing of natural events in relation to climate (mainly temperature), including studies in dedicated phenological gardens. There are also instances of records going back centuries compiled by non-scientists who noted the dates of natural events, either simply as a pastime or to discern the optimum timing for agricultural practices [4].

Today’s climate is being influenced by natural variability and by additional forcings due to human activities, and the latter is beginning to impact natural systems. Last year’s Fourth Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) concluded that, globally, it is likely that many natural systems are being affected by anthropogenic climate change [5] (in the strict language of IPCC reports, “likely” means a 66 to 90% probability).

In the *Nature* article, Cynthia Rosenzweig and her colleagues seek to extend the IPCC’s assessment from the global to the continental scale by mapping the spatial distribution of natural systems’ responses onto the grid of observed temperature changes. Their analysis considers 829 and ≈ 28,800 changes in physical and biological systems, respectively, reported in nearly 80 recent publications. To be included, a data set must span at least 20 years and, according to its original authors, show that a physical or biological system has undergone a statistically significant change in the period 1970 - 2004. The direction of the system’s response is categorised as either “consistent” or “not consistent” with warming and must be statistically significant: indeed, studies where no statistically significant changes were detected are excluded from this analysis, the justification being that null results tend to be under-reported in the scientific literature.

The next step was to aggregate all the reported (statistically significant) changes within a given 5° × 5° latitude-longitude grid box. This is a binary decision: the grid box is labelled “consistent with warming” if more than 80% of the reported changes therein are in the direction expected for a warming climate; less than 80% and the grid box is “not consistent with warming”. The inhomogeneous geographical distribution of the observational data (see Figure 2 in the *Nature* article) means that many grid boxes play no part in the analysis because no studies have been conducted at those locations or they have not observed any statistically significant climate-induced changes. Thus 183 grid boxes around the globe were identified as having experienced an aggregate change in biological and/or physical systems, and in 88% of those the aggregate change was consistent with warming. Furthermore, most of the grid boxes where an aggregate change (in either direction) had been identified have experienced a “significant warning” or a “warming” according to the HadCRUT3 grid of observed temperature changes used in the IPCC reports. The figure below reproduces the global results, and the *Nature* article additionally shows histograms for the different continental areas.

The authors then performed statistical tests to assess whether the geographical distribution of system changes could have arisen from natural climate variability (due to volcanic activity, variations in solar irradiance) or could be attributed to anthropogenic climate



change. Pattern congruence statistics were used to compare the spatial distribution of aggregated system changes consistent and not consistent with warming with, firstly, the sign of the observed temperature change within the grid boxes and, secondly, a measure of the natural temperature variability within grid boxes calculated from a range of climate models. These tests found that the global pattern of system responses is very unlikely (<<1%) to be explained by the climate's natural variability. On the continental scale, the probability that the correlated pattern of system responses and temperature changes is due to natural variability is less than 5% for Asia and for North America and only around 10% for Europe. For other continents, the pattern congruence is less significant due to the paucity of observational data (also tropical and subtropical regions have less pronounced temperature seasons making phenological events harder to discern). In contrast, the pattern of system responses correlates well with observed temperature changes for the global data and for many continents and, since the IPCC has concluded that most of the observed temperature changes are very likely (>90% probability) to be due to anthropogenic greenhouse gases, Rosenzweig *et al* conclude that "anthropogenic climate change is having a significant impact on physical and biological systems globally and in some continents".

There are issues with using a binary indicator to aggregate climate impacts. For example, a large number of studies within one 5° × 5° latitude-longitude grid box pulling predominantly in the same direction of "consistent with warming" (such as there might be in Europe) yields just one piece of aggregate information for the pattern congruence tests. Also as discussed in a review of Rosenweig *et al's* article in the same issue of *Nature* by Zwiers and Hegerl [6], the pattern congruence tests are insensitive to some of the more subtle aspects of climate change attribution because they implicitly assume that the effects of local climate change are manifested locally within the same grid box. Instead, it is likely that changes span multiple grid boxes. For example, a species of migratory bird might adjust its behaviour due to changing conditions at the location where it spends the winter, or where its arrival in spring is recorded as a phenological event, or a combination of changes along its route.

Furthermore, Rosenzweig *et al's* "joint attribution" approach is still only a two step process where (i) an aspect of climate change (in this case temperature change) is attributed to anthropogenic forcing (in this case by the IPCC) and then (ii) changes in natural systems are subsequently attributed to climate change. Zwiers and Hegerl argue that it would be better to employ an end-to-end analysis to examine all of the main processes driving variability in a chosen system and hence attribute any observed response unequivocally to anthropogenic effects on climate. There have been a few end-to-end studies, but their number is dwarfed by the ≈ 30,000 data sets contributing to the Rosenzweig analysis. Thus Zwiers and Hegerl agree that the sheer number of changes considered across vastly differing biological and physical systems outweighs the sampling limitations and conclude that this type of statistical analysis is currently the most effective way to link regional and global impacts to anthropogenic climate change.

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Sustainable management of arsenic contaminated water and soil in rural areas of Latin America

Final project summary

This two-year project has been an international partnership investigating the sustainable management of arsenic contaminated water and soil in rural areas of Latin America. The target zones are near Calama in the Antofagasta region of northern Chile and the province of south-east Cordoba in the Chaco-Pampean plains of Argentina. In both areas high levels of volcanic arsenic are affecting rural water supplies and agriculture through contaminated soils and irrigation water. In Antofagasta, Chile, copper mining is an additional source of arsenic contamination.

A previous account of this EU-funded project appeared in the *ECG Bulletin* July 2007. The final meeting for the project was held early in December 2007 in Bell Ville, Argentina, one of the sites of the Argentinean field trials. The meeting was divided into an update and briefing session for the partners, and included a field visit to a local dairy farm, which had participated in trials measuring arsenic concentrations in milk, as well as a two-day workshop.

The meeting was attended by partners from the Agrarian Technological Institute of Castilla y Leon (ITACYL) (Spain), University of Valladolid (Spain), the Centre for Transdisciplinary Studies on Water Resources (C.E.T.A) (including the Facultad de Ciencias Veterinarias, Universidad de Buenos Aires) (Argentina), the Scientific Technological Mining Research Centre (including Universidad Católica del Norte and Universidad de Antofagasta) (Chile) and Cornwall College (UK). The dissemination workshops were open to interested stakeholders from local and regional government environmental departments, local activist groups and the public.

During the first day, the project participants from each of the target zones presented information about the health and socio-economic effects of the high levels of soil and arsenic water in the target zones and similarities with other arsenic-contaminated regions around the world. The second day focused on monitoring and remediation methods, including soil washing, phytoremediation and water treatment technologies. It was vital to inform stakeholders without causing alarm, and to offer simple and affordable solutions which may be implemented at the community level.

Continuation of this project is unlikely in the immediate future due to the lack of availability of EU funding for arsenic contamination research. However, it is hoped that the valuable partnerships forged during this project may be maintained and further investigations into field trial remediation in the target zones resumed when funding does become available.

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A dairy farm at Bell Ville, Cordoba, Argentina: a possible site of arsenic contamination

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1st July
www.MRWrecycledmaterial.co.uk

Green chemistry and the consumer
University of York
1st – 2nd July
www.rsc.org

Renewable Energy in the Urban Environment
Berlin
7th – 11th July
http://www.ies-uk.org.uk/events/Urban_Renewables_11Jul08.pdf

Water conservation
Swindon
9th July
www.swig.org.uk

Impact of Analytical Innovation on Geochemical, Environmental, Exploration & Food Science
London
15th July
http://www.ies-uk.org.uk/events/events.html

NCAS Mesoscale Modelling Workshop
University of Reading
18th July
http://www.ies-uk.org.uk/events/events.html

20th International Symposium on Gas Kinetics
University of Manchester
20th – 25th July
www.gk08.org.uk

Dioxin 2008 — 28th International Symposium on Halogenated Persistent Organic Pollutants
Birmingham
17th – 22nd August
http://dioxin2008.org/

Geochemistry of the Earth's Surface 8 (GES8)
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18th – 22nd August
http://www.minersoc.org/GES8.htm

5th International Conference on Environmental Catalysis
Belfast
31st August – 3rd September
http://www.centacat.qub.ac.uk/5icec/index.html

3rd International Conference on Environmental Effects of Nanoparticles and Nanomaterials
University of Birmingham
15th – 16th September
http://www.gees.bham.ac.uk/research/nanonet/conference

Contaminated Land and Brownfield Remediation
London
16th – 17th September
http://www.newzeye.com/conferences_education/conferences_display.cfm?item_ID=123

PUrE International Conference on the Impacts of Pollution in a Changing Urban Environment
The University of Manchester, UK
17th – 19th September
www.pureconference.org.uk

Air Pollution 2008
Skiathos, Greece
22nd – 24th September
http://www.wessex.ac.uk/conferences/2008/air08

Accelerated Carbonation for Environmental and Materials Engineering
Rome
1st – 3rd October
http://w3.uniroma1.it/ACEME/

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Cardiff University
6th – 7th October
http://www.imarest.org/events/event.asp?ID=5448

Sustainable Innovation 08 Future Products, Technologies And Industries
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