

The Stern Review on the Economics of Climate Change

The Tyndall Centre is a national UK centre for trans-disciplinary research on climate change. It is dedicated to advancing the science of integration, to seeking, evaluating and facilitating sustainable solutions to climate change and to motivate society through promoting informed and effective dialogue. Researchers at The Tyndall Centre welcome the opportunity to submit evidence to this important review and would like to be kept informed of subsequent developments.

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The comments here address the issues raised in the terms of reference:

- 1 Assessment of the economics of moving to a low-carbon economy and
- 2 Assessment of the potential of different approaches for adaptation (including the economic, social and environmental consequences of climate change in developed and developing countries as well as possible adaptation actions and their costs).

The evidence provided here is derived from collaborative research within the Tyndall Centre over the past five years funded by the NERC, ESRC and EPSRC with external funding from DTI, DEFRA and other sources.

1 Assessment of the economics of moving to a low-carbon economy

Tyndall Centre research on the UK potential transition to a low carbon economy has demonstrated the requirement for a comprehensive policy approach across sectors of the economy and sectors of government responsible for them. The Tyndall Centre has produced UK de-carbonisation scenarios that are the first to fully integrate the energy system and include carbon dioxide emissions from air, sea and land transport. The scenarios integrate the perspectives of energy analysts, engineers, economists and social and environmental scientists to provide a whole system understanding of how the UK Government can achieve a true 60% carbon dioxide reduction target by 2050.¹

This Tyndall Centre research shows the failure of governments and international Conventions to account for emissions from international aviation and shipping has led to a serious underestimation of the actions necessary to achieve a true 60% reduction. Within the UK this is particularly evident; whilst the Government's Energy White Paper emphasises the need for significant carbon reductions, the Aviation White Paper supports considerable growth in air travel. Research conducted at the Tyndall Centre demonstrates the urgent need for coherent climate policy across key departments.

¹ Anderson, K., Shackley, S., Mander, S. and Bows, A. (2005) *Decarbonising the UK: Energy for a Climate Conscious Future*. Tyndall Centre. Available at: http://www.tyndall.ac.uk/media/news/tyndall_decarbonising_the_uk.pdf

The Tyndall scenarios clearly illustrate that even a true 60% reduction in the UK's carbon dioxide emissions is technically, socially and economically viable. Consequently, it is within our grasp to reconcile a dynamic and economically successful society with low carbon dioxide emissions. The Tyndall Centre research in this area derives policy lessons for decarbonising energy demand and supply, transport and suggests specific roles for government in this process.

On decarbonising energy demand:

Efficiency improvements can dramatically decarbonise many sectors

There is significant potential within many sectors to reduce their carbon emissions through relatively small increases in the incremental rate at which their efficiency 'naturally' improves. This is particularly the case when these can be allied with similar incremental reductions in the carbon intensity of their energy supply. The net rate of decarbonisation must exceed the economic growth rate for absolute reductions to occur.

Demand-reduction offers greater flexibility than low carbon supply

The natural replacement rate of domestic and commercial end-use equipment avoids the long term lock-in associated with new and capital-intensive energy supply such as power stations. Moreover, the costs of end-use technologies are spread amongst millions of consumers, whilst the initial capital outlay of supply alternatives are typically borne by a small number of companies (or government).

On decarbonising energy supply:

Supplying low-carbon energy is both technically and economically viable

Whilst many low-carbon technologies still require considerable development, overcoming technical difficulties is unlikely to be a constraint on low carbon energy supply. Similarly, given that economies of scale will likely reduce the cost of these technologies, large scale deployment of low carbon energy supply is likely to be economically viable.

A society with high energy demand will face future infrastructural challenges

The extensive infrastructure associated with high energy futures, for example, large increases in the number of power stations, transmission networks, airports and roads, may be problematic for the UK's small and densely populated mainland.

On decarbonising transport:

Low-carbon futures do not preclude increases in personal mobility

Substantial increases in the number of passenger-km travelled, both nationally and internationally, are compatible with the UK's true 60% target. A higher target will likely curtail the rate of growth in personal mobility as well as the choice of transport modes and fuels, however it is difficult to envisage a target that would necessarily reduce mobility.

Emissions from international aviation and shipping must be included in carbon targets. Aviation and shipping are the two fastest growing emission sectors. Failure to include them will lead to the misallocation of resources earmarked for carbon-reduction measures. The Government's projected expansion of aviation will force emission

reductions from all other sectors to substantially exceed 60% if the UK is to make its fair contribution to “avoiding dangerous climate change”.

Specific recommended roles for the UK government include:

To implement and enforce minimum energy standards

The best available equipment and appliances on the market are often twice as efficient as the typical product sold. Consequently, in many situations a 50% reduction in carbon emissions is already available. Government must supplement labels and customer goodwill with binding and incrementally-improving relative and absolute efficiency standards.

Equity concerns will demand innovative policy mechanisms

It is difficult to envisage the public accepting policies for achieving large carbon reductions which require the majority to reduce their current carbon-intensive consumption patterns whilst permitting a significant minority to continue to enjoy a high-carbon lifestyle. Consequently, more innovative policies that go beyond the simple price mechanism and consider quantity constraints directly may be required.

All 60% futures require immediate action - but some require more action than others

The 60% carbon reduction target can be reconciled with high, as well as low, energy consumption. However, high energy consumption futures require immediate action in relation to both energy supply (e.g. R&D and site evaluations for large infrastructure) and energy demand (e.g. stringent efficiency standards and carbon taxes), whilst low energy consumption futures require immediate action in relation to energy demand only.

Ancillary environmental benefits from GHG mitigation

The IPCC’s Third Assessment report (TAR, 2001) notes that there are potential ancillary environmental benefits from GHG mitigation that may, in some national circumstances, be comparable in scale to the estimated costs of mitigation. See (Swart et al. 2004) for a more recent discussion. The most researched and highly valued benefits are from reductions in local air pollution, especially fine particulate matter, on human health. The conditions in which these benefits will be substantial are:

- Use of inefficient engines and boilers burning low-quality fossil fuels,
- which are close to high-density human populations,
- where and when the prevailing winds maintain or focus concentrations, and
- when and where the health and circumstances of the population are particularly susceptible to additional stresses.

The problem of air pollution is widespread in urban areas, especially in developing countries with young poorly nourished populations and traffic congestion; the health benefits can be very high but are highly specific to local circumstances. An example of how regional circumstances can affect the benefits is that, as a result of prevailing westerly winds and high population densities, Europe is likely to have higher ancillary benefits from a given reduction in pollutants than the USA.

The nature and scale of these benefits is well documented (see reviews in TAR, 2001 and European Environment Agency, 2004). New estimates for Europe since the TAR are reported and discussed in (Syri et al. 2001;; Amann et al. 2004). Benefits for developing countries are covered by Cifuentes et al. (2001). The problem in introducing them into models estimating global mitigation costs is that the benefits are

local, highly diverse and uncertain. They are also short term, if policies and measures are expected to reduce or eliminate the pollution. As a consequence, the global integrated assessment models have largely set these benefits aside, often by assuming a pollution-free baseline. However these are the reductions in damages for which we have evidence. The relationship between emissions and health is highly complex (emissions are diffused and mixed, changed by weather and sunlight, concentrated through the food chain and absorbed by the lungs). There are likely to be unknown pollutants, which may become more evident through observation and research. Thus the general conclusion is that the estimates in the literature are the minimum benefits to be expected. However, since the valuation relies on that of human life and health, it is confounded by ethical and measurement problems.

Other benefits from reduced burning of fossil fuels are less well researched. There are improvements in agricultural productivity from reduced ozone concentrations and less stress on natural ecosystems.

Air pollution is a local problem and the policies and measures best suited to reduce it will not necessarily be the same as those for GHG mitigation. However there are obvious further benefits from taking them into account when designing GHG mitigation policies, e.g. bringing reduction in local pollution into account when national GHG mitigation strategies are designed.²

2 Assessment of the potential of different approaches for adaptation (including the economic, social and environmental consequences of climate change in developed and developing countries as well as possible adaptation actions and their costs).

Tyndall Centre research has estimated impacts of climate change across a range of sectors and regions and assessed the processes by which adaptation is already occurring, will occur in the future, and the consequences of active choices and strategies to adapt. In this note we summarise results from DEFRA funded research on global scale estimates of impacts of climate change and from Tyndall-funded research on emerging lessons on stabilization targets and on adaptation.

2a) global scale estimates of impacts under diverse future scenarios

Research by members of the Tyndall Centre beginning in 1998 have provided estimates of the global-scale impacts of defined climate-model based climate scenarios. This set of studies is known as the Fast Track studies funded by DEFRA.³

² Amann, M., Cofala, J. and Klimont, Z., (2004) Linkages in emissions and control options between air pollution and greenhouse gases. European Environment Agency.

³ The Defra "Fast Track" study is a series of sequential studies, all funded by Defra to use rapidly the latest output from Hadley Centre climate models in global-scale impact assessments. The three main phases of the project examined HadCM2 output under IS92a emissions, the effect of stabilisation of greenhouse gases (with scenarios based on HadCM2 runs with S750 and S550 stabilisation pathways), and the implications of different SRES emissions and socio-economic scenarios for the estimated impacts of climate change. The Fast Track studies were described in brochures produced for COP

The research attempts to produce generalised "damage functions" showing impacts against temperature change ("millions at risk" diagrams). More recent work has constructed damage functions for water resources scarcity from climate scenarios representing different global temperature changes.

The characteristics of the Fast Track study are:

- use of consistent scenarios for climate change, derived from Hadley Centre climate models, and consistent scenarios for changes in socio-economic characteristics;
- spatially-explicit simulation of the impacts of climate change for water resources availability, coastal flood risk and wetland loss, food production and risk of hunger, risk of malaria transmission, and change to terrestrial ecosystems;
- reasonably consistent indicators of impact – namely population at risk of impact by sector;
- variable representation of adaptation between sectors, reflecting the different characteristics of the impact indicators.

The key conclusions from this research effort include:

(i) The impacts of future climate change depend on the future socio-economic characteristics of the world. Not only is the absolute magnitude of social and economic change important in determining impacts (the A2 world has high impacts because it is populous), but the regional variation in impact varies between storyline.⁴ Also, the greatest absolute impacts are not necessarily in the world with the greatest climate change, but in the world with the greatest amount of exposed social and economic assets and population.⁵

(ii) The impacts of climate change vary geographically, with some regions experiencing an increase in "risk" and others an apparent decrease. However, it is not appropriate to calculate the net change as the difference between "winners" and "losers" because (a) the consequences of "winning" and "losing" are not the same and (b) "winners" and "losers" tend to be in different parts of the world. In each of the sectors considered, Africa appears to be the most consistently adversely affected by climate change.⁶ These results, particularly on the global distribution of impacts and

events in the late 1990s, generated a number of papers, and informed the selection of the government's 60% emissions reduction target (the Royal Commission on Environmental Pollution's report cites the Fast Track work in a footnote justifying its recommendation of the 60% target).

⁴ Arnell, N. W., R. Nicholls, et al. (2004). "Climate and socio-economic scenarios for climate change impacts assessments: characterising the SRES storylines." *Global Environmental Change* **14**: 3-20.

⁵ Arnell, N. W., M. G. R. Cannell, et al. (2002). "The consequences of CO₂ stabilisation for the impacts of climate change." *Climatic Change* **53**: 413-446.

⁶ Arnell, N. W. (2004). "Climate change and global water resources: SRES emissions and socio-economic scenarios." *Global Environmental Change* **14**(1): 31-52.

Levy, P. E., M. G. R. Cannell, et al. (2004). "Modelling the impact of future changes in climate, CO₂ concentration and land use on natural ecosystems and the terrestrial carbon sink." *Global Environmental Change* **14**: 21-30.

Nicholls, R. J. (2004). "Coastal flooding and wetland loss in the 21st century: changes under the SRES climate and socio-economic scenarios." *Global Environmental Change* **14**: 69-86.

Parry, M. L., C. Rosenzweig, et al. (2004). "Effects of climate change on global food production under SRES emissions and socio-economic scenarios." *Global Environmental Change* **14**: 53-67.

Van Lieshout, M. et al. (2004). "Climate change and malaria: analysis of the SRES climate and socio-

vulnerability are directly in line with other international assessments of the distribution of impacts on poorer regions including health impacts, sea level rise in coastal areas and small islands and water availability.⁷

(iii) The regional impacts of climate change vary between climate model scenario, largely due to differences in the regional pattern of rainfall change, although the broad pattern of change is consistent. There are differences between different HadCM models, and larger differences when other climate models are considered.

(iv) To at least the 2050s, it is difficult to identify differential effects between different emissions scenarios. This is partly because the underlying climate differences are small until then (at least in mean climate), but largely because multi-decadal climatic variability in rainfall is large relative to the climate change signal and it is difficult to distinguish clearly between climate model simulations.

Table 1 summarises key impacts, at the global scale, by the 2080s. All show changes relative to the situation at that time without climate change.

Table 1 Increase (millions of people) over situation without climate change: 2080s

A1 world		A2 world	
Risk of hunger	290	Risk of hunger	550-580
Increased water stress	1820	Increased water stress	4700-5400
Risk of malaria	93	Risk of malaria	107-157
Exposed to coastal flood	43	Exposed to coastal flood	67
B1 world		B2 world	
Risk of hunger	50	Risk of hunger	150-170
Increased water stress	1700	Increased water stress	2800-3100
Risk of malaria	132	Risk of malaria	139-215
Exposed to coastal flood	27	Exposed to coastal flood	39

2b) Temperature changes and related impacts with and without mitigation policy

Tyndall Centre research has also sought to shed light on the specific relationships between emissions, concentrations and global temperature change (and hence critical and potentially dangerous impacts) in the absence of climate policy in order to assess strategic options and the scale of potential global policy interventions.⁸

In the absence of climate policy or some decision to move towards a globally sustainable world carbon dioxide emissions are predicted to rise to between 12 and 30 GtC/yr (currently 7 GtC/yr). This would raise carbon dioxide concentrations in the

economic scenarios." *Global Environmental Change* **14**: 87-99.

⁷ Barnett, T. P., Adam, J. C. and Lettenmaier, D. P. (2005) Potential impacts of a warming climate on water availability in snow-dominated regions. *Nature* **438**, 303-309;

Patz, J. A., Campbell-Lendrum, D., Holloway, T. and Foley, J. A. (2005) Impact of regional climate change on human health. *Nature* **438**, 310-317.

⁸ Warren, R. (2006) Impacts of global climate change at different annual mean global temperature increases, in Nakicenovich et al. (eds) *Avoiding Dangerous Climate Change*. Cambridge University Press.

atmosphere from the current 2005 level of 379 ppm (compared to 274 ppm in pre-industrial times) to between 600 and 1000 ppm. This and increasing emissions of other greenhouse gases (methane and di-nitrogen oxide) would cause global annual average temperatures, which have already risen by 0.6C since pre-industrial times, to continue to rise to reach ~3 to 4.8C above pre-industrial by 2100 and up to 9C eventually. The IPCC range for 2100 is 1.5 to 4.8C, but it is important to realise that the lower portion of this range represents the possibility that low carbon technologies, energy efficiency measures and so on might be deployed in the absence of specific climate policy, through a global transition to a more sustainable way of life for example. None of these estimates take into account the latest studies of possible values of the earth's climate sensitivity, which have concluded that high values of this quantity could not be ruled out on the basis of observations and modelling. Therefore, higher temperature rises are possible also.

The effects of climate change are already being observed globally as global annual average temperature has already risen by 0.6C since pre-industrial times, mostly due to human activities. For example, glaciers are retreating world wide, threatening local water supplies in Peru and endangering towns located downstream of glacial outflow lakes in the Himalayan region which may suddenly release their additional load of water. Spring phenology has advanced by an average of 5 days, coral reefs are bleaching and marine plankton composition is changing impacting fish and bird populations as sea surface temperature rises. The Golden Toad has become extinct in the cloud forest of Central America. Sea levels are rising, threatening small island states and low lying coasts, and permafrost is melting across the Arctic in both Alaska and Siberia, causing damage to infrastructure. The incidence of dengue has increased in areas where temperature has increased. The WHO has calculated that 150,000 lives may be being lost/year to climate change that has occurred since the 1970s. Other observations, such as the collapse in 2002 of the Larsen B ice shelf in Antarctica, the increasing prevalence of forest fires, the increasing prevalence and severity of extreme rainfall events (floods and droughts), and the increasing intensity of hurricanes are also likely to be associated with climate change.

Based on the peer-reviewed literature, predictions of climate change impacts on the earth system, human systems and ecosystems can be summarised for different amounts of annual global mean temperature change (δT) relative to pre-industrial.

At $\delta T = 1^\circ\text{C}$ (only 0.4C above today's temperatures) 80% of world coral reefs would be lost, with different ecosystems variously transformed by 2 to 47%. Serious drought would be expected in Peru owing to the loss of glacier melt. Crop yields would begin to decline in Africa, whilst they might increase elsewhere if carbon dioxide fertilisation occurs. However, this fertilisation process is highly questionable since it would be offset by increased drought intensity and frequency, reduced crop quality, damage due to tropospheric ozone, and outbreaks of pests and disease which are predicted to increase in a warmer world. Vector born disease such as malaria and dengue would begin to spread. Extinctions would begin in sensitive ecosystems such as Australia where half the rainforest of Queensland would be lost. Marine ecosystems would be damaged due to acidification and further changes in plankton composition, and Arctic ecosystems would be damaged. Rainfall variability, sea level rise and water stress would increase worldwide.

These effects will now be difficult to avoid, unless there is dramatic progress in the development and application of mitigation and carbon sequestration technologies and programs. It is likely to be necessary to attempt to adapt to this change. The costs and limits of adaptation are very difficult to quantify. Inevitably there would still be potentially serious residual impacts in some regions and also for natural ecosystems such as coral reefs.

At $\delta T = 1.5^\circ\text{C}$ irreversible Greenland Ice Sheet melting would begin. This could be prevented for very low stabilisation levels of carbon dioxide in the atmosphere, in the region of 350 ppm. Eventual sea level rises of 7m would then be expected over perhaps a millennium. Together with sea level rise due to thermal expansion of the oceans, sea level rise would then rise by a few m over the next few centuries, threatening the long-term existence of many coastal cities throughout the world.

The risks of occurrence impacts expected for a 2C annual global average temperature rise can be greatly reduced by stabilisation of carbon dioxide in the atmosphere. The following impacts can be avoided with around 80% confidence if we stabilised emissions at 400 ppm carbon dioxide equivalent, and with around 40% confidence if we did so at 450 ppm carbon dioxide equivalents. Otherwise at $\delta T = 2^\circ\text{C}$ agricultural yields would fall across the world (the amount depending on the controversial carbon dioxide fertilisation process mentioned above). Increased drought would triple poor harvests in Russia straining inter-regional relations. Drought in the Mahgreb region of Africa would be likely to induce human migration. Billions of people would experience increased water stress, additional hundreds of millions may go hungry, sea level rise would displace millions from coasts, and malaria risks would spread further. Different ecosystems would variously be transformed by between 5 and 66%. Arctic summer sea ice would be lost completely. Hence the Inuit hunting culture and the polar bear would disappear. In general Arctic ecosystems would collapse with 53% of the tundra lost. Extinctions would take off as regional ecosystems disappear, for example in the Queensland rainforest which holds the endemic Golden Bowerbird, and the world's richest floristic region, the Karoo of S. Africa. The Antarctic ecosystem could also be stressed and coral reef ecosystems would become extinct.

Some impacts are predicted to occur between global annual average temperature changes of between 2 and 3C. There can be prevented at 450-550 ppm stabilisation of CO₂-eq with around 35% confidence. Clearly, higher confidence may be desired so lower stabilisation targets would be advisable. Otherwise at $\delta T = 2\text{--}3^\circ\text{C}$ the Amazon and other forests and grasslands would collapse. The West Antarctic Ice Sheet may commence melting, adding a further 5m to sea level rise over the coming centuries. N American maples (fall colours) would be at risk, S African parks would lose >40% animals, Great Lakes ecosystems would collapse, and extinctions would accelerate. In Malawi fisheries would collapse and crop failures of 75% in Africa are predicted. Desertification of the Tibetan Plateau would be expected and also mobilisation of the Kalahari dune-fields. Both these processes would impact severely on the local human inhabitants.

A wide range of very serious impacts are predicted for a global annual average temperature rise of 3C. A stabilisation target of 550 ppm CO₂-eq might prevent these but only with 33% confidence. A target of 450 ppm CO₂-eq would provide much greater confidence in avoiding these outcomes. Otherwise, at $\delta T = 3^\circ\text{C}$, for any

socioeconomic scenario, millions at risk to water stress, flood, hunger and dengue and malaria would increase further. In particular 65 countries would lose a minimum of 16% agricultural GDP, even if CO₂ fertilisation is assumed to occur, and consequently between -20 to +400 million additional people would be at risk of hunger, 75% of them in Africa. Overall losses of between 20-400 m ton in cereal production could be expected. This could include losses in Chinese rice yields (again depending on CO₂ fertilisation effects). Up to 25-40 millions would be displaced from coasts in the absence of protection from sea level rise, a further 1200-3000 mar could be at risk water stress depending on the socioeconomic scenario. An 18% increase in seasonal and perennial malaria transmission zones (200-300 mar) is expected, and 55% of the global population could be exposed to dengue (in 1990 this figure was 30%).

Few ecosystems can adapt to a 3C annual global average temperature rise so large numbers of species would become extinct globally, and 50% of nature reserves could not fulfil their conservation objectives. 7 to 74% of ecosystems would be transformed and 22% loss coastal wetlands would be lost. Large loss of migratory bird habitat would occur and many alpine species would become extinct.

The North Atlantic thermo haline circulation which transports warm water to the coastal waters off NW Europe, keeping winter temperatures several degrees higher than they would otherwise be, has been predicted to collapse in the range $\delta T = 1-5^{\circ}\text{C}$. The literature suggests that a stabilisation target of 550 ppm carbon dioxide equivalent has a reasonable chance of preventing this, whilst a 450 ppm carbon dioxide equivalent target is considerably safer in this respect. However, recent observations suggests that there is already a reduction of 33% in the net amount of warm water transported northwards by this current.

Whilst the numbers of people exposed to climate impacts (and hence the magnitude of the impacts) is strongly affected by the global population – which of course is also a strong driver of emissions – for any given socioeconomic scenario, impacts increase significantly as global annual average temperature increases. All of the impacts above are cumulative, that is, for example, that at a 2C temperature rise all of the impacts which were listed for a 1C temperature rise would also be predicted to occur. Thus a mitigation strategy which reduces the risks of impacts associated with a 2C temperature rise by say 50% also reduces the risks of impacts associated with a 1C temperature rise, and does so by more than 50%.

Further increases in extreme weather events such as flood and drought are expected as climate changes, and the intensity of hurricanes and windstorms is predicted to increase. Likewise, the acidity of the ocean would continue to increase. Different species would respond differently to temperature change potentially decoupling predators from their prey and pollinators from their flowers and crops. Whilst no particular thresholds have been identified for these processes, their effects would be reduced incrementally by increasingly stringent mitigation policies. Uncertainties surround many temperature thresholds and hence for all impacts more stringent mitigation reduces the risk of their occurrence.

The emission reductions implied by such policies have been considered by Rachael Warren (2006) and depend initially on the relationship between stabilization and temperature (Box 1) the probability of overshooting (Box 2)

Box 1 Estimates for the relationship between stabilisation and temperature

IPCC 2001: assuming a climate sensitivity of 1.7 to 4.2
Temperature rises in 2100 (and eventually, at equilibrium)
450 ppmv produces $\delta T = 1.5$ to $2.6C$ (1.8 to 4.2)
600 ppmv produces $\delta T = 2.0$ to $3.4C$ (2.5 to 5.8)
700 ppmv produces $\delta T = 2.2$ to $3.7C$ (3.1 to 7.3)

The figures in Box 2 are based on one analysis⁹ which used two of the various published probability distributions for climate sensitivity.

Box 2

- 400 ppmv CO₂-equivalent stabilisation level has
 - 13-33% risk of overshooting $\delta T = 2C$
- 450 ppmv CO₂ equivalent stabilisation level has:
 - 40-78% risk of overshooting $\delta T = 2C$
- 550 ppmv CO₂ equivalent stabilisation level has:
 - 75-100% risk of overshooting $\delta T = 2C$
 - 33% risk of overshooting $\delta T = 3C$
 - 10% of overshooting $\delta T = 4C$

A thorough analysis of the exact numerical values of these risks would require further review of the literature so the figures given here should be taken as initial estimates.

To prevent high risks of exceeding 2C we may need to stabilise at 400 CO₂-eq.
To prevent high risks of exceeding 3C we may need 450 CO₂-eq.
To achieve 450 ppm CO₂-eq stabilisation, global emissions must peak by 2015 to avoid a requirement otherwise for rapid future emission reductions of >2.5%/year if the target is to remain attainable. If we delaying emissions reductions until 2020-2025 then from 2025 onwards it requires emissions reductions of 5%/year global to reach 450 ppm CO₂-eq.
This also implies that USA and non-Annex 1 major players must participate by 2025 to avoid drastic EU & other non-Annex-1 action if we are to keep to a 2C target.
Specifically:
400 ppm CO₂-eq is attainable if emission reductions are applied at an average rate of 2.6%/year globally if we start now. This reduced emissions to a level of 50-55% below 1990 by 2050.

⁹ den Elzen, M.G.J., and Meinhausen, M. (2005) *Meeting the EU 2C climate target: global and regional emission implications*. Report no. 728001031/2005.

450 ppm requires 1.8%/year to reach 30-40% below 1990 by 2050
500 ppm requires emissions to be reduced to 15-25 % below 1990 by 2050
550 ppm requires emissions to be reduced to 5-10 % below 1990 by 2050

The implications of this analysis lead to a set of conclusions concerning global mitigation strategies that are discussed in Warren's paper for the Exeter Dangerous Climate change conference.¹⁰ To prevent sea level from rising several metres over next few centuries immediate drastic emission reductions are required. African farmers, Himalayan villagers and coral reefs will require enormous attention to attempt to enhance their adaptive capacity to climate change, since it will be difficult to prevent temperature from rising to a level of 1C above pre-industrial levels. To prevent further impacts expected for a global annual average temperature rise of 2C above pre-industrial temperatures, significant emission reductions are required now. Otherwise, expected impacts include crop failures in Africa, loss of Arctic sea ice, polar bear & Inuit, increasing frequencies of extreme events such as flood, drought and windstorms, increasing intensities of hurricanes, and increases in hunger, water stress and disease, large transformations of ecosystems risking associated extinctions, extinctions of species such as the Golden bowerbird, etc. To prevent these impacts emissions need to be reduced now at an average of ~2.6% year globally (to avoid more drastic rates of emission reduction later on).

Slower emission reductions preclude only the very worst effects avoidable. For example at a stabilisation target of 550ppm, there is a large chance (2 in 3) that temperature rise could still reach 3C for a stabilisation level of 550 ppm. Therefore, hunger, disease, flooding, water stress and extinctions would become even more widespread. In summary, delaying global mitigation action is dangerous: stabilization at 450 ppm becomes increasingly difficult to attain. With any level of mitigation there will always be residual impacts, so adaptation will still be required, and there will be impacts that we cannot adapt to and impacts that ecosystems cannot adapt to.

2c) Adaptation strategies and options

Given the scale and scope of potential impacts outlined in Tyndall Centre research above, the need for effective adaptation is critical. Research within the Tyndall Centre on adaptation has, for the first time, documented actual and planned adaptations to climate change and assessed the social and technical processes by which adaptation occurs. Relevant findings of this research include:

- adaptation involves a wide array of public and private actors acting both in response to observed climate change and to expected climate change;
- not all adaptation is equal – its uptake is patchy, its benefits and costs unevenly distributed, and its sustainability often in question;
- the capacity to adapt is similarly unevenly distributed – sections of society are thus extremely vulnerable to impacts;
- the costs of mitigation and adaptation are inter-related - funding for adaptation investments could be linked to responsibility for mitigation.

¹⁰ Warren 2006 op cit.

Wide array of actions make up adaptation: Adaptation to climate change refers to the desire to or the act of preparing for climate change, in anticipation of, during or after impacts. It can manifest itself as a) building adaptive capacity such as learning, reading, gathering information, and research; b) taking action, which includes implementing policies and regulations such as planning policy guidelines for building design, investing in infrastructure to mitigate specific risks such as flooding, or seeking seasonal to decadal climate forecasts to affect *ex ante* investment decisions.

Adaptation actions are taken by any individual, group or government, consciously or subconsciously. They can be organised or accidental, can involve changes in laws, regulations or policies; changes in organisational structures; or behavioural changes. Adaptation can be a one-off coping with a problem or it can be a learned response. Much adaptation is taken by private agents without positive spillovers in terms of social learning, while public investment (in risk assessment and information provision) are pure public goods with diffuse benefits. The most important implication of this diversity in adaptation response is that the costs of adaptation are difficult to assess for either national economies or at a global scale.

Not all adaptation is equal: In the UK, there are already numerous examples of adaptation practices. They have been summarised by the Tyndall Centre in work undertaken for DEFRA and in conjunction with UKCIP to develop a database of existing adaptations. Table 2 demonstrates selected examples of these currently observed adaptations.

Table 2 Examples of observed adaptations to climate change in the UK distinguished by their purposefulness and primary focus

	Implementing adaptation	Building adaptive capacity
Planned (deliberate)	<p>Millennium Green urban development, Nottingham, UK: climate change-sensitive design for energy and water usage.</p> <p>Norwich Union Flood Maps: Accurate assessment of flood risk for properties to estimate insurance premiums.</p>	<p>National planning regulation (PPG25) on development and flood risk promoting precautionary decision-making taking account of climate change in development decisions.</p> <p>London Climate Change Partnership is made up of public, private and voluntary sector organizations and produces scenarios and plans for adaptation for London under climate change.</p>
Unplanned (non deliberate)	Thames Barrier	UK Rail Safety and Standards Board has planned for impacts of weather extremes on railway infrastructure for the UK that incorporates scenarios consistent with climate change.

Source: Adapted from Tompkins et al. (2005)¹¹

In reviewing experience on currently observed adaptations to observed or expected climate changes, the unevenness of response becomes clear. While some countries and sectors of the economy invest in planning for climate change, others do not. In a study of water utilities and house-building sectors in the UK, Tyndall researchers demonstrated that the diversity of potential adaptation options were exploited by individual firms while the competence of the sectors to adapt in general remained largely unaffected.¹² While the Cayman Island government has invested social and institutional adaptation to cope with hurricane risk, other countries (with similar exposure and adaptive capacity) have not implemented adaptation action.¹³ Research on building design for future warmer climates demonstrated that technological lock-in to energy intensive solutions in many buildings can lead to higher overall emissions – adaptations to perceived higher summer temperatures are at present to install air-conditioning thus increasing summer energy demand.

Thus, what may be considered a successful adaptation today might lead to problems in the future, for example, moving to a protected area on the coast away from an unprotected area of the coast today might seem like a good adaptation while in future the area might not be protected. Government planning for flood risks associated with climate change is being developed in Norway and the Netherlands.¹⁴ In both cases research shows that despite high potential benefit-cost ratios of these plans, they are limited in their effectiveness in uptake by municipalities and by the need for consensus planning over land uses. Thus virtually all adaptation actions involve multiple stakeholders and require adaptation to be in line with broad principles of sustainability including consideration of effectiveness at reducing risk, efficiency, equity and vulnerability implications; and inclusive planning that promote uptake and trust in affected sections of society.¹⁵ We believe that evaluative tools for sustainable adaptation are a high research priority given the diversity and unsustainability of presently observed adaptations.

The capacity to adapt is unevenly distributed: Research within Tyndall Centre and internationally continues to demonstrate that the capacity to adapt is associated with levels of development, while the mechanisms of social capital, networks and resilience remain key capacities to avoid vulnerability. Research demonstrates that, at

¹¹ Tompkins E.L. et al. (2005) *Linking Adaptation Research and Practice. A report submitted to Defra as part of the Climate Change Impacts and Adaptation Cross-Regional Research Programme*. Tyndall Centre for Climate Change Research, School of Environmental Sciences, University of East Anglia, Norwich.

¹² Berkhout, F. and Hertin, J. and Gann, D. M. (2006) Learning to adapt: organisational adaptation to climate change impacts. *Climatic Change*. in press

¹³ Tompkins, E. L. (2005) Planning for climate change in small islands: insights from national hurricane preparedness in the Cayman Islands. *Global Environmental Change* **15**, 139-149.

¹⁴ Tol, R. S. J. et al. (2003) Adapting to climate: a case study on riverine flood risks in the Netherlands. *Risk Analysis* **23**, 575-583.

Næss, L. O., Bang, G., Eriksen, S. and Veavtne, J. (2005) Institutional adaptation to climate change: Flood responses at the municipal level in Norway. *Global Environmental Change* **15**, 125-138.

¹⁵ Adger, W. N., Arnell, N. W. and Tompkins, E. L. (2005) Successful adaptation to climate change across scales. *Global Environmental Change* **15**, 77-86.

the national level, adaptive capacity of countries is associated with good governance, civil and political rights and literacy as well as the level of economic development. Hence countries in sub-Saharan Africa and countries that have recently experienced conflict have lowest adaptive capacity.¹⁶

But regions and populations are vulnerable to more than climate change at any one time. Adaptation by the tourism sector to changes in climate, for example, has been shown to be driven as much by changes in demand associated with changing population and income as by climate. In India, the vulnerability of farming populations to climate change risks are exacerbated by vulnerability of livelihoods to changes in agricultural markets associated with international trade in agricultural commodities.¹⁷

The implications of this research for adaptation are primarily in focussing priorities for international action on adaptation. While it may be difficult to appraise the global incremental costs and benefits of adaptation, it is clear from the approaches of many international development agencies that targeted adaptation actions can be funded and that development assistance investments should at the very minimum, avoid creating new vulnerabilities to climate change risks from flooding heatwave or water availability.¹⁸ Similarly there is increasing evidence that public sector planning and local level conservation of ecosystem services can build resilience and flexibility that enhances autonomous and effective adaptations.¹⁹

A further issue is the capacity to adapt to risks beyond biophysical thresholds. Adaptation to so-called low probability high-impact events (such as collapse of West Antarctic Ice Sheet and significant sea-level rise, abrupt climate changes associated with THC collapse and others) may be beyond present technological ability, incur costs that are difficult to assess within the realms of macro-economic models, and which create new vulnerabilities among large proportions of the world's population.²⁰ While studies of the risks of abrupt climate change have yet to assess systematically even the impacts of such scenarios emerging analysis suggests that these are real risks where precautionary mitigation action is essential to avoid them.²¹

¹⁶ Brooks, N., Adger, W. N. and Kelly, P. M. (2005) The determinants of vulnerability and adaptive capacity at the national level and the implications for adaptation. *Global Environmental Change* **15**(2), 151-163.

¹⁷ O'Brien, K. L. et al. (2004) Mapping vulnerability to multiple stressors: climate change and globalization in India. *Global Environmental Change* **14**, 303-313.

¹⁸ Richard J.T. Klein, S.E.H. Eriksen, Lars Otto Næss et al. (2005) Mainstreaming of adaptation to climate change into development assistance. Presented at Climate or Development? Hamburg Institute of International Economics, Hamburg, October 2005.

¹⁹ Tompkins, E. L. and Adger, W. N. (2004) Does adaptive management of natural resources enhance resilience to climate change? *Ecology and Society* **9**, 10. www.ecologyandsociety.org/vol9/iss2/art10.

Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R. and Rockstrom, J. (2005) Social-Ecological Resilience to Coastal Disasters. *Science* **309**, 1036-1039.

²⁰ Dessai, S., Adger, W. N., Hulme, M., Turnpenny, J., Köhler, J. and Warren R. (2004) Defining and experiencing dangerous climate change. *Climatic Change* **64**, 11-25.

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Arnell, N. W., Tompkins, E. and Adger, W. N. (2005) Eliciting information from experts on the likelihood of rapid climate change. *Risk Analysis* **25**, in press.

²¹ Mastrandrea, M. D. and Schneider, S. H. (2004) Probabilistic integrated assessment of dangerous climate change. *Science* **304**, 571-575.

The costs of mitigation and adaptation are inter-related: There is a demand for information on the costs of adaptation to judge the best adaptation on cost-effectiveness grounds and to assess the trade-offs between adaptation and mitigation. Research in the Tyndall Centre shows that in the traditional sense, adaptation and mitigation are substitutes: if mitigation costs can be reduced (e.g. through technological change) then mitigation becomes more attractive and the amount of adaptation required is reduced.²² However, if mitigation costs affect adaptation, then mitigation and adaptation can be substitutes. And if technological or institutional changes affect both the costs and uptake of mitigation and adaptation jointly (as suggested in analysis of resilient institutions), then they are complements in a technical sense.

The inevitability of the need for adaptation, and the unevenness of the distribution of adaptive capacity and vulnerability (as well as responsibility for the costs) means that public transfers of resources are a key role of government action. The level of public or private transfers depends on issues such as the ability to allocate responsibility for individual events in terms of overall climate change (and hence liability); and on the development of international institutions and mechanisms for adaptation assistance. There is ongoing research on the nature of liability and attribution.²³ Within Tyndall, research has addressed equity in adaptation and the issue of the scale of compensation required. Principles for fair adaptation in the climate change regime include avoiding dangerous climate change, forward-looking responsibility, putting the most vulnerable first and equal participation of all. Current projections, as outlined in above in this submission, mean disregard for basic human rights of vulnerable people and nations – inhabitants of low-lying atoll nations, for example, are likely to lose their rights to sovereignty enshrined in the UN Charter as result of dangerous impacts of sea level rise making their islands uninhabitable.²⁴ Estimates of revenue from a carbon tax of \$20–50 per carbon equivalent have been argued to be necessary for global adaptation.²⁵ Other analysis of fairness principles demonstrates that an equivalent per capita transfer of \$26 per capita per year from greenhouse gas polluting (Annex 1) countries represents the scale of transfer required for minimal adaptation.²⁶

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²² Ingham, A., Ma, J. and Ulph, A. M. (2005) *Can adaptation and mitigation be complements?* Working Paper 79, Tyndall Centre, University of East Anglia, Norwich.

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²³ Allen, M. R. and Lord, R. (2004) The blame game. *Nature* **432**, 551-552.

²⁴ Barnett, J. and Adger, W. N. (2003) Climate dangers and atoll countries. *Climatic Change* **61**, 321-337.

²⁵ Paavola, J. and Adger, W. N. (2006) Fair Adaptation to Climate Change. *Ecological Economics* in press.

²⁶ Baer, P. (2006) Adaptation: who pays whom? In: Adger, W.N., Paavola, J., Huq, S., Mace, M.J. (Eds.), *Fairness in Adaptation to Climate Change*. MIT Press, Cambridge, pp. 131-153.

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APPENDIX - online publications:

Köhler J., Barker T., Pan H., Agnolucci P., Ekins P., Foxon T., Anderson D., Winne S., Miozzo M, Green K, (2005) *New Lessons for Technology Policy and Climate Change. Investment for Innovation; a briefing document for policymakers.*: Briefing Note 13 http://www.tyndall.ac.uk/publications/briefing_notes/note13.shtml

New Lessons for Technology Policy and Climate Change - Investment for Innovation: a briefing document for policymakers

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Executive Summary

There is a new understanding of the role of government policy in addressing the problem of climate change. The emphasis is now on policies for innovation and investment to initiate a transition to a low carbon global economy and society, in addition to the economic instruments of taxation and permit trading systems or regulations and standards.

This is a long-term issue – not just climate change, but also the widespread adoption of new technologies. There are very large infrastructure assets in both the energy and transport systems. These assets will take a long time to replace, whatever the technologies chosen. The key question is how policy can direct the continuing investments that will be necessary in energy systems towards low carbon technologies, can stimulate and support innovation and investment to bring about the transition to a low carbon economy. To have the requisite impact in 2050, it is necessary to start directing investment towards low carbon technologies in the immediate and short term from now to 2010, and to persist with such low-carbon investments thereafter. The net cost of low carbon technologies will depend crucially on the extent to which policies to encourage innovation and investment are successful. This is a significant departure from the recommendations of economic analysis based on the ‘standard’ or ‘traditional’ approach to the cost-benefit analysis of environmental problems. A new approach is emerging – the analysis of economic development as a series of disequilibria with endogenous/induced technical change.

Many of the technologies for a low carbon energy system are already available, but not yet fully competitive under current policies and markets. Energy efficiency improvement is central, but not sufficient, to achieve a 60% CO₂ reduction. Energy efficiency technologies will themselves be subject to the same considerations of innovation and investment as other energy technologies.

Possibilities and insights for new policies

- An international initiative focussed on encouraging innovation and the adoption of new energy technologies and practices, as the Prime Minister himself has recognised, may offer new opportunities for co-operation based on already strong national policies in many countries, and for moving ‘beyond Kyoto’.
- The policy framework should reflect uncertainty - the fuel/generation mix is sensitive to the assumed technology costs, which themselves depend on assumptions about innovation and technical change.

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- Policy must be durable to reduce investors’ uncertainty, being appropriate for the various phases of innovation and adequate to see the new technology through to commercial competitiveness.
- Analyses suggest that the costs of achieving a low-carbon economy in this way need not be large, relative to estimates of economic growth.
-

The Climate Change Levy (CCL)

- The design of the Renewables Obligation and Energy Efficiency Commitment have made them effectively invisible to consumers, in contrast to the high-profile CCL.
- Analysis of the CCL shows: there was an ‘announcement effect’ in the period after the announcement of the CCL in the Commerce and Public Sector which contributed a reduction in carbon emissions that was comparable to the pure price effect.
- There was an over-achievement of 2002 energy efficiency targets associated with the Climate Change Agreements (CCAs) – substantial cost-effective efficiency opportunities in industry were taken up, which might be termed the ‘awareness effect’ of the CCAs.
-

Introduction

Recent work on energy policy has come to a new understanding of the role of government policy in addressing the problem of climate change. The emphasis is now on policies for innovation and investment to initiate a transition to a low carbon global economy and society, in addition to the economic instruments of taxation and permit trading systems or regulations and standards. The UK has been active in policy innovation for climate change and now has opportunities to develop policies to meet

the goals set out in the Energy Policy White Paper (DTI, 2003a). Drawing on the results from the Tyndall Centre ETech projects (Tyndall Centre, 2004), this paper explains the analysis of long-term technological and industrial change leading to this new approach and assesses the Climate Change Levy, a major climate policy initiative. Opportunities for technology and investment policy at national and international levels to address climate change are identified. Current findings, drawing on modelling approaches incorporating the potential for technological change, which suggest that the costs of a transition to a low Carbon economy may be relatively low, are discussed. One fundamental conclusion from this research is that:

the issue is not just how much do low carbon technologies cost, but how to direct the continuing investments that will be necessary in energy systems towards low carbon technologies, in ways that will stimulate innovation and reduce these costs?

A long-term issue – not just climate change, but also the widespread adoption of new technologies

There are very large infrastructure assets in both the energy and transport systems. These assets will take a long time to replace, whatever the technologies chosen. The systems in place in 2050 will largely depend on investments made from 2005 to 2020. Therefore, although moving to a low carbon energy and transport system is a long term policy objective, it is necessary to start directing investment towards low carbon technologies in the immediate and short term from now to 2010 and the decade thereafter. The UK government has already implicitly recognised this in the Energy Policy White Paper (DTI, 2003a) by adopting the Royal Commission on Environment and Pollution target of a 60% reduction in greenhouse gas (GHG) emissions from 1990 levels by 2050 (RCEP, 2000). However, for this target to be credible in the eyes of the investment community, it needs to be supported by policy measures and processes that promote the innovation and deployment of a range of low carbon technologies (Foxon et al., 2005a).

What do we know about the long term? - Things will change

Capitalist economies have been characterised by successive ‘Kondratiev waves’ of new clusters of technologies (such as the current IT wave), which change the economic structures of production and consumption (Freeman and Louça, 2001). Looking at current technologies and current costs is a poor guide to the energy sector in 2050. Persistent long-term changes in society and economies can be identified in all regions of the globe: (rural to urban, agriculture to manufacturing to services, more human & product mobility). The long-run global economy seems likely to be characterized by increasingly specialised production & generalised consumption. This will increase trade leading to more currency unions, lower trade barriers, global branding and life-styles, and markets increasing in numbers, scale and specialisation with associated reduction in costs. Competitive innovation and obsolescence is another characteristic of a global economy in which information costs are falling rapidly. For the long-run global energy system, there is an increasingly unequal distribution of oil and gas resources, although coal is plentiful and transportation costs are falling.

Resource demands will change with economic structure.

The most probable next ‘Kondratiev waves’ are the generic technologies that manipulate information, organisms and materials (currently known as information technologies (IT), biotechnologies, and nanotechnologies). These technologies will have major impacts on input structure and resource efficiency. For example, it is forecast that, by 2100, 82% of world GDP will be in the service sector, mainly due to massive IT investment and diffusion. There is an inextricable link between technological change, industrial dynamics and environmental impact over the long term. As a result of industrial structure change, energy demand and associated CO₂ emissions could increase, depending on the resulting primary energy mix. Dewick, Green, Fleetwood and Miozzo (2004) highlight how, by 2050, the adoption and diffusion of biotechnologies and nanotechnologies could change industrial structure:

- Biotechnology has the potential to create many generic platforms and have a pervasive effect across a wide range of industries: pharmaceuticals, health care diagnostics, agriculture, food, materials technology, energy, and environmental monitoring. In bulk chemicals, advanced biotechnology-facilitated production processes are also likely to significantly reduce value inputs of electricity (currently 5.2% of total inputs into the EU chemicals industry).
- Nanotechnology could instigate the growth of a new ‘advanced materials’ industry: emulating the growth of synthetic materials since the 1950s.
-

The effect of the developments of these key technologies will depend, however, on the international division of labour, as driven by the operation of multinationals and the international and national regulatory systems. Evidence of consistently higher resource efficiency in the EU against the USA across different sectors, for example, raises questions about the differential diffusion of these key technologies in production and the effects on CO₂ emissions (Miozzo, Dewick and Green 2005).

60% emissions reduction is a long term goal, but action is needed now

As explained above, the energy system cannot change instantaneously. It has a very large stocks of assets, so large scale changes will require large investment in new assets over a long period of time – both infrastructure and supply and energy use technologies. An important example is the building stock, which currently has an average life of 100 years. The same argument is true for the transport system. Therefore, policies to stimulate innovation and investment in low carbon technologies are central. This will bring further efficiency improvements, cost reductions and environmental benefits.

The contribution of innovation also raises new questions for policies at the national and international levels. The case for innovation policies has been made several times (ICEPT 2001, 2003). It has three elements:

- Creating options or bringing them forward in time, improves the flexibility of policy, which all studies agree is key both to reducing costs and to winning public acceptance.
- Reducing uncertainties about the performance of a technology before it is turned to on a large scale increases the *option value* of a policy;
- Reducing costs to future investors and consumers, and enabling environmental problems to be solved sooner has appreciable positive external benefits.
-

This is a significant departure from the recommendations of economic analysis based on the ‘standard’ or ‘traditional’ approach to the cost-benefit analysis of environmental problems.

There is considerable controversy over the economic theory behind these arguments, though it is becoming clear that technological change must be included in any modelling of this kind (DeCanio, 2003). Out of this controversy a new approach is emerging – the analysis of economic development as disequilibria with endogenous/induced technical change.

The most important policy question is, therefore: how can policy direct and support innovation and investment to bring about the transition to a low carbon economy?

Bringing new technologies to the market

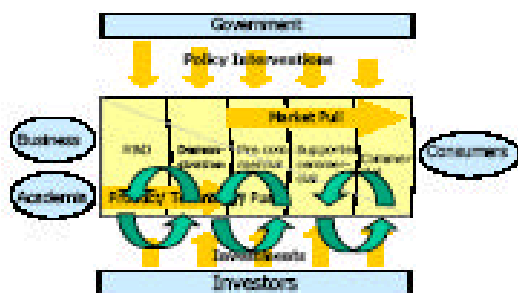
There is also a new recognition of the complex nature of the innovation process as illustrated in figure 1 (Grubb, 2002; Foxon, 2003). Successful new technologies come to the market through an innovation chain which may require policy intervention at different points to overcome institutional and market barriers to radical new technologies and products (ICEPT/E4Tech, 2003; Foxon et al., 2005b)

Many of the technologies for a low carbon energy system are already available, but not yet fully competitive under current policies and markets

There is a diversity of technological options already available for addressing the climate change problem, most of which are capable of significant further development. The recent analysis in *Science* by Pacala and Socolow (2004), “Stabilization Wedges: solving the climate problem for the next 50 years with current technologies” provides a well-researched overview. They consider the possibilities for reducing world carbon emissions by 7 gigatons (GtC) per year by 2050, which for expository reasons they break down into seven 1 GtC ‘wedges’. Nuclear power and carbon capture and storage from the use of fossil fuels (especially from coal, which would have the advantage of providing a lower cost route to the ‘hydrogen economy’) are two of the options. The other five include a range of technologies

Figure 1 The innovation process

Source: Foxon, 2003 adapted from Grubb, 2002.



and practices for improving the efficiency of energy supply, conversion and use; the full range of renewable energy technologies, including solar, biomass from crops and wastes, onshore and offshore wind, and energy from waves and tidal streams; new technologies for transport, including fuel cell and hybrid vehicles; new, highly efficient decentralised forms of supplying combined heat and power; and novel emerging methods of storage, for hydrogen and for ‘intermittent’ renewable energy. The economic choice between these technologies rests on social costs, values and perceptions, not technological necessity. Most studies, including the MARKAL studies undertaken for the Energy White Paper, but also numerous studies in other countries and at the international level, point to the importance of pursuing several options and avoiding an excessive focus on one or two (Leach, Anderson et al., 2005).

International Policy

A broad body of professional opinion has argued for incentives to support innovation directly, *as a complement* to carbon taxes or tradable permits (e.g. Alic et al., 2003; Rennings et al., 2003). This is now winning support throughout the OECD countries, and raises the possibility of a new international initiative.

The argument is not simply theoretical. All OECD countries now have innovation policies of one form or another, those of the US and Japan perhaps being the most notable, as does the rapidly developing regions of China, India and Brazil. At the international level, however, the role of innovation is still not fully recognised; the Kyoto process has concentrated on targets, with little emphasis on joint technological cooperation and development. This has proved to be restrictive and, as has been shown by modelling in the US, for all the faults and extreme assumptions of such modelling, holds the danger of raising costs and inviting opposition by reducing flexibility (see e.g. Toman et al., 1999). The advantages of cap and trade policies are that such an approach covers the full set of greenhouse gas emissions sources, which stem from a huge variety of activities as indicated earlier, and governments have the freedom to select the least-cost mix of abatement opportunities with which to meet their target; also it is hard to think of other approaches which would as effectively incentivise governments to address barriers to improving energy efficiency. However, the direct incentives for innovation from cap-and-trade agreements are weak. An agreement like the Kyoto Protocol only gives *indirect* incentives to innovation, by indicating that low carbon technologies are likely to have higher value in the future if and as emission targets are strengthened through successive negotiating rounds; but this is unlikely to be sufficient to finance the degree of risky technology and innovation investments required. Governments need to adopt more active policies to stimulate innovation across the full innovation chain from R&D to large-scale

commercialisation, at least at national but probably international level as well. Kyoto has only weak provisions that encourage governments to cooperate on R&D and technology standards, and to facilitate technology transfer. In this sense, the Kyoto architecture is incomplete and could be usefully complemented by more direct agreements to drive innovation in various technology areas.

An international initiative focussed on encouraging innovation and the adoption of new energy technologies and practices, as the Prime Minister himself has recognised¹, may offer new opportunities for international co-operation based on already strong national policies in many countries, and for moving 'beyond Kyoto' (Leach, Anderson et al., 2005).

Energy efficiency and uncertainty

The Tyndall Centre ETech projects have used these new approaches to analyse long term changes. They confirm the findings of other surveys that the costs of climate change mitigation may be little greater than the costs of investing in current energy technologies, depending on the extent to which innovation can reduce the costs of low-carbon technologies. Costs are further discussed below. Other policy conclusions (Anderson and Winne, 2004) are:

- Energy efficiency improvement is central, but not sufficient, to achieve a 60% CO₂ reduction.

¹ UK Prime Minister's speech on climate change, 14 September 2004, available at <http://www.number-10.gov.uk/output/page6333.asp>; see also ICEPT (2003) and earlier PCAST reports (1997, 1999).

- the transport sector has a relatively high cost of carbon reduction;
- the fuel/generation mix is sensitive to the assumed technology costs; and
- the policy framework should reflect this uncertainty;
- the importance of durability in policy, support must persist until new technologies become commercially competitive. This also reduces investors' uncertainty.

• Current UK policy and the Climate Change Levy

The Energy White Paper (DTI, 2003a) says that:

- The goal is putting the UK on track to a 60% reduction – but not committing now to how that will be achieved. But in period to 2020, the emphasis is on energy efficiency (8-12 MtC reductions); renewables (3-5 MtC); and emissions trading (2-4 MtC).
 - - The –60% target “is a massive challenge”.
 - Because of public expenditure and wider political considerations, the design of the Renewables Obligation and Energy Efficiency Commitment have made them effectively invisible to consumers, in contrast to the high-profile Climate Change Levy (CCL). Analysis of the CCL shows (Agnolucci and Ekins, 2004.):

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- There was an ‘announcement effect’ in the period after the announcement of the CCL in the Commerce and Public Sector which contributed a reduction in carbon emissions that was comparable to the pure price effect (Agnolucci et al, 2004).
- There was an over-achievement of 2002 energy efficiency targets associated with the Climate Change Agreements (CCAs) – substantial cost-effective efficiency opportunities in industry were taken up, which might be termed the ‘awareness effect’ of the CCAs.
- CCA targets were not demanding (except Mineral Products in some cases) – asymmetry of information (managers achieved cost-effective reductions they had claimed did not exist).
- With tax alone a given carbon reduction is cheaper to achieve without rebates BUT
- ‘Awareness effect’ means that CCL + CCAs may have outperformed a no-rebate CCL both environmentally and (less certainly) economically (Ekins and Etheridge, 2005).
-

The Energy White Paper (DTI, 2003a) says that costs should be lower the more that the longer term framework is understood, i.e. as market players know and understand the policy direction. The analysis of the CCL has shown that key issues in this respect include:

- Regulatory uncertainty & market risk cost money;
- A “theoretically” efficient instrument is not always the cheapest options to promote renewable, as can be seen by comparing costs: Germany (feed-in tariff): 8.7 and 5.5 Euro cent /kWh; Netherlands: 7.8 Euro cent/kWh; Denmark: 2.9 Euro cent/kWh + electricity market price < 6.5 Euro cent/kWh; UK (Renewables Obligation): 9.1-10.3 Euro cent/kWh (electricity market price included).
- Increasing information/attention for energy use saves money to firms.
-

What are the economic impacts of GHG mitigation policies?

The first question usually asked is: how much will it cost? This paper is perhaps unusual in dealing with this question last. This is because the new analyses suggest that the costs are crucially dependent on the success of policies to direct investment and stimulate innovation. If such policies are successful, the costs need not be large, relative to estimates of economic growth. Practically all estimates, including the results of the MARKAL modelling work (DTI, 2003b), show the effects would rise from a low level today to a range of 0-2% of world GDP by 2050 (Leach, Anderson et al., 2005). In terms of GDP output lost, this represents a maximum cost of a loss of one year’s growth in 2050, i.e. the modelled output in 2050 would not be reached until 2051, in a context in which GDP is likely to have risen by two to three hundred percent in most economies by this date. Recent surveys confirm these results (Grubb, Köhler & Anderson, 2002; Grübler, Nakicenovic and Victor, 1999; Tyndall Centre, 2004), depending on the success of innovation in reducing the costs of low-carbon energy options. In addition, the possibility of an economic surprise, of welfare being

higher in a low-carbon economy, not lower, cannot be ruled out, depending on the ancillary benefits of the policy (such as other forms of pollution being reduced, and the achievement of more secure energy supplies) and the contribution of innovation to the reduction of costs. As Barker and Ekins (2004) point out, most modelling studies to date have not included these potential benefits. If the higher range of estimates were to be the case, 2% of GDP would of course represent a considerable loss in absolute terms; but this needs to be weighed against the very considerable potential costs of unmitigated climate change.

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