THE ROYAL SOCIETY

Economic instruments for the reduction of carbon dioxide emissions

Policy document 26/02

November 2002

ISBN 0 85403 585 0

This report can be found
at www.royalsoc.ac.uk

excellence in science

Economic instruments for the reduction of carbon dioxide emissions

Contents

page

Summary **vii**

1 Introduction **1**

2 Overview of economic instruments **3**
2.1 Controlling emissions 3
2.2 Carbon taxation 3
2.3 Tradable permits 3
2.4 The choice between taxes and permits 4
2.5 Key economic instruments in current UK energy policy 6
2.6 Conclusions 6

3 Level of carbon tax **7**
3.1 Introduction 7
3.2 Options for setting carbon price: cost–benefit analysis *versus* mitigation targets 7
3.3 Escalation of carbon tax rates 7
3.4 Practical implementation of carbon taxes 8
3.5 The price elasticity of carbon and energy usage 9
3.6 The required levels of carbon taxes 10

4 Economic impacts of a carbon tax **11**
4.1 Impacts on national economies 11
4.2 Impacts on industrial sectors 12
4.3 International competitiveness 13
4.4 Carbon leakage 15
4.5 Methods of preventing loss of competitiveness and carbon leakage 15
4.6 Conclusions 16

5 Impact of economic instruments on the viability of low carbon technologies and on the security of supply **17**
5.1 Introduction 17
5.2 Impact of a carbon tax on the viability of various sources of renewable energies 17
5.3 Impact of economic instruments on the security of supply 21

6 Measurement of emissions **23**
6.1 Estimating national emissions 23
6.2 Measurement methods 23
6.3 Sources of error 24
6.4 Point of application 24
6.5 CO_2 sequestration 25
6.6 Conclusions 25

7 Political and social obstacles to the use of economic instruments **27**
7.1 Corporate distrust 27
7.2 Loss of competitiveness 28
7.3 The social impact of economic instruments 28
7.4 Reluctance to move towards harmonisation 29
7.5 Experience within the European Union 29

8 Discussion and recommendations **31**

Appendix A **List of respondents** **35**

Appendix B **Programme for seminar on European experience** **36**

Appendix C **Overview of current UK schemes** **37**
C.1 UK Emissions Trading Scheme 37
C.2 The UK Climate Change Levy 37
C.3 New Electricity Trading Arrangements (NETA) 38
C.4 Utilities Act 2000 (Renewables Obligation) 38

Appendix D **Outline of proposed European emissions trading scheme** **39**

Appendix E **List of countries in Annex B of Kyoto protocol** **40**

Appendix F **Glossary** **41**

Appendix G **References** **42**

ISBN 0 85403 585 0

Science Advice Section
The Royal Society
6–9 Carlton House Terrace
London SW1Y 5AG

Preparation of this report

This report has been endorsed by the Council of the Royal Society. It has been prepared by the Royal Society working group on economic instruments for the reduction of carbon dioxide emissions.

Chair	Sir Eric Ash, FRS, FREng	Treasurer, Royal Society
Members	Dr Mary Archer	President, National Energy Foundation
	Dr Terry Barker	Department of Applied Economics, Cambridge University
	Professor Geoffrey Boulton, FRS	Department of Geology and Geophysics, University of Edinburgh
	Sir Alan Budd	Provost, The Queens College, University of Oxford
	Mr Peter Ewins, FREng	Chief Executive, Met Office
	Professor Ian Fells, FREng	Fells Associates and University of Newcastle upon Tyne
	Dr John Hassard	Department of Physics, Imperial College, London and HydroVenturi Ltd
	Professor Geoffrey Hewitt, FRS, FREng	Department of Chemical Engineering and Chemical Technology, Imperial College, London
	Sir John Horlock, FRS, FREng	Formerly Director of National Grid Company; Formerly Vice-Chancellor, The Open University
	Professor Michael Laughton, FREng	Visiting Professor Imperial College Centre for Energy Policy and Technology
	Professor David Pearce	Department of Economics and CSERGE (Centre for Social and Economic Research on the Global Environment), University College London
Secretariat	Mr Richard Heap	Manager, Science Advice Section, Royal Society
	Dr Rachel Quinn	Senior Manager, Science Advice Section, Royal Society
	Ms Marisa Goulden	Science Policy Officer, Science Advice Section, Royal Society

Summary

The need to reduce anthropogenic emissions of greenhouse gases into the atmosphere – notably carbon dioxide (CO_2) – is crucial to slowing down the rate of global climate change. Governments can reduce these emissions by advocacy, by regulation and by the application of economic instruments. Economic analysis shows convincingly that placing primary emphasis on the use of economic instruments provides the most cost-effective route for such emission reduction. In this report we consider two generic types of economic instrument that could provide the most effective solution to rising CO_2 emissions: a carbon tax imposed on all CO_2 emissions, and the allocation of tradable emission permits.

The primary aim of a policy based on the application of either economic instrument is to correct the failure in the market, which at present makes emission of CO_2 cost free. An economic instrument will associate a cost with the emission. The effect will be to make fossil fuels more expensive for the consumer, thereby encouraging switching to lower carbon technologies and energy sources, and reducing consumption through conservation and efficiency. At the same time it makes renewables, nuclear and carbon sequestration more viable; these influences may turn out to be of equal or even greater importance.

We recommend that the economic instrument should eventually be applied to all sources of emitted CO_2: industrial, domestic and transport (including aviation). Because 96% of all emissions derive from the combustion of fossil fuel, the primary means of collecting the tax should be on the wholesale purchase of fuel. We believe the Climate Change Levy, in its current form, is an inefficient way to reduce CO_2 emissions, primarily because it excludes certain energy users (including households and transport) and targets energy use in general rather than carbon emissions in particular. It also acts somewhat crudely on the *demand for energy*, but fails to provide anything significant for the *supply* side of the equation.

We realise that an economic instrument will make domestic energy more expensive, and no government would contemplate increasing the number of 'fuel poor'. To avoid penalising the more vulnerable members of society the Government could introduce or extend appropriate measures. However those members of society should be compensated, but not shielded, from the tax.

Concern has been expressed that either economic instrument would have a negative impact on the economy. However, both a carbon tax and auctioned emission permits produce substantial revenues. Economic modelling demonstrates that if these revenues are optimally recycled, the overall cost to the national economy – to the Gross Domestic Product (GDP) – would be modest, even for the very large reduction in emissions that are likely to be required beyond 2012 (the Kyoto period). Indeed, some studies suggest that the effect may be positive. We hope that the recognition of these facts will facilitate the eventual achievement of international harmonisation.

Although the total change in GDP may be modest, the impact on individual sectors of the economy will be substantial. Some sectors such as the renewable energy industries will see gains. Industries whose energy costs amount to a large percentage of the total will face particular challenges. However, we recommend that any measure to shield carbon-intensive industries from the impact of the tax should be time-limited, and should be transparent in the form of explicit subsidies. The tax is intended to increase the price of carbon-intensive products.

As with any economic instrument or regulation, it is crucial that industry is given time to adjust. In the case of a carbon tax this implies that it should start at a low level, and with some indication by Government of the probable profile of future increases. For tradable permits, there is a case for initiating the scheme by 'grandfathering': i.e. allocating permits free-of-charge to companies based on their past emissions. However, we recommend that this stage should be strictly time-limited, with the aim of proceeding to a wholly auctioned permit.

Because global climate change affects all nations, solutions are needed that will ultimately achieve agreement with as many other nations as possible. Increasing the number of countries that impose a carbon tax or that participate in a tradable permit scheme reduces the required rate of tax or cost of permit, lowers costs and lessens any loss of price competitiveness. The chosen economic instrument should aim for convergence between the nations of the European Union (EU) – and beyond. We do not underestimate the enormous problems in reaching the needed international agreements. However a vital first step is to seek and reach an understanding *in principle* - that emission control, would, in future be based on the application of a carbon tax or related economic instrument.

Reaching an agreement on as wide an international basis as possible is more important than the speed with which a fully fledged scheme is implemented. In considering an appropriate economic instrument both nationally and internationally, it is vital to give due weight to the need for simplicity and transparency. Ultimately, it is society that has to be convinced. A scheme that is beyond the comprehension of most will fail in both of these respects. Eventually, nations will have to agree. But it is not inevitable that they adopt the remedies at the same rate. What is essential is agreement of a principle and agreement to converge to a solution, even if the convergence is only achieved after a decade or more of delay. We take some hope from the Kyoto Protocol, which provides a framework for international agreement and mechanisms for emissions trading.

1 Introduction

The need to curtail the emission of greenhouse gases is now almost universally accepted (IPCC 2001*a*). Although debate remains on the scale of the global climate change that will result from these emissions and on the urgency with which the problem should be addressed, there are few who would deny that a sharp change in the direction of our energy technology is imperative – a conclusion emphasized by the fact that 177 nations have subscribed to the Kyoto protocol. Although the practical impact of the first commitment period of the Kyoto Protocol is exceedingly modest, it has a value that should not be underestimated in signalling an international intent.

Some of the means at our disposal to reduce greenhouse gas emissions, and particularly carbon dioxide (CO_2), have been surveyed in many recent reports (see for example, Marshall 1998; OST 2002; PIU 2002; RCEP 2000; Royal Society and Royal Academy of Engineering 1999; 2000; Royal Society 2001). The problem in securing their effective adoption lies in societal and political inertia, and the economic sacrifices believed to be involved. The obstacles are formidable within the context of a single nation; they become a great deal more so when coherent action on a global scale is required. Climate change is one of the first truly global problems that the world has encountered. It is, then, not too surprising that embarking on the needed remedies seems barely within imaginable diplomacy.

Yet, seen from a top-down vantage point, there are two factors that encourage the hope that we could succeed: analysis shows that the changes needed are not prohibitively expensive (Chapter 3), because their application will probably only require a modest reduction in the growth rate of the world's economy. We will still be getting richer, but at a slightly reduced rate. The second encouraging factor is that although in geophysical terms the changes needed are urgent, they are not desperately so when measured against the political time clock. In a democracy, imposing even minor burdens that would feature in the contest for the next election is problematic. But if the main consequences can be expected to surface only at the next election but one, it brings the issues more readily within the scope of the possible.

The basic issue is the current, largely cost-free emission of greenhouse gases into the atmosphere. A first step in reducing these emissions must be to use less energy. The second is to use energy sources that do not involve greenhouse gas emissions. The third is to ensure that the act of emitting greenhouse gases into the atmosphere ceases to be cost-free. These three broad approaches are intertwined. Making energy more expensive encourages conservation. Making emission more expensive encourages the use of non-polluting energy sources as a substitute.

Control theory, which plays important roles in engineering and science, would lead one to apply a penalty directly to the parameter that one wishes to reduce. The simple concept of direct taxation of emission commends itself to scientists, economists and engineers. But governments, who alone can impose taxes, have many issues to consider, of which greenhouse gas emission is just one. Nevertheless, it is our intention in this report to examine the extent to which economic instruments can succeed.

Because global climate change affects all nations[1], to achieve agreement we need solutions that look favourable to as many other nations as possible[2]. This immediately implies that the remedies should be as free as possible from purely parochial considerations. Above all, they should be simple and easily understood by the electorate. The simplicity would also aid the needed diplomatic negotiations and prevent the search for ingenious escape routes – the so-called 'hot air'[3] remedies. Ultimately, nations will have to agree. But it is not inevitable that they adopt the remedies at the same rate. Clearly no-one would expect India immediately to impose the controls that might be agreed for Europe. What is essential is agreement of a principle and agreement to converge to a solution, even if the convergence is only achieved after a decade or more of delay.

In its previous reports on energy, the Royal Society has expressed the view that the introduction of the correct economic instruments is a key part to a sustainable energy policy (Royal Society and Royal Academy of Engineering 1999; 2000). In this report we examine the role of economic instruments in more detail. The Department of Trade and Industry will publish a white paper on energy policy towards the end of 2002. This report is partly intended as a response to the associated consultation document. We begin in Chapter 2 with an overview of economic instruments currently in place, and the extent to which they reduce greenhouse gas emission. In Chapter 3 we examine the magnitude of a carbon tax[4] that might be needed to make a serious

---

[1] Although by no means equally – a very major part of the complexity that is faced

[2] We see the European Union as a good starting point

[3] For example, purchasing an emission permit from another country, for emissions that would in any event not have taken place

[4] In this Chapter a 'carbon tax' is also intended to embrace related economic instruments such as auctioned permits, discussed in Chapter 2

impact on the problem. In Chapter 4 we look at the overall economic impact of such a tax.

A carbon tax provides an incentive to reduce emissions of CO_2. But it also has an important bearing on the commercial viability of non-emitting energy sources. In Chapter 5 we examine the impact of a carbon tax on the emergence of renewable energies, the prospects for sequestering the CO_2 stemming from the combustion of fossil fuels, the additional incentive for conservation measures, and the prospects for a renaissance of nuclear energy. Although peripheral to our main theme, we also touch on the role that a carbon tax can play in improving the future security of supply.

A carbon tax can only work if we can measure the emissions, whether they are direct (e.g. in the flue gases of a power station) or indirect (e.g. created in the manufacture of an imported item). Chapter 6 is devoted to the methods of measuring emissions.

We are very much aware of the barriers to the imposition of a carbon tax. Some of the factors involved are discussed in Chapter 7. Finally, in Chapter 8, we make specific recommendations.

We are grateful to those organisations and individuals that responded to our call for views that was issued at the start of the study. The organisations that contributed in this way are listed in Appendix A. In many cases their comments and concerns have been reflected in our report.

Our work has been much aided by a seminar to which we invited representatives from five European countries. Their experiences with the imposition of economic instruments in their own countries were most instructive and helpful. Details of the meeting are in Appendix B.

2 Overview of economic instruments

2.1 Controlling emissions

If it is essential to reduce emissions of CO_2, how can this best be achieved? The costs of reducing emissions (so-called abatement costs) will vary from industry to industry and from plant to plant. The most efficient forms of abatement will encourage the reduction of emissions where this can be achieved at the lowest cost in terms of real economic resources. We argue that economic instruments or market-based instruments provide the most efficient solution and we shall examine the two main forms: taxes and tradable permits.

Economic instruments may be contrasted with so-called command-and-control methods, which have been widely used in environmental policy, and which operate by setting standards. Individually or collectively, polluters are given an environmental standard to which they must adhere. For example, there may be a common emission limit for all plants in a particular industry. Alternatively, there may be a limit for a firm or one particular industry sector. Another approach (a technology-based standard) imposes a particular form of technology on all operators. Such methods may seem effective in delivering a particular emission-reduction objective, but the disadvantage is that they limit, to one degree or another, the freedom for polluters to choose the method of complying with the regulation. Even if there is some freedom, the imposition of a target on an individual plant provides no incentive for the plant to reduce emissions below the target, even if it is relatively cheap to do so. Technology-based standards, which are the most widespread form of regulation, are the most expensive form of control. This means that the prevailing environmental policy is almost certainly unnecessarily expensive. Alternative approaches that reduce this cost, without sacrificing environmental goals, are therefore highly desirable.

Economic instruments set out to minimise compliance costs by maximising flexibility of response. They set a price (typically in the form of a tax) or a quantity and then leave the producers to decide how they will respond. A price-based system has two effects. A tax on emissions raises the cost of the polluting product or process. It therefore reduces demand for the product. It also encourages the producer to find ways of reducing emissions by changing the source of energy or changing technology to reduce emissions or fuel use. A quantity-based approach sets a quantity of pollution, say X tonnes of CO_2 emissions, and leaves polluters the freedom to adjust to that target. This would also define the traditional environmental standard approach to the problem, but a quantity-based economic instrument differs because the allocated quantity target can then be bought and sold between polluters. The price of the permit acts just like a carbon tax and helps to minimise the cost of reducing emissions.

2.2 Carbon taxation

A carbon tax, by increasing the cost of a fuel, should reduce demand for that fuel as consumers economise on use or switch to a lower carbon source. The extent to which it does this depends on the price elasticity of demand, i.e. the percentage change in demand for a 1% change in price (OECD 2001). It will also depend on the extent to which the imposition of a tax encourages the supply of non-polluting forms of energy. Substitution is likely to be most marked over a longer time period, as it may involve replacing equipment, such as changing to more efficient boilers, which may wait until it reaches the end of its economic life (which is, in any event, hastened by the carbon tax). For this reason, long-run price elasticities tend to be bigger than short-run ones. Typical fuel and travel price elasticities of demand are shown in Table 1; as the wide ranges quoted suggest, these are somewhat subjective indications. The substitution effect may be enhanced by introducing the carbon tax at a relatively 'low' level and signalling that it will rise through time. The UK already has experience with taxes that incorporate these 'announcement effects': the landfill levy, for example, and the (now discontinued) fuel duty escalator.

2.3 Tradable permits

In principle, tradable permits achieve the same result as environmental taxes. Whereas a tax sets a *price* (the tax) and leaves the polluter to adjust the *quantity* (the level of emissions), a tradable permit system sets a *quantity* (a quota of emission permits), and the *price* (the price of the permit) adjusts according to the resulting supply and demand for permits. In practice, there are several considerations that may favour one option over the other.

The basic mechanics of a tradable permit are simple. An overall quota of emission allowances is first determined. For greenhouse gases, this would be a quota based on a national target, which would be allocated to different sectors of the economy. For any sector, the quota of allowances is allocated between firms or economic agents. The mechanism for allocation can vary, but only two are usually considered: *auction*, whereby polluters bid for the permits, and *grandfathering*, whereby quotas are allocated without charge according to actual historical emissions. Grandfathering suffers from the basic defect

Table 1. Typical price elasticities of demand in Organisation for Economic Co-operation and Development (OECD) countries. Data come from analysis of multiple studies, which in part explains the ranges.

Fuel		Short-run elasticity	Long-run elasticity
Gasoline:	*most OECD countries*	–0.15 to –0.38	–1.05 to –1.40
	Europe	–0.15	–1.24
Residential electricity		–0.05 to –0.90	–0.20 to –4.60
Car travel		–0.09 to –0.24	–0.22 to –0.31
Air travel		–0.36 to –1.81	
Rail travel		–0.37 to –1.50	

that those who polluted most in the past are most rewarded in the allocation of permits. It is also inherently bureaucratic. It is difficult to make the system flexible – to allow for growth or decay. **It may, however, none the less be tolerable as a way of *initiating* a scheme, provided that it has no on-going implications.**

Once permits are allocated, firms are free to buy and sell them. Typically, firms who find it expensive to reduce emissions will have to buy permits from other emitters if they wish to go beyond their initially allocated quota, and firms who find it cheap to abate will sell permits. Such permits can be traded nationally or internationally. It might, for example, be advantageous for one manufacturer using coal as fuel to buy permits from another who has access to gas. It is, of course, important to guard against trades where permits are sold from an inactive organisation who would not have emitted CO_2 – an example of a 'hot air' trade. Also, there must be provision for imposing punitive fines on organisations whose emissions exceed their permit entitlement.

There are many variants of tradable permit systems, but two basic ones, allowance trading and emission reduction credit trading, are described below.

2.3.1 Allowance trading

Allowance trading is sometimes referred to as 'cap and trade'. Each emitter is assigned a quota of emissions and they can emit up to this quota, but not beyond it unless they acquire extra allowances. In an allowance system all polluters are assigned quotas at the outset, and everyone concerned must agree issues such as the baseline level of emissions (what would happen without the quotas), methods of certifying the emissions reduction, procedures for quantification, and, above all, the initial allocation. Setting the initial allocation is the most controversial feature because the allowances are, effectively, assets: assets that are initially allocated by the regulator. Without an allowance, expenditure on costly abatement equipment (or other measures) has to be undertaken. Hence allowances function like any other financial asset. The initial agreement on allocation is therefore crucial for the firms concerned, and considerable resources can be spent in agreeing this allocation. This tends to explain why grandfathering solutions are advocated by the business sector rather than the auctioning solution. Grandfathering gives 'comfort' to polluters in that they can be assured they will get a quota that is at least proportional to their current or recent past emissions. Auctions offer no such assurance.

2.3.2 Emission reduction credits

The alternative form of trading is Emission Reduction Credit trading. This is often known by other names: offsets, joint implementation, bubbling, netting, banking, among others. Under an allowance system it is the regulator who creates the allowances. Under a credit trading system, emitters create credits by reducing emissions below some standard (quota – again determined by the regulator). Although the same issues of certification, monitoring and measurement arise, they may in some ways be less complex than in an allowance system. The basic reason for this is that credit trading does not require prior agreement on these issues by *all* parties. Instead, a few emitters can create credits and other parties can join the system as it evolves. In the same way, provision for credits arising from carbon sequestration can be incorporated later. Above all, credit trading involves no prior allocation system, so the grandfathering-auction debate does not arise. Credit trading therefore tends to be more *ad hoc* and flexible than allowance trading. It is no accident that credit trading is how permit trading began in the USA. Although the USA allowance system for SO_2 is a recent innovation and a demonstrable success, the idea of credit trading dates back to the 1970s. Allowance systems can evolve from credit trading systems. Indeed, a major advantage of credit trading is that it evolves with experience, whereas there is a large premium on getting an allowance system 'right' at the outset.

2.4 The choice between taxes and permits

Although there is general agreement, at least among economists, that economic instruments are superior to command-and-control as a means of reducing pollution, the debate continues on the choice between taxes and permits.

2.4.1 The advantages and disadvantages of taxes

First, demand for carbon-intensive fuels is reduced over time, especially so as firms and individuals respond by changing the technology they use in product development and in electricity generation. This arises because the tax is paid on *all* pollution, as opposed to pollution in excess of some agreed standard. There is also an incentive to search for less polluting technology.

Second, in contrast to command-and-control measures, taxes raise revenues. Revenues can be used in several ways. They can be regarded as part of normal tax revenues, the argument in favour of this being that taxes can then be allocated to the highest 'social return'. Alternatively, they can be allocated (hypothecated) to specific uses. One attractive possibility would be to devote part of this revenue to increase the resource devoted to renewable energy research and development. The UK has already introduced several environmental taxes, most of the proceeds of which are allocated to reducing distortionary labour taxes such as employer's national insurance[1]. This form of hypothecation is associated with the '*double dividend*' argument, whereby the tax induces a switch out of carbon-based technology into low or non-carbon technologies (the 'first dividend'), and also encourages labour retention and new employment (the 'second dividend'). In practice, the issue is far more complex and there is a substantial debate about the overall net effects of hypothecated taxation. The problems arise because there are really four effects that need to be traced through the economy:

- The improvement in human well-being that comes about because of the effects of the pollution tax in reducing pollution: the 'Pigovian effect' (Pigou 1920).
- The gain from using the revenues from the pollution tax to reduce some other distortionary tax: the 'revenue recycling effect'.
- The probably beneficial effect of the reduced pollution on human health and hence on labour productivity (Schwartz & Repetto 1997).
- The distortionary effect of the pollution tax through its effects on raising the price of polluting goods, leaving aside the benefits of reduced pollution: the 'tax interaction effect'.

The first three are positive. The fourth effect is negative (though, of course, positive where its influence on CO_2 is concerned). Although it cannot be established that the three positive effects outweigh the one unfavourable one, it can reasonably be assumed that this is the case.

Finally, since taxes offer the potential to minimise the cost of compliance they should also help to secure future co-operation with new policy measures. However, it must be recognised that an emissions tax, payable on all emissions, can generate strong opposition.

2.4.2 Advantages and disadvantages of tradable permit schemes

Probably the most important feature of a tradable permit scheme is that it secures the environmental target in question. It does this by specifying the quantity of emissions, e.g. tonnes of CO_2 that will be allowed in total. Moreover, the quantity can be decreased through time as environmental targets become stricter. By contrast, to secure a quantity target with a tax (a price) there must be fairly certain knowledge about the relevant price elasticities of demand for energy, transport, etc. Given that these magnitudes are uncertain, there will always be some doubt about whether the emissions target will be met. However, in view of the fact that either system would be introduced gradually, with a carbon tax it would be possible to observe the emission reduction, and adjust the tax level appropriately.

A tradable permit scheme allows for economic growth arising from the introduction of new firms into a sector. New entrants are required to secure permits from existing emitting sources.

Tradable permits work especially well for pollutants that are 'uniformly mixed', i.e. where the source of the pollutant does not significantly affect the damage done. Greenhouse gases are the clearest cases of uniformly mixed pollutants. Each tonne of emission does the same damage regardless of the location of the emission.

Tradable permits can be largely self-financing. A firm seeking to reduce pollution below its quota, with the aim of securing an emission reduction credit, can sell the credit and thus finance the emission reduction.

Tradable permits can become inefficient, leading to an increase in compliance costs, when emitters are allocated an incorrect amount of permits, or if a dominant firm uses its position to control permit prices and therefore to affect costs to competitors. This will lead to inefficiency, with the overall cost of meeting climate-change targets rising. Empirical work so far (Hahn 1984; Koutstaal 1999) does not appear to suggest that market dominance is a serious hindrance to emissions trading schemes; but it cannot be assumed that this experience is readily extrapolated to all

---

[1] 'Distortionary' here means that the tax has an undesirable effect in reducing work effort, or risk taking, or saving. Studies from the USA suggest that the loss per $1 of tax raised because of the distortionary effects may be around 40% for taxes on labour, 50% for taxes on income, and as high as 90% for taxes on investment (Morgenstern 1996).

circumstances. None the less, it appears that very strong 'cartelisation' is required before the market-power syndrome produces significant inefficiency. Even then, a tradable permit system is likely to be more efficient than any command-and-control system.

2.4.3 Similarities between taxes and tradable permits

Like taxes, a tradable permit system has the potential for stimulating technological change in emissions abatement. The more this stimulus occurs, the lower the abatement costs of emitters becomes and hence the lower one would expect the equilibrium price of permits to be. Exactly this effect has occurred with the acid rain trading programme in the USA, where resulting permit prices were markedly lower than predicted. The main reason appears to have been the switch into low-sulphur coal rather than any direct stimulus to other forms of abatement. In a similar way to taxes, tradable permits can raise revenues, with all the consequent arguments about 'double dividends', which were discussed in section 2.4.1.

The price of a permit in an auction system approximates that of a carbon tax. However, the proposed procedure in the EU Draft Trading Scheme is for permits to be grandfathered and without charge, i.e. allocated according to emission levels over some previous period (see Appendix D). The rationale for grandfathering tends to be political and strategic. Auction systems are strongly resisted by polluters because they amount to a transfer of wealth from polluters to regulator (government), whereas grandfathering actually confers wealth on emitters. The great risk with grandfathering is the trade in 'hot air': emission reductions that would have occurred anyway. Polluters have a strong incentive to disguise business-as-usual reductions as reductions brought about by commitment to the trading programme. Auctioning avoids this problem because polluters have to pay for permits and they are not likely to pay to reduce emissions they would reduce anyway. We do not believe grandfathering to be a rational way of allocating permits, except possibly for a short period when launching the permit system.

2.5 Key economic instruments in current UK energy policy

In April 2002 the UK launched its voluntary Emissions Trading Scheme, details of which can be found in Appendix C. There is some suspicion that this scheme may embody some 'hot air' trading. Unlike any of the schemes we have considered it is funded by Government and actually *pays* participants according to their success in reducing emissions. It is unlikely to serve as a model for future developments.

The Climate Change Levy, in its current form, is an inefficient means of reducing emissions primarily because it excludes certain energy users (including households and transport) and targets energy use in general rather than carbon emissions in particular (see Appendix C). The political factors that produced the Climate Change Levy are clearly obstacles to the introduction of a carbon tax. The main ones are (a) sensitivity to taxation of the domestic sector, and (b) concern to continue protection of the coal industry and 'manage' the 'dash for gas'. However, the price paid in environmental terms for these concerns is very high. The Climate Change Levy acts somewhat crudely on the *demand for energy*, but fails to provide anything significant for the *supply* side of the equation, i.e. it fails to induce substitution in the generation of electricity. Moreover, in carbon intensity terms, it taxes gas more highly than coal. The tax also penalises nuclear power, which is effectively carbon-free. On the assumption that nuclear energy fully bears its own environmental and risk costs, it would be far simpler to set a carbon tax that would benefit nuclear power, leaving it to compete realistically in an environmentally adjusted market mechanism. Revenues might be more aggressively used than those under the Climate Change Levy to invest in carbon-free energy sources and, if needed, to offset the income-reduction effects of a tax.

2.6 Conclusions

In comparing the advantages and disadvantages of various schemes, it is vital to give due weight to the need for simplicity and transparency. Ultimately, it is society that has to be convinced, and nations that have to gain the confidence that sacrifices are shared in a rational manner. A scheme that is beyond the comprehension of most will fail in both of these respects.

3 Level of carbon tax

3.1 Introduction

In the previous chapter we outlined the various economic instruments that might be brought to bear on minimising the emission of CO_2. In this chapter, we consider the level at which an economic instrument needs to be applied. We shall talk of a carbon tax, but also embrace other forms of economic instrument that also have the effect of determining a price for the emissions.

3.2 Options for setting carbon price: cost–benefit analysis versus mitigation targets

There are broadly two approaches to finding an appropriate rate for the carbon tax as an instrument for mitigating climate change: cost–benefit analysis or mitigation targets.

Cost–benefit analysis assesses the costs and benefits of climate change, adaptation and mitigation, and then calculates the carbon tax that will minimise net present costs (Pearce 2003). This is logical, and considerable efforts have been made to estimate such social damage costs. However, the estimates are controversial because:

- many damages are unknown, have an impact far into the future, and involve the Earth's ecosystems;
- uncertainty is rife and the possibility of unpleasant surprises is high.

We note that the Government has produced a damage cost of £70 per tonne of emitted carbon as a guiding value to be used in project and policy evaluations across departments. Although there is some dispute about the its validity, a figure of this magnitude would more than meet the Kyoto targets set for the UK.

The alternative approach of adopting mitigation targets involves the setting of targets related to some past level of emissions. The task of policy then becomes one of reaching these targets in ways that are effective, efficient and equitable. The carbon tax is one of several instruments available to reach the targets.

The mitigation-target approach has been accepted as a practical response to climate change by governments in several international treaties (e.g. United Nations Framework Convention on Climate Change, Kyoto Protocol and the EU Burden Sharing Agreement). In the Kyoto Protocol, choice of instruments to reach the targets is left to governments, including participation in the three flexibility mechanisms, one of which is emission permit trading. Thus, within the present form of the Kyoto framework, an international carbon tax would have to take the form of an auctioned emissions-permit scheme. The calculation of the rate of carbon tax required to reach a particular target (e.g. for the EU or the UK) is normally done using large-scale models. It requires the solution of integrated energy–environment–economy models forecasting the future and allowing for different fuels with different carbon contents, and different sectors with different institutions and behaviours, including different response times. Because an effective carbon tax is likely to raise considerable revenues, the analysis must also consider the recycling of revenues by different means, e.g. by reducing taxes on employment such as social security contribution by employers, or eventually by a gradual replacement of value-added tax (VAT) or income tax.

3.3 Escalation of carbon tax rates

Looking ahead, how might the rate of carbon tax be expected to change? Assuming that there will be a succession of greenhouse gas reduction targets (below 1990/1995 levels), starting with Kyoto targets (e.g. the 8% EU target), and continuing to a target of 60% by 2050, as recommended by the Royal Commission for Environmental Pollution (RCEP 2000), an escalation seems likely, simply because the targets are getting more stringent over time. However, there are several other reasons why the carbon tax rate should escalate.

- As the costs of adjustment are related to the time available for the adjustment, costs can be reduced by alerting industry to the probable trajectory of the future tax increases. A low initial rate will give low costs, whereas the expectation of a high long-term rate will encourage a shift to new long-lived capital associated with a low-carbon economy.
- Low-cost, easy options to reduce greenhouse gas emissions are likely to be implemented first, so that as these options become exhausted, higher rates are required for higher cost reductions. Countering this argument, some options for abatement may yield substantial economies of scale and specialisation, such that the costs fall over time (e.g. the development of wind power in the 1990s).
- Similarly, some components of demand for fossil fuels, e.g. road transport, are likely to grow with increases in income. To offset this effect the tax rate must rise over time.

What is clear is that the rate required is uncertain and will change according to changes in prevailing and expected prices in the energy market as well as other factors. Because some of these prices, particularly the world price of crude oil, are notoriously volatile, any proposal for a carbon tax to achieve an absolute reduction in CO_2 emissions should consider how the rate might adjust to changing circumstances and accumulating evidence of its effects. Some form of automatic reaction to changes may help to reduce the volatility of energy prices and keep up the pressure to reduce emissions. For example, the rate may be set semi-automatically to prevent prices falling, so that the rate is raised when oil prices drop sharply. Such a 'ratchet' for market prices of fossil-based energy will help to reinforce the general trend towards energy and carbon saving, but reduce the damaging effects of sharp and unexpected increases in prices of those fuels.

3.4 Practical implementation of carbon taxes

The practical implementation of carbon taxes has been cautious, modest and limited to six European countries (Finland, Norway, Sweden, Denmark, The Netherlands and, most recently, Italy) (Ekins & Barker 2001). Even for those countries without specific carbon taxes, taxes on fossil fuels act as implicit carbon taxes, but they are not as effective or efficient as carbon taxes, even if their purpose is to reduce greenhouse gas emissions. Carbon taxes were introduced in the 1990s. Carbon tax revenues compared with energy tax revenues are most significant for Sweden, but even then they constitute only 26% of these revenues. This reflects the fact that energy taxes were important revenue-raising taxes long before there were any concerns about climate change, and therefore long before carbon taxes became a policy concern. Four of the six countries (Denmark, The Netherlands, Sweden and Italy) introduced carbon taxes as part of a reform of existing energy and other taxes to give greater emphasis to environmental considerations. Other countries now treat energy taxes *de facto* as environmental taxes, even if they were introduced purely for revenue reasons and have no specific environmental focus. With the exception of Finland, the countries with carbon taxes, compared with the countries without them, derive a relatively large proportion of their tax revenues from energy and environmental taxes. If this proportion is an indicator of environmental policy concerns, then it may be that other countries will introduce carbon taxes if such concerns continue to increase.

All the countries that have introduced a carbon tax have also introduced special tax reductions, rebates or exemptions, to address concerns about the effect of the tax on industrial competitiveness (of course, this applies to many countries' treatment of energy taxes as well), as discussed below and in Chapter 4. These exemptions are complex and discussed in detail elsewhere (Ekins & Speck 1999). Some of the principal features of these special arrangements for industrial energy users are as follows:

- In Sweden, manufacturing industry only pays 50% of the carbon tax rate of around €147/tonne carbon (£92/tC).
- In Denmark, the carbon tax rate varies according to whether the use is for space heating, when it is around €293/tonne carbon (£184/tC) for households and businesses, 'light industrial processes', which pay around €44/tonne carbon (£28/tC), and 'heavy industrial processes', which only pay around €11/tonne carbon (£7/tC). Such a differential in tax rates has serious implications for the theoretical efficiency advantages of using carbon taxes to reduce carbon emissions.
- In Norway, the carbon tax rate varies with the fossil fuel, from about €59/tonne carbon (£37/tC) for heavy fuel oil, to around €73/tonne carbon for coal (£46/tC), to around €161/tonne carbon (£101/tC) for natural gas. In addition, reduced tax rates apply for some industrial sectors. For example, the pulp and paper industry and the fishmeal industry only pay 50% of the tax on heavy fuel oil.

The 1992 proposal from the European Commission for a carbon/energy tax provided for the exemption of the six most energy-intensive industrial sectors, but even so failed to be implemented, at least partly because of strong business opposition.

Such differentials in tax rates have serious implication for the efficiency advantages of carbon taxes in reducing CO_2 emissions and may be expected to increase the macroeconomic costs of mitigation. This will be further discussed in section 4.5.2.

Of the five north European countries with carbon taxes, Finland, Norway and Sweden allocate the revenues from their carbon taxes to the general government budget. This means that, for a given level of government expenditure and fiscal balance, other taxes are lower than they would otherwise be, but there is no specific offsetting of other taxes against the carbon taxes as is sometimes the case in what is called 'environmental tax reform'. In Denmark the carbon tax revenues from industry are recycled back to industry through reduced social security contributions and through investment incentives, and in The Netherlands the revenues are recycled back to households and industry through personal and corporate tax relief.

The problems of estimating the environmental effectiveness of a carbon tax *ex ante* are in no way reduced *ex post*. This is because *ex post* evaluations have to compare the situation after the event with a baseline of what would have happened without a carbon tax. Constructing such a baseline faces identical problems to estimating the effects of the tax *ex ante*. In addition, carbon (and energy) taxes are often introduced as part of a carbon-control policy package, rather than as separate measures. Estimating their effectiveness then requires the impact of the different components of the package to be separated out, which can prove impossible. Notwithstanding these difficulties of evaluation, most countries that have introduced carbon taxes have sought to estimate their effectiveness. Thus the Dutch Green Tax Commission in The Netherlands has calculated that each €450m raised from its fuel taxes leads to a CO_2 reduction of 1–1.5 MtC. A study found that the total effect of the Norwegian carbon tax on CO_2 emissions was 3–4% for the period 1991–93 (Larsen & Nesbakken 1997). The Danish Environmental Protection Agency (DEPA) estimated that the Danish carbon tax would reduce CO_2 emissions by 1.6% (DEPA 1999). In Sweden a study commissioned by the Swedish Environmental Protection Agency (SEPA) concluded that Swedish CO_2 emissions in 1994 'were just under 5 Mt lower than they would have been without the CO_2 tax' (SEPA 1997).

3.5 The price elasticity of carbon and energy usage

The effectiveness of a carbon tax in reducing CO_2 emissions can be assessed in three parts: it reduces the carbon content of energy used in an economy; it reduces the energy content of energy services (e.g. comfortable, temperature-controlled indoor living; fast and flexible personal transportation; power and light on demand); and it reduces the overall demand for these energy services.

3.5.1 Reducing the carbon content of energy

The carbon content of energy is reduced by the carbon tax raising the cost of carbon-based fuels, so encouraging substitution away from these fuels in the overall supply of energy. In electricity production, one of the main sources of CO_2 emissions in the UK and the EU, a carbon tax will make coal less attractive than gas, and both fuels less attractive than renewables and nuclear power. A carbon tax would also support schemes for carbon sequestration, which we will further discuss in Chapter 5. In energy use for heating in factories, offices, shops and houses, substitution away from high-carbon fuels will be encouraged, e.g. a further shift towards the use of gas instead of coal, and towards combined heat and power, instead of a conventional heating system with electricity purchased from the grid. This type of substitution can be substantial, with the overall level of energy supplied remaining the same while its carbon content is reduced. The potential for such substitution with its associated CO_2 emission reduction is lost if the tax is on energy supply (the basis of the Climate Change Levy) rather than the carbon content of that energy supply.

The price elasticity of substitution away from carbon-based fuels in energy production and use can be very high in the long term, depending on the availability of renewable sources of energy such as wind and tidal power, the costs of low-carbon technologies, and their political and social acceptability. The fact that coal-fired generation remains a substantial component of both UK (coal was 36% of fuel used for electricity generation in 2000 (DTI 2001); most of the coal is now imported) and EU electricity supply indicates that a substantial opportunity remains to reduce CO_2 emissions at low cost or even benefit.

3.5.2 Reducing the energy content of energy services

The carbon tax will also reduce the energy content of energy services by raising the overall cost of energy, depending on the substitution away from carbon-based fuels in the energy mix. The higher cost of energy encourages substitution away from energy use towards alternative ways of providing the services associated with energy, e.g. the comfort of warm homes, or car transport. These services can often be supplied with much lower energy inputs for the same quantity and quality of the service through improvements in the fuel efficiency of appliances and engines, and in other characteristics of the capital stock, such as design and insulation of buildings. Because the improvements are in the capital stock, some of which is very long lived and replaced infrequently, it can take many years for such improvements to take place and for energy use to decline. The carbon tax gives a price incentive to such improvements and can help to prevent a 'rebound effect' (see Box 1) if such improvements are done as a result of other policies, such as appliance standards, agreements to raise efficiencies of vehicle engines and building regulation, that leave fuel prices unchanged.

3.5.3 Reducing the demand for energy services

The last substitution is that away from energy services that can be heavily carbon-intensive, such as temperature control or travel, towards other forms of consumption that can involve low emissions of CO_2, such as health and fitness or home-based socialising. The great strength of a comprehensive carbon tax is that this more general substitution is unobtrusive, pervasive and diffused. This substitution may be small, slow and long term because it involves institutional and life-style changes, but the climate-change problem is also long term and slow adjustment is feasible.

The overall responses to carbon taxes are likely to be small in the short term, but the evidence from past behaviour after energy price increases is that they are much larger in the long term, e.g. after 5 years or more.

Box 1 The rebound effect

This effect, also known as the 'take-back' effect, is the extent to which the energy saving produced by an investment in energy efficiency is taken back by consumers in the form of higher energy consumption. The rebound effect comes about because improvements in efficiency reduce fuel use and cost for a given activity, e.g. heating a house or making a car journey. The reduced cost of fuels encourages more use of fuels, e.g. for a warmer house, more or longer journeys, and the greater use will offset some of the direct energy savings from the improvement in efficiency. The rebound effect could in exceptional conditions be large enough for an energy-efficiency programme to lead eventually to more rather than less energy use. However, the combination of energy-efficiency programmes with a carbon tax can mean that carbon savings can be achieved at small or no extra costs to the consumer because the lower total cost of energy from the increase in efficiency is offset by higher cost from the tax.

3.6 The required levels of carbon taxes

The rate of a carbon tax needed to achieve a target level of CO_2 emissions for an economy depends on many factors. Opportunities vary across countries, industries and social groups for shifting to lower-carbon fuels, more efficient processes or different consumption patterns. Any exemptions or discounted rates, e.g. for energy-intensive industries, may mean that the full rate has to be higher, depending on the effectiveness of any agreements with the exempted sectors in reducing their CO_2 emissions in exchange for the exemption (see section 4.5.3 for a discussion of exemptions). The modelling approach and the assumptions adopted can also have substantial effects on the estimate of the required level of the tax. Finally, as the target is fixed in relation to a past level of emissions, the expected development of the economy and the energy system (i.e. the baseline) is also important. A baseline projection with high economic growth and low fossil-fuel prices is likely to require a much higher carbon tax to achieve the fixed target than one with low growth and high fuel prices. Because the costs of reducing CO_2 emissions differ across countries, the carbon tax required to achieve a given reduction for a group of countries, e.g. the EU countries or those in Annex B[1] of the Kyoto Protocol (see Appendix E), is lower than if each country achieves the same target using only domestic policies.

The Intergovernmental Panel on Climate Change Third Assessment Report (IPPC 2001*a*) provides a range of estimates for carbon tax rates required to reach Kyoto targets for OECD Europe, with the estimates coming from several global general equilibrium models (see Chapter 4, Box 2). The range is \$20–\$665 per tonne carbon in 1990 dollars, falling to \$20–\$135 if international trading in CO_2 emission permits is allowed between Annex B countries (IPCC 2001*b*). These estimates do not include any 'no-regrets options' such as the use of carbon sinks, or the mitigation of other greenhouse gases where the benefits to society go beyond those of avoiding climate change and outweigh any costs. Because the baseline assumptions were not standardised across the models, these carbon tax rates achieve a range of CO_2 reductions. A study of how the EU might achieve the Kyoto target, allowing for all greenhouse gases, used a disequilibrium, dynamic, simulation model to estimate that an escalating carbon tax of €15.3 per tonne carbon (£9.60/tC) per year 2001–10, reaching €153 per tonne carbon (£96/tC) in 2010 is required; this reduces annual CO_2 emissions by 9.4%, or 89 MtC averaged over 2008–12 (Barker & Rosendahl 2000).

These models are of course based on assumptions about the reactions of individuals to additional costs – the price elasticities. They should also take into account the prospects for advances in technology. Although in the short term fuel demand by road transport is notoriously inelastic, a substantial carbon tax could shift engine design towards radical alternatives such as fuel cells, possibly using hydrogen generated by renewable sources or nuclear plants in off-peak periods. The prospect for major reductions in emission from air transport look less promising. At present air transport only produces approximately 3% of human-generated CO_2, but it is also on a rising trajectory.

---

[1] Industrialised countries identified by the Kyoto Protocol and original signatories. They have emission targets defined by the Protocol (see Appendix E for full list).

4 Economic impacts of a carbon tax

4.1 Impacts on national economies

The theoretical and empirical literature emphasises that a carbon tax[1], with revenue recycling that reduces other taxes, will reduce emissions at lower cost than regulations to achieve the same CO_2 reduction (Repetto & Austin 1997). The benefits of the revenue-recycling effect will be higher when cuts in employment taxes increase labour demand, especially where there is unemployment. Carbon taxes without revenue recycling via distortionary taxes (or emission permit schemes that do not raise auction revenues) will be more costly than carbon taxes with revenue recycling.

The GDP is normally used in the modelling literature to assess the macroeconomic cost of greenhouse gas mitigation using carbon taxes and permits. However, GDP is not a complete measure where environmental effects are concerned because it confuses production and expenditure. To compare climate change and other environmental effects with the conventional GDP effect, they have to be converted into monetary values.

When the effects of a carbon tax on GDP are assessed using economic models, the outcome depends on the models' treatment of production. Usually an explicit production function is included in the model with energy as a factor of production. In this case, the form of the production function and the estimated or imposed parameters will determine how output will change when energy prices rise as a result of a carbon tax or the cost of buying carbon permits. The way this is done almost always implies that a carbon tax will have the effect of reducing output and GDP. If the parameters are imposed, as they are with nearly all the models[2] whose results are quoted in IPCC (IPCC 2001*a*), then the extent of the GDP cost will be a direct result of the size and sign of these parameters. Because there is a wide range of plausible values for the parameters, there is also a wide range of computed effects of the carbon tax on output. In addition, most of the models used are general equilibrium optimising models (see Box 2) with a market optimum defined without taking into account the environment. In such models the effects of a carbon tax are necessarily costly, because the tax moves the market outcome away from the optimum. In other words, the GDP costs given in the literature are likely to be the direct result of assumptions rather than the outcome of empirical research. The costs are significantly affected by the researchers' judgements of what values to adopt for parameters in the wide range available.

This feature is confirmed by a detailed analytical comparison and weighted averaging of the results in the literature obtained on the effects of carbon taxes on GDP. A comparative study of the results from models of the economy of the USA used econometric regression techniques to assess the role of assumptions in determining the projected GDP costs of CO_2 mitigation (Repetto & Austin 1997). Most of the studies used a carbon tax explicitly or as an implicit addition to the price of carbon needed to restrict its use. The study of 16 models covered 162 different predictions and it explains the percentage change in US GDP in terms of the CO_2 reduction target, the number of years to meet the target, how the revenues are 'recycled' through the economy and six model attributes. It estimates that in the *worst case* combining these assumptions and attributes, a 30% reduction in baseline emissions in the USA by 2020 would cost about 3% of GDP. The corresponding *best case* implies an increase of about 2.5% in GDP above the baseline. The spread of 5.5% in these estimates of future GDP can be allocated as follows:

- the recycling assumption (1.2%);
- the use of general equilibrium models (giving lower costs than macroeconometric models) (1.7%);
- the inclusion of averted non-climate change damages, e.g. air pollution effects (1.1%);
- the inclusion of Joint Implementation and/or international emission permit trading (0.7%);
- the availability of a constant cost backstop technology[3] (0.5%);
- the inclusion of averted climate change damages in the model (0.2%);
- the allowance in the model for product substitution (0.1%).

Over 70% of the variation in GDP is explained by all these factors, including the CO_2 target reductions. In summary, worst-case results come from using a macroeconometric model (see Box 2) with lump-sum recycling of revenues, no environmental benefits in the model, no emission permit trading and no backstop technology.

This study is convincing in showing how model approaches and assumptions influence the results. It

---

[1] We are again for simplicity using 'carbon tax' to stand for any economic instrument that sets a price on the emission of CO_2

[2] The models generally assume no environmental constraints on economic activity. They also assume no strong nonlinearities, and in particular no thresholds.

[3] A backstop technology provides an unlimited amount of reduction at a fixed cost. An example would be an abundant energy source that provides electricity with no CO_2 emissions at all. Where a backstop technology exists, its cost sets a ceiling on the investment in reducing emissions.

Box 2 Computable general equilibrium and macroeconometric models

There are two main types of macroeconomic model used for assessing the costs of greenhouse gas mitigation: general equilibrium models and time-series econometric models.

The main characteristic of general equilibrium models is that they adopt the assumption that economic agents act rationally and seek to maximise utility or profits. With other assumptions about free-market pricing, constant returns to scale in industrial production (where output rises at the same rate as costs), many firms and perfect competition, the models give an equilibrium solution for prices and quantities in all markets in an economy. The global models, which project to 2100 and beyond, are estimated on one year's data (currently 1995).

Macroeconometric models do not require these assumptions, and simulate economies by relying on time-series data methods to estimate their parameters, providing dynamic, short-term, disequilibrium solutions. In principle, they can be tested by simulation over history.

It is usually argued that general equilibrium models are more suitable for describing long-run steady-state behaviour, whereas macroeconometric models are more suitable for forecasting the short-run dynamics of an economy. However, the macroeconometric models have increasingly incorporated long-run theory and so they can also provide long-run solutions.

reveals the influence of the model methodology adopted and the importance of the assumption concerning the recycling of tax revenues. If the published estimates of the macroeconomic effects of carbon taxes are interpreted in the light of these findings, the results of carbon taxes for the USA and indeed for the implementation of the Kyoto Protocol may not be as costly as it first appears.

The range of GDP costs that follow from the global models in IPCC is much narrower than that of the carbon tax rates (although a high carbon tax does not necessarily imply high GDP costs) (IPCC 2001*b*). **The range of estimates for OECD Europe to reach Kyoto Protocol targets without emissions trading is a reduction of 0.3–1.5% of GDP below baseline values for 2010, and 0.1–0.5% GDP with Annex B trading.** However, all these effects are of GDP falling below the baseline. It is very likely that this result comes from the assumption in these studies that all the revenues from the carbon tax are returned to the economy by lump-sum payments to consumers. When they are returned by reducing employment taxes, many national and EU studies report increases for European countries of between 0 and 2% GDP by 2010 (IPCC 2001*c*).

As discussed in Section 2.4.1, carbon taxes have additional environmental benefits that are potentially so important that they may more than offset any estimated economic costs (OECD 2000). These benefits come from the reduction in emissions and social costs associated with the burning of fossil fuels, apart from the greenhouse gas emissions, e.g. SO_2, NO_x, small particles and noise. Taxation reduces these costs as a side effect. The GDP effects of a carbon tax should be qualified by these ancillary benefits, with many studies reporting ancillary benefits as a significant (e.g. from 20 to 100%) proportion of the cost estimates.

Studies on mitigation using worldwide carbon taxes over the next 100 years to achieve stabilisation of CO_2 concentrations have also reported GDP costs, subject to the same caveats as the estimates of the costs of Kyoto. **The average reduction in GDP below base across all models, baseline scenarios and stabilisation levels is 1.3% by 2100 (implying a negligible fall in the average growth rate from 2.300% a year to 2.299% a year).** The study with the highest cost reports 6.1% of GDP below base by 2100, also negligible in relation to the expected growth of GDP and the uncertainties in making such projections (Ekins & Barker 2001). The reason for these low estimates is that fossil fuels account for only 2–4% of GDP in most industrialised economies. Over the next 100 years, given the availability of alternatives and expected technical progress, it seems unlikely that replacing them with non-carbon-based fuels would cost much more than this share, and it may even cost much less.

4.2 Impacts on industrial sectors

The overall effects of a carbon tax on GDP, whether positive or negative, conceal large differences between sectors, such as the coal industry, the oil and gas industry, electricity, manufacturing, transportation and households. It is a feature of the sectoral effects that compared with the situation for potential gainers, the potential sectoral losers are easier to identify, and their losses are likely to be more immediate, more concentrated, and more certain. The potential sectoral gainers (apart from the renewables sector and perhaps the natural-gas sector) can only expect a small, diffused and rather uncertain gain, spread over a long period. Indeed many of those who may gain do not yet exist, being future generations and industries yet to develop. The coal and (in the long term) perhaps the oil industries are expected to lose substantial proportions of outputs relative to those in the baseline, depending on how quickly new technologies such as CO_2 sequestration or *in situ* gasification develop. Gas, which has the lowest carbon content per unit of useful energy of the main fossil fuels, is likely to benefit, depending on availability of supply and possibilities of substitution for other fossil fuels. Energy-intensive sectors, such as heavy chemicals, iron and steel, and mineral products, face higher costs, accelerated technical or organizational change, or loss of output (again relative to the baseline) depending on their energy use. **Other industries, including renewables, nuclear energy and services, can be expected to benefit as a result of their low carbon contents and from the availability of financial and other resources that would otherwise have been taken up in fossil fuel production.** They may also benefit from reductions in tax burdens, if the carbon tax revenues are recycled as reductions in employer or corporate or other taxes bearing on industry.

This is the general picture. The tax will also affect sectors through increased scrapping of carbon-using equipment, and more energy efficiency and technical progress. The effects on international competitiveness, a major obstacle to the introduction of a carbon tax, are considered below.

4.2.1 Increased scrapping

A change in relative prices caused by the imposition of a carbon tax might affect economic development by making existing capital equipment uneconomic, thereby bringing forward its scrapping date. This could be a major potential source of adjustment costs related to the tax. The least disruptive imposition of a carbon tax would be one introduced initially at a low level, with modest annual increases over a substantial, pre-announced period of time. This would allow responses to the tax to be synchronised with normal investment schedules. Models generally show that there is a significant increase in the tax rate required to meet, and the associated cost of meeting, a given target if the target date is brought closer or if action is delayed, or if the target entails cutting existing emissions rather than preventing future growth. However, increased scrapping can be highly beneficial to economies in some circumstances. The increased scrapping may lead to higher long-term growth that outweighs the short-term adjustment costs because the change in industrial structure and markets and the new equipment are sufficiently productive and innovative.

4.2.2 Improvements in energy efficiency

The energy market appears to be far from perfect. There is considerable evidence that substantial reductions in CO_2 emissions could be achieved at benefit rather than cost. The reductions are only partly achieved, simply because of various market failures, such as lack of information, inertia, excessive discount rates, and landlord–tenant differences in attitude to energy efficiency. A continuously increasing carbon tax, by providing a continuously increasing incentive to correct such failures, would result in substantial investments in energy efficiency and further innovation. This would provide support for reaching the energy efficiency targets proposed in the Performance and Innovation Unit[4] report (PIU 2001).

4.2.3 More technical change

In addition to encouraging the adoption of existing energy-efficiency technologies, rising carbon prices would also give a positive stimulus to the development of new energy-efficiency and non-fossil energy technologies. Such induced technology development may cause asymmetrical elasticities of energy demand (in general, falls in energy prices have not increased energy demand by as much as the preceding energy price increases reduced it). Technologies evolve in response to pressures, which may be the competitive forces of the market, or the demands of public policy.

4.3 International competitiveness

Competitiveness is ‘the ability to compete in international markets by industries or nations as depending on the prices and qualities of the goods and services they produce’. Price competitiveness is distinct from non-price competitiveness, which mainly depends on quality of products. Sectoral competitiveness refers to a particular industrial sector assuming that exchange rates are constant; national competitiveness is affected by the exchange rates.

If one country unilaterally introduces a carbon tax, there will be a loss of price competitiveness in carbon-intensive products. The tax raises costs of burning fossil fuels and hence the costs of producing exports. These exports would then lose price competitiveness, and hence the market share of the exposed industries falls; industries in other countries that do not face the increase in costs will take that market share, increasing their use of fossil fuels and leading to ‘carbon leakage’.

---

[4] Now part of the Strategy Unit.

However, the effects of unilateral action also depend on the use of the revenues from the tax. If they are returned to the economy by reductions in taxes that bear on sectoral competitiveness, such as taxes on employers, the initial loss of price competitiveness would be reduced, depending on each industry's use of fossil fuels and labour. Although energy-intensive industries may still lose out, there may be a *net increase* in price competitiveness of labour-intensive industries. If all the tax collected from exposed industries were to be recycled to those industries, in the form of a subsidy or support for carbon-saving research, development and investment, then their competitiveness may increase in relation to other industries. However, the extent of reductions in other taxes would be lower and the outcome may be less efficient.

Furthermore, there may also be an increase in more general non-price competitiveness. Three factors could give rise to such a result:

- the encouragement given to domestic industries specialising in CO_2 abatement technologies may lead them to develop international markets in these technologies or improve their ability to compete in these markets;
- any associated improvements (e.g. reduced traffic congestion or reduced emissions of other pollutants) caused by the carbon tax could boost the attractiveness of the country; and
- technological development and hence growth of exports may be stimulated by efforts to reduce CO_2 emissions. The scale of these improvements in non-competitiveness may be difficult to judge as it depends on the initial energy efficiency of the industries bearing the tax and the unexploited innovations available to them.

In macroeconomic terms, competitiveness (i.e. price and non-price competitiveness) is not necessarily reduced over the long-term by a substantial carbon tax. The outcome depends on the use of the extra revenues by the government and the response of governments and other economic agents to higher prices. If there is a reduction in labour or other costs of industries and an increase in energy-saving innovation and technology, then competitiveness may even increase. In addition, any overall loss in competitiveness of currency regions, such as the UK or the Eurozone (in relation to the rest of the world), would be compensated in the long term by an adjustment of the exchange rates. For exposed industries or firms, however, the effects may be serious. The problem is already evident in the new competition from heavy energy-using industries in Eastern Europe, which are located in countries with low environmental standards. This is a sensitive issue because World Trade Organisation rules do not allow the imposition of tariffs in these circumstances.

4.3.1 Competitiveness effects of carbon taxation

Some evidence of the price competitiveness effects comes from studies of the determinants of international trade. These studies are hard pressed to find significant relative price effects, and when they do so it is clear that changes in exchange rates, labour costs and even raw material prices are more important than changes in taxes on carbon or energy. If the national competitiveness of economies is considered, it is clear that high energy prices, brought about by high taxes or lack of domestic energy supplies, are no obstacle to industrialisation or rapid economic growth (witness the successes of Singapore and Hong Kong). Conversely, the availability of ample reserves of low-cost oil and gas, let alone coal, is not sufficient to provide a high degree of success in international trade (consider Nigeria and Iran).

Reviews of the effects of carbon taxation on international competitiveness (Ekins & Speck 1998; Barker & Johnstone 1998) show that the outcome for a particular sector will depend on how any tax revenue has been recycled, and whether the exchange rate has adjusted to compensate at the national level. The conclusions from these surveys are that the reported effects on international competitiveness are very small, and that at the firm and sector level, given well-designed policies, tax-based policies to achieve targets similar to those of the Kyoto Protocol will not produce a significant loss of competitiveness. These conclusions are confirmed by later studies (Ekins 2000), although in general the effects of environmental taxation in one country on sectors in other countries are not well covered by the literature.

The conclusion that environmental taxes need not result in unacceptable effects on industrial competitiveness would appear to be borne out by the experience of Denmark, which has a small, open economy, and which has been a pioneer in the area of environmental taxation. According to its Ministry of Economic Affairs: 'Danish experience through many years is that we have not damaged our competitiveness because of green taxes. In addition, we have developed new exports in the environmental area' (Kristensen 1996). The study of the Norwegian Green Tax Commission has also endorsed this conclusion: 'Reduced competitiveness of an individual industry is not necessarily a problem for the economy as a whole. … It is hardly possible to avoid loss of competitiveness and trade effects in individual sectors as a result of policy measures if a country has a more ambitious environmental policy than other countries or wishes to be an instigator in environmental policy. On the other hand, competitiveness and profitability will improve in other industries as a result of a revenue-neutral tax reform' (Norwegian Green Tax Commission 1996).

4.4 Carbon leakage

4.4.1 The extent of `carbon leakage'

Carbon leakage would occur if a country or trading block takes unilateral action to reduce CO_2 emissions, and this action results in higher emissions elsewhere in the world. Leakage takes place through two principal channels:

- Relocation of trade in manufactures. When a set of countries restricts emissions by imposing taxes (or instituting an emission permit regime) the relative cost of carbon-intensive production increases. This potentially shifts the comparative advantage of non-constrained economies towards the production of those goods that tend to be carbon-intensive, thus increasing emissions by changing the composition of world output *across* sectors.
- Substitution effects arising from a fall in oil prices. An emission tax or permit regime will also reduce the demand for oil, potentially lowering the world pre-tax price depending on the response of suppliers. This may increase the carbon intensity of production processes *within* individual sectors, depending on the fuel substitutability in individual economies.

There may, therefore, be increased emissions due to both sectoral composition and sectoral production processes. To some extent, these two effects may be counter-balanced by income effects if the coalition that imposes the tax experiences a significant fall in income and in its imports from the rest of the world. This fall in the rest of the world exports may then reduce its energy demand and its emissions, so offsetting any increase in emissions from the first two routes for carbon leakage.

One of the few studies for the industrialised countries listed in Annex 1 of the United Nations Framework Convention on Climate Change (see Appendix E) concludes that substantial cuts in emissions can be achieved with almost no leakage (Oliveira-Martins 1995). Indeed, far from there being leakage, some studies suggest that it seems likely that if economic activity is reduced as the carbon tax is introduced in the OECD area, then emissions in the rest of the world will fall ('negative leakage').

4.5 Methods of preventing loss of competitiveness and carbon leakage

Actual or perceived losses in international competitiveness and carbon leakage can be reduced by widening the area covered by the carbon tax to include more countries (e.g. the EU or Annex B of the Kyoto Protocol) or by special treatment of carbon-intensive sectors. The first method is preferable because it increases efficiency and reduces costs because mitigation can take place in the lowest cost countries. Exemption or other special treatment for carbon-intensive sectors is likely to be less efficient because the sectors tend to be among the larger emitters and they may have greater opportunities for low-cost mitigation than other sectors, through new processes and products as well as higher energy efficiency.

4.5.1 Widening the area covered by the carbon tax

This reduces the required rate of tax, lowers costs and reduces any loss of price competitiveness and any carbon leakage. At the limit, if all countries in the world applied the same tax rate then the lowest cost mitigation would be achieved with no loss of competitiveness, except that against lower-carbon-intensive sectors, which is a necessary condition of efficiency. The loss of price competitiveness becomes less important as the number of countries imposing the tax or participating in the auctioned permit scheme increases, especially if they are close trading partners. The cost of trading with the rest of the world increases relative to the cost of the carbon tax as the number of close trading partners in the group increases, so any loss of price competitiveness from a carbon tax is reduced. In addition, if the exchange rates between groups of countries are flexible, any overall loss in price competitiveness can be compensated by an exchange rate fall.

4.5.2 Special treatment: the use of exemptions

The exclusion of certain industries from coverage of the tax because of competitiveness reduces the effectiveness of the tax in achieving its objective of reducing greenhouse gas emissions. Carbon taxation is intended to bear most heavily on goods and services that release most CO_2 in their production, yet on current UK plans some of the most energy-intensive industries are to be excluded. Clearly, this will limit the impact of the tax on energy consumption and CO_2 emissions, but there are two additional problems. The first is that the industries that do not pay the tax will improve their competitive position compared with those industries that do pay. There will therefore be some switching of demand towards the products of energy-intensive industries, precisely the reaction that such a tax should avoid. The other problem is that companies that find themselves paying the tax will try to be reclassified as exempt or eligible for rebates if at all possible, thereby further limiting the impact.

4.5.3 Special treatment: incentives for innovation

A more promising way of supporting the exposed industries is to use some of the revenues from the tax to subsidise them, particularly if the subsidy takes the form of incentives for low-carbon innovation. Any loss in price competitiveness may then be compensated by an increase in non-price competitiveness, which is likely to be more conducive for long-term economic growth. The allocation of some of the revenues from the Climate

Change Levy in the UK to a Carbon Trust is a step in this direction, but it would be far more effective if the Levy was in proportion to carbon content, if it covered exposed industries at the full rate, and if the extra revenues from these industries were all available to them for low-carbon processes and products.

4.5.4 Special treatment: allocation of CO_2 emission permits to CO_2 emitters

The carbon tax with subsidies to carbon-intensive sectors is a poor political instrument for direct compensation of industries, as it makes any required transfer of revenues from tax-payer to polluting producer obvious and perhaps unacceptable. The creation of a market in emission permits for large fixed-point emitters (where transaction costs are likely to be low) appears to be an attractive alternative. The permits can be freely allocated to the exposed industries or indeed to all CO_2 emitters on the basis of past CO_2 emissions, assuming the cost of participation is sufficiently low in relation to the benefits. However, two problems are associated with free allocation, if applied other than for a strictly limited period, in order to initiate a scheme. The first problem is that it appears inequitable by rewarding those who have done least to curb past emissions and it contradicts the Polluter Pays Principle. The second is that it may restrict entry into the market and slow down innovation and change.

To initiate a scheme, a proportion of the permits required for a particular CO_2 target could be directly allocated, the remaining portion being auctioned. The proportion of free permit allocations would be reduced over a period, perhaps at different rates for different industries so as to help carbon-intensive sectors to adjust to the higher prices for carbon-based fuels. Eventually all permits would be acquired by auction.

4.6 Conclusions

The effects of a carbon tax on economic growth, employment and indeed inflation depend critically on what is done with the revenues. As this analysis shows the impact of a carbon tax on GDP would be small, ranging between 1.3% and 6.1% below baseline by 2100. The macroeconomic effects will be minimised if the tax replaces another expenditure tax, such as VAT, with the tax being gradually phased in to the required level. The problems of loss of international competitiveness of exposed industries would be considerably reduced if the economic instrument was extended across the EU. Large emitters facing a new tax on their emissions could be initially shielded by introducing an emissions permit scheme with some initial free allocation of permits, tapering to zero over a period of time. This would allow adjustment of the industry to the higher carbon-based fuel costs. We will address the impact a tax would have on other vulnerable sectors, such as households with low incomes and high fossil fuel bills, in Chapter 7.

5 Impact of economic instruments on the viability of low carbon technologies and on the security of supply

5.1 Introduction

Reducing the use of fossil fuel and replacing it by non-fossil alternatives is clearly a desirable aim. The problem is that most of the alternative forms of energy cannot compete with the cheapest fossil fuel – currently natural gas – particularly when the latter's costs are not yet internalised. A carbon tax (or auctioned permits) would move the balance in favour of the renewables. Given a high-enough level of taxation it would lead to the ultimate abandonment of fossil fuels and indeed this is what some analyses suggest might be needed by the end of this century[1].

For the present, we are more immediately concerned with the impact of a 'small' carbon tax. By small we imply a tax that, initially, will change the cost of electricity by not more than 1 pence / kilowatt hour (p/kWh) – less than the variability of electricity costs between various countries in Europe. This level of tax would also imply an increase price of petrol to the motorist of about 6p/litre. The difficulty in assessing the impact of a carbon tax lies in the fact that the technologies involved are in most cases not fully developed, and have not been tested in full-scale demonstrations. Nevertheless, and aware of the variability, we shall attempt to gauge the extent by which such a carbon tax could affect the prospects of non-fossil fuel energy.

Global climate change is one concern. Security of supply is another. Because later on in this decade a growing portion of our fossil fuel will be imported, our future ability to purchase these fuels at an economic price is a further concern. We discuss the impact of economic instruments on this issue in section 5.3.

5.2 Impact of a carbon tax on the viability of various sources of renewable energies

5.2.1 Wind energy

The total installed capacity worldwide is 24 GW. In the UK the figure is currently 600 MW and in the EU 9.7 GW. It is important to appreciate that these are *peak* powers, i.e. the power generated under optimal conditions. The power output *averaged over a year* is about one third of these figures. For 5% of the time the power (averaged over all UK wind farms) would be less than 10% of the total installed peak capacity (RAEng 2002).

In calculating the cost of wind power one needs to count the direct cost as well as the cost of intermittency. Providing conventional standby equipment would become important if wind provided a large proportion of the total energy supply. This cost has been estimated in several studies. A working document submitted for the Performance and Innovation Unit report estimates 0.1 p/kWh for a wind component of up to 10% and 0.2 p/kWh for a penetration of up to 20% (Milborrow 2001). However, it is important to appreciate that these estimates are based on models that in themselves contain parameters which are not easy to estimate.

In addition to the direct intermittency cost, the current New Electricity Trading Arrangement (NETA) system for electricity purchase militates against supplies that cannot be readily predicted. NETA may be modified to make them less onerous in this regard. One is also looking towards steady improvements in the ability to forecast wind conditions, which for short time scales are already very reliable.

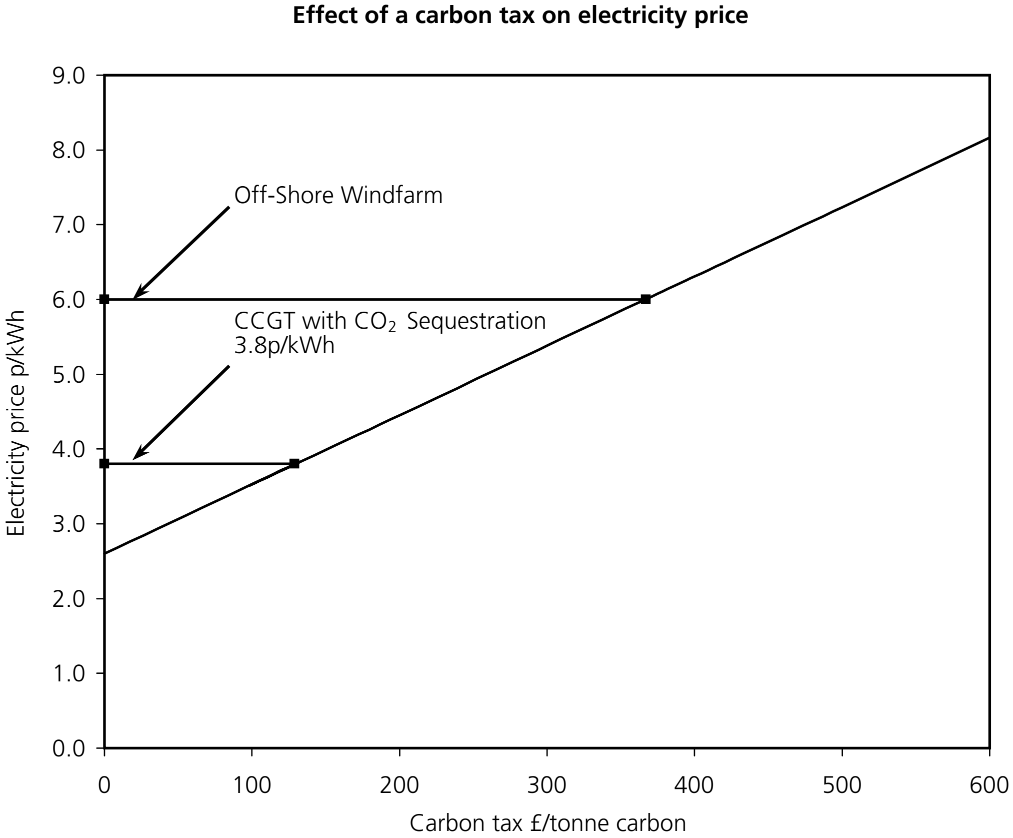
Taking just the direct costs it would appear that for on-shore wind farms the cost of electricity produced at the best sites could be as low as 2.5 p/kWh. Ignoring the intermittency problem, on-shore wind power is within range of being economically viable. The Renewable Energy Obligation (reviewed in Appendix C) makes it economic for electricity suppliers to purchase wind power at up to 3 p/kWh over their own generation costs. If one were instead to rely solely on the impact of a carbon tax, we conclude that a tax equivalent to 1p/kWh (approximately equivalent to £100/tC) would suffice to make on-shore wind power viable. However, it is recognised that the scope of on-shore wind power may continue to be limited by opposition from planners, or the local community (or both).

Offshore wind power, although not totally free from local community or planner objections, has much less of a problem in this regard. However, the additional cost of going off-shore is substantial. Current estimates for the total capital cost run at £1000/kW. Assuming a discount rate of 10%, a lifetime of 20 years and an average output of one third of maximum capacity, one arrives at a capital cost of 4.0 p/kWh. Adding a component for the additional connection costs to the grid, and some maintenance costs, leads to a figure in the range 5.5–6 p/kWh, in line with those quoted in the Performance

---

[1] Indeed there are strong arguments that complex hydrocarbon mixtures are much more valuable as feedstocks for the plastic and pharmaceutical industries than as a fuel.

Figure 1. The inclined line on the figure shows the effect of a carbon tax on the electricity price for a state-of-the-art Combined Cycle Gas Turbine (CCGT) plant using gas at a price of 0.75 p/kWh. The plant is assumed to run at an efficiency of 54% and to have a capital cost of £450/kW. The untaxed price of electricity generation is then estimated to be 2.6 p/kWh. The electricity price for the same plant with substantial sequestration of CO_2 is indicated and is equivalent to imposition of a carbon tax of £128/tC on the basic plant (Horlock 1995; Chiesa & Consonni 2000).



and Innovation Unit report (PIU 2002). We show this result, again relative to Combined Cycle Gas Turbine (CCGT) generation costs, as a function of a carbon tax in Figure 1. This suggests that to make off-shore wind viable – in the absence of other government subsidies – would require a carbon tax equivalent to 3–4 p/kWh. This result is of course highly sensitive to the assumed discount rate and equipment lifetime. Capital costs are dominated by those of the turbines and towers, costs that will certainly decrease with experience. It is evident that a tax to reach this level would have to be gradually introduced over an extended period.

Currently several off-shore wind farms are planned (BWEA 2000) and are intended to run on a commercial basis. The renewable obligation certificates provide a support of up to 3 p/kWh. In addition, the government is providing subsidies to defray some of the capital costs. One should regard these developments as large-scale demonstrations, generating the needed experience. Expressing the costs in terms of a carbon tax, however, reveals that significant cost reduction will be needed if off-shore wind power is to make a contribution in accord with government aspirations (PIU 2001).

5.2.2 Carbon sequestration

The idea of carbon sequestration (Royal Society and Royal Acadamy of Engineering 1999) is simple and powerful: segregate the CO_2 from the fossil-fuel combustion products, and then deposit it in a place where it will remain safely for a substantial period[2]. However, there are concerns over measurement and these are addressed in Section 6.5.

In electricity generation, gas-fired power stations are reaching maximum thermal efficiency – there are fundamental reasons for not anticipating further major advances. But the emission of CO_2 from such plants could be reduced virtually to zero if the plant was designed to *sequester carbon*, and if confidence could be established that the CO_2 could be disposed of in, for example, the emptying oil fields of the North Sea**.**

---

[2] One would seek latency periods of not less than a century.

The technology for separating CO_2 from the flue gases exists. The key question is the assessment of the costs involved. Figure 1 shows how this would work for a state of the art Combined Cycled Gas Turbine Plant.

For the assumed figures such plants achieve an overall efficiency of 54%. For a capital cost of £450/kW this leads to a cost of electricity production of 2.6 p/kWh. Sequestration of the CO_2 involves additional plant and processing costs and also reduces the overall thermal efficiency of the plant. An estimate of costs suggest that the price of electricity would rise to 3.8 p/kWh. Any level of tax in excess of 1p/kWh – equivalent in this case to £110/tonne of carbon emitted – would make sequestration viable. However, it will need large-scale demonstrations before one could place full confidence in the level of tax required. A great deal of work is underway in several different countries and is likely to lead to progressive reduction of sequestration costs.

5.2.3 Solar thermal energy

Solar-thermal concentrating systems such as the 354 MW system in the Mojave Desert or the new 15 MW Solar Tres power tower planned by Spain focus direct sunlight onto a receiver. Currently the costs are high – estimated at 13 p/kWh for the Solar Tres system. Costs are expected to decrease as experience is gained. However, it seems unlikely that a carbon tax at levels under consideration could bring such systems[3] into the realm of commercial viability.

However, flat-plate solar collectors for water heating are economic in sunnier climates. Even in some parts of the UK they have been used for domestic hot water supply. Typically the payback period in the UK for such systems is 20 years (STA 2002). A modest carbon tax would provide some encouragement for extending the usage.

5.2.4 Photovoltaic cells

Currently available single-crystal silicon cells can convert sunlight into electricity with an efficiency that in the most advanced models can reach 24%. Standard commercial cells will have efficiencies nearer 16%. The cost of electricity produced by such modules is high, around 40 p/kWh in areas with low incoming solar energy such as Western Europe and 15 p/kWh in Southern Europe, the USA and much of the developing world. Despite these high prices, photovoltaic modules are economically viable for applications where there is no easy access to the grid[4].

However, as a direct competitive source of electricity, photovoltaics are currently well out of range. A carbon tax would help the growth of remote photovoltaic usage, where diesel power would otherwise be used, and the introduction of building-integrated photovoltaic cells, where the cost of conventional building cladding is avoided. For other uses the impact of a realistic carbon tax would be minimal.

That is the current situation. However, photovoltaic technology is an exciting area of materials science and is advancing rapidly. There are advances in crystalline silicon-cell technology. Tandem cells based on III–V semiconductors, in which several single-junction cells of decreasing bandgap are stacked one below the other, are capable of substantially higher efficiencies of around 30%. There is the possible development of higher-performance amorphous silicon cells, the use of other semiconductor materials, the dye-sensitised nanocrystalline TiO_2 Graetzel cell, and polymer co-blend photovoltaic cells (Peterson & Fies 2002). It would be wrong to write photovoltaics off as a future source, and when it gets closer to grid electricity prices a carbon tax would of course enhance its usage.

5.2.5 Nuclear energy

Nuclear power currently supplies about a quarter of the UK's electricity needs. On present retirement plans and assuming no new build, this contribution will fall rapidly in the next decade and reach zero in about 2035 (Royal Society and the Royal Academy of Engineering 1999). The choice is either to embark on building new reactors, or to evolve a strategy for building non-emitting replacement sources. We shall not revisit the complex set of decisions involved, except that a new-build policy would require the following essential ingredients:

- Political will by government.
- Long-term strategy involving the building of a series of near-identical reactors.
- Recasting the planning/licensing procedures so that they can be completed in months rather than years.
- Evolution of a strategy for waste disposal, (which would be needed whether a new-build strategy is implemented or not).
- Understanding and mitigation of the risks of terrorist activity.

The industry has advanced plans for reactors that are safer, less expensive and can be built faster than current reactors[5]. The industry estimate – given a positive resolution of the above five points – is that the costs would be close to those currently achieved by Combined Cycled Gas Turbine generation. If this is so, a carbon tax of 1p/kWh would suffice to make nuclear

---

[3] One would seek latency periods of not less than a century.

[4] Or where there is a perceived public relations benefit in signalling the 'green' intention of a country or a company.

[5] We would question the judgment in the PIU report that 'Nuclear power is a mature technology' implying that advances would be only incremental.

energy competitive. The current Climate Change Levy is applied to nuclear energy even though it is emission-free.

In the longer term there remains the hope of the ultimate success of fusion energy (Rodgers 2002). If it could be developed to a commercially viable stage it would be immensely important – possibly **the** answer to the energy problem. It is currently too far from this stage for questions on the impact of a carbon tax to be relevant.

5.2.6 Hydrogen and fuel cells.

Hydrogen is a potentially important energy vector. It could be generated using renewable energy sources – e.g. wind energy[6] or nuclear energy. There are now real prospects for the wider application of fuel cells. Recent improvements in the power density and output of proton exchange membrane fuel cells have now positioned them as prime candidates for fuel cell cars – the fuel being hydrogen. The desirability of cars in urban centres that emit nothing worse than water is evident. In Los Angeles, recent legislation will require cars be non-emitting[7] and it is likely that other cities will follow this trend. There are many technical and logistical problems to be solved, and it is not yet possible to make a realistic estimate of the cost. Clearly a carbon tax will provide additional support for this development.

5.2.7 Wave and tidal energy

In principle there is a vast amount of energy in the form of waves and tides. Moving water has an energy density nearly two orders of magnitude above that of air, and the power can be extracted with systems that are far simpler than those already close to perfection for wind. Tides are highly predictable and in many situations the phase of a tide changes as one goes along a coastline, thus allowing the peak of the nominally sinusoidal power distribution to be greatly widened. Tidal systems can be made to be completely unobtrusive and noise-free. There is intensive work devoted to harvesting this energy source. Costs have been modelled and come into the range of 3–5 p/kWh. If these estimates can be confirmed, a carbon tax of 1p/kWh would suffice to make a system viable at least at the lower cost estimate range.

Wave energy in favourable locations can reach over 70 kW per metre. Very many ingenious schemes for exploiting this energy have been devised (Thorpe 2002). The engineering problems are formidable, and the chance of evolving systems that could compete with grid electricity prices seems remote though applications in isolated areas may be viable much sooner. It is hard to estimate ultimate costs, until there have been some major demonstrators for each of the competing technologies.

5.2.8 Energy crops and biomass

Energy Crops are grown specifically for their energy content. The CO_2 produced when the energy crops are burned is largely taken up by the growth of the next crop. Net emission then arises only from the fuel used in planting, harvesting and transport. The 'energy ratio' is a measure of the energy generated to the energy required for these purposes.

Biomass is organic material derived from plant or animal life and includes wood, wood waste, arable crops, grasses and animal manure, all of which can be burned as fuels. Biomass plays an important role in the world's energy economy, currently supplying about 14% of global final energy consumption and about 25% in developing countries.

Wood is the largest store and source of biomass energy. Fuel wood is often gathered and burned unsustainably but trees such as willow and poplar can be grown as sustainable energy crops in so-called short rotation coppice. Sweden leads the EU in the use of wood as fuel, with some 18,000 hectares[8] under this regime. The economic viability is aided by the taxation regime, which obtains in Sweden (WEC 2002).

The economics of electricity generation become more favourable where the energy crops are located in the vicinity of an existing conventional plant and the biomass is used in conjunction with coal or gas. Rather than direct combustion there are more advanced technologies based on gasification or pyrolysis, which may be the means of further cost reduction. In the fourth 'non-fossil fuel obligation' round in 1997 offer prices of 5.5 p/kWh were realised (DTI 1997). A study for the future prospects of these more advanced technologies concludes that for a 20 MW plant the price could eventually drop to 4–5 p/kWh (Toft & Bridgwater 1997). A more recent study by Future Energy Solutions, AEA Technology, predicts that by 2025 costs could be in the range 3–4.5 p/kWh (IAG 2002).

The total biomass power in the UK is currently 200 MW. Some of the demonstrator projects currently planned will need to have run for several years before the accuracy of these predictions can be tested. However, as an interim conclusion, a carbon tax of the order of 2 p/kWh might suffice to make biomass power economic without the help of additional subsidies.

---

[6] This would in fact overcome a major problem in grid-connected wind electricity generation – the problem of the occasional day with virtually no wind power.

[7] Though the motivation is reduction of NO_x and particulates rather than CO_2.

[8] One hectare = 10,000m^2

5.3 Impact of economic instruments on the security of supply

The UK will be importing an increasing portion of its primary fuels in this and the next decade. By 2020 more than half of the country's gas and oil will need to be imported. There are political and economic risks attending this situation, which are not readily countered by a liberalised market economy – they come clearly under governmental responsibility.

Economic instruments are advocated to internalise the costs of carbon emission, and to achieve a reduction in those emissions at minimum cost. They are not primarily designed to address the problem of security of supply. However, adopting a regime of economic instruments – whether a carbon tax or auctionable, tradable permits – would also have a beneficial impact on the security of supply.

Economic instruments are designed to make fossil fuel power more expensive relative to the alternatives of conservation and carbon-free sources of energy. They will bend the market in a direction that will reduce reliance on imports and hence enhance the security of supply. Is this influence likely to be large or small? It depends, of course, on the level of carbon tax envisaged. For now, we shall keep a tax of 1p/kWh in mind, with an expectation that this level would rise progressively as we move towards the stricter emission requirement needed by 2050. As we have seen in previous sections a carbon tax of 1p/kWh is likely to have a significant positive effect on the development of wind, wave, tidal and nuclear energy, and carbon sequestration technology. It would also provide significant additional inducements for all forms of energy conservation. We conclude that even at 1p/kWh[9], a modest carbon tax could make a contribution to the viability of non-fossil fuel energy, and hence reduce reliance on imported sources. An increasing level of carbon tax, which is the likely situation over the next few decades, would further extend this improvement to security of supply.

---

[9] And we repeat, that this is less than the variability of electricity prices between various EU countries

6 Measurement of emissions

6.1 Estimating national emissions

Signatories to the Kyoto Protocol are required to submit a national inventory of greenhouse gas emissions. Table 2 shows the latest UK submission of CO_2 emissions. National inventories can be generated either from top-down or from bottom-up calculations. The top-down method, such as the IPCC Reference Approach (IPCC 1996), estimates emissions by deducting usage and storage data (including storage in products and sequestration) from known carbon inputs of primary fuels e.g. crude oil. Because CO_2 emissions are largely determined by the carbon content of a fuel, emissions can readily be estimated from the consumption of each primary fuel, as follows:

Fuel Consumption = Production + Imports – Exports – Stock change – Fuel used in international transport[1].

A bottom-up method uses detailed operational data and requires an understanding of fuel consumption and industrial processes at a company or sector level. The UK inventory data, which is submitted to the IPCC, is based on a bottom-up approach. As Table 2 shows, **by far the most significant source of CO_2 arises from the combustion of fossil fuels, which accounts for 96% of the UK annual emissions**. The rest are derived from numerous smaller, but significant activities, in particular cement production and agricultural practices.

6.2 Measurement methods

Measurement of CO_2 emissions can be effected either directly from the source, such as monitoring CO_2 in the flue gases, or indirectly using proxy data. Direct measurement techniques are well established[2] but are

*Table 2. UK submission to IPCC in 1999 based on bottom-up calculations. *Positive values indicate an increase in emissions since 1990. Negative emissions indicate natural carbon sinks such as forests where CO_2 is reduced and stored in organic matter (DETR 2001).*

Emission sources for CO_2 in UK	MtC	Percentage of 1999 emissions	Percentage change 1990/99*
Energy industries	48.8	34	–21
Manufacturing industries and construction	24.2	17	–6
Transport	33.2	23	4
Other sectors (fuel combustion)	32.0	22	5
Other (fuel combustion)	0.9	1	–40
Total fuel combustion (sectoral approach)	139.1	96	–8
Solid fuels	0.6	0.4	–25
Oil and natural gas	1.6	1	–36
Total fugitive emissions from fuels	2.2	2	–33
Mineral products incl. cement production	2.5	2	–4
Chemical industry	0.3	0.2	–18
Metal production	0.9	1	1
Total industrial processes	3.7	3	–5
Changes in forest and other woody biomass stocks	–2.2	–2	11
CO_2 emissions and removals from soil	2.8	2	–22
Other (land–use change and forestry)	0.7	0.5	–11
Total land–use change and forestry	1.3	1	–46
National total	**145.0**	**100%**	**–9%**

---

[1] Proportion of emissions from fuel used in global air and marine transport that can be attributed to the UK.

[2] For flue gases, there is a range of available techniques. Classical 'wet chemistry' techniques (e.g., absorption of CO_2 in potassium hydroxide solution in the classical Orsat apparatus) are described in British Standards (see for instance BS1756-2:1971) and, of course, methods such as gas chromatography can also be employed in this case.

rarely used and are done mainly for verification purposes by bodies such as the Environment Agency for assuring compliance with Integrated Pollution Prevention and Control regulations. Indirect measurement requires identification of source of emissions, an understanding of the process involved, and allocation of a proxy measure of activity that can then be converted to provide the amount of emission. Each emission process, whether combustion or chemical reaction, requires a protocol for calculating the actual emissions. For combustion these are based on simple emission factors that convert the calorific value[3] of any one type of fuel to kilograms of CO_2 emitted. Similarly, emissions from other processes, e.g. chemical processes, are easily derived.

The IPCC have defined standard international protocols and emission factors for all greenhouse gases. The IPCC do, however, recognise that there are variations in the fuels and processes, e.g. chemical processes, and the standards should be used as default values when more accurate data are not available. The UK guidelines (DEFRA 2001) for participants in the UK Emissions Trading Scheme (UKETS), were designed to be compatible with the IPCC standards, but have been modified to account for national variation. The initial set of protocols only cover the major processes including fossil-fuel combustion and industrial processes such as clinker production for cement manufacture, lime production, metal production and waste incineration. Other protocols are being established, but owing to the wide variation in processes and plant, site-specific data will provide a more accurate measure of the emissions. In line with IPCC recommendations, companies are invited to submit protocols that they can use subject to independent verification. It should, however, be emphasised that because 96% of the emissions are directly attributable to fossil-fuel combustion, the detailed protocols relate to what is in essence a very minor part of the measurement task.

6.3 Sources of error

Statistical errors are inevitable when handling data and measuring materials, and estimates can be made for the size of these margins. What is harder to estimate is the size of errors from implementation of the protocols. The IPCC provides clear guidelines identifying where these errors in calculating greenhouse gas emissions may occur (IPCC 1996).

One of the main sources of error occurs when carbon compounds other than CO_2 are derived from the process or combustion. A top-down approach, for simplification, assumes that all the carbon in the fuels is converted into CO_2 by combustion, ignoring other compounds such as CO and CH_4. It also treats all processes as combustion, requiring corrections to be made for chemical processes. Overestimation of the CO_2 emissions and duplication of greenhouse gas emissions may occur when inventories for other gases are drawn up.

Carbon may also be stored in the products, for example plastics. A top-down calculation, by assuming that all fuels are burnt and not accounting for the type of process involved, will ignore carbon that remains in the plastic product. Corrections can be made to account for this but they must account for emissions that come from the final disposal, which may occur in a different emissions-accounting period. Final disposal may be by incineration, leading to immediate CO_2 release, or the product may be recycled or landfilled, in which case there may be little or no decay.

In emissions trading, clear boundaries of responsibility for emissions are required to prevent double counting. In the UKETS scheme a company is only liable for its own generation and import of energy (including heat and steam) but not any of its exports. This is particularly important in refineries and chemical complexes where several companies on the same site will generate heat or steam and sell it to neighbours.

6.4 Point of application

Technically, a top-down or bottom-up approach could be used for calculating emissions and applying a carbon tax and tradable permits. A top-down system, as devised by the IPCC Reference Approach, would mean applying the tax upstream to primary fuels before it reaches the refinery. A bottom-up system, as used to calculate the UK CO_2 inventory, would apply the tax downstream at the point of supply to the individual companies and would be based on the amount each consumes. For tradable permits, the DEFRA guidelines for the UKETS adopt a bottom-up approach where companies determine their greenhouse gas emissions for particular activities. By relating their emissions to the flow of materials, changes are easily measured and translated to permits. Alternatively, if the carbon content of a fuel was determined further upstream, then companies, when buying fuel, would also buy a permit for the related emissions.

Comparing the Reference Approach estimates of CO_2 emissions and the UK inventory bottom-up calculations shows only a small difference of between 2 and 5%. The main explanations for the discrepancy have been addressed earlier but they are summarised below (AEA Technology 2002).

---

[3] Calorific value of any one fuel is closely related to its carbon content.

- Conversion of carbon to non-CO_2 forms e.g. CH_4 and CO.
- Statistical differences between the two methods. A significant proportion of the discrepancies will be from the measurement of liquid fuel volumes.
- The top-down approach treats all non-energy use of fuels as if it were combustion. Deductions will be required to account for storage of carbon in products.
- Storage of carbon in the product may be released at a later date.
- The carbon content of primary fuels is likely to vary more than secondary fuels. A bottom-up approach is based on the consumption of secondary fuels, where the carbon content is known with greater accuracy.

Because of this small difference there is no technical reason why either permits or taxes cannot be applied upstream. There is an attractive simplicity in basing the collection of the tax predominantly on the sale of primary fuels. The individual company and the individual consumer will pay the charge through this increased price of the fuels they use. For a power generator who includes provision for carbon sequestration, the amount of carbon that is not emitted would attract the appropriate credit.

6.5 CO_2 sequestration

Sequestration and storage of CO_2 either in biomass, e.g. forests, or physically, e.g. in extinct oil wells or in liquid form deposited at the bottom of a deep (greater than 3 km) ocean, have been proposed as methods to reduce CO_2 emissions. The key concerns about this method of disposing of CO_2 emissions are the measurement of quantities captured, how much can be stored by this method, and how permanent and secure is the storage.

Although there are technological considerations about physical disposal for each of the different types of available repository,[4] a major concern is the ability to measure accurately the amount of CO_2 captured. The amount of CO_2 sequestered from a power station can be measured either by changes in the flue gas concentrations or by the volume of liquid removed. Technologically both are feasible though care would be needed when measuring volumes captured as any gaseous CO_2 will complicate the measurement. Uncertainty surrounds the permanence of physical disposal and further research is needed (Royal Society and the Royal Academy of Engineering 1999).

Parties to the Kyoto Protocol are encouraged to employ policies that enhance the capacity of forests and agricultural land to absorb CO_2 emissions. Countries are also allowed to count certain land carbon-sink projects (at home and abroad) against a percentage of their emission reduction requirements under the Protocol. Trading in carbon credits from land carbon sinks already exists and accounts for most international trading that has occurred, even before ratification of the Kyoto Protocol.

The role of land carbon sinks was considered in a report published by the Royal Society in July 2001 (Royal Society 2001). The report recognised that there is still considerable uncertainty in the scientific understanding of the causes, magnitude and permanence of the land carbon sink. It also raised concerns about the techniques that will be required to monitor, quantify and verify land carbon sinks established under the Kyoto Protocol, and it stated that an increase in the accuracy of these techniques is urgently needed before land carbon sinks are used to any significant extent.

Given these uncertainties, the Royal Society recommended that projects designed to enhance land carbon sinks should not be allowed to divert financial and political resources away from the restructuring of energy generation and use (e.g. increased use of renewable energy), technological innovation (e.g. increased fuel efficiency, sequestration of carbon at source) and technology transfer to less-developed countries.

6.6 Conclusions

The amount of CO_2 emitted can be accurately measured using several internationally recognised methodologies. It is recognised that discrepancies can occur but these appear to be small and can be clearly attributed and adjusted. Accurate measurement and verification of emissions is essential for providing a basis for economic instruments. Crucial to measurement is the need for a common methodology. Not only does it need to be accurate and practical, it also has to be internationally recognised. This will assist in future international harmonisation and the implementation of Kyoto mechanisms, such as international emissions trading. We believe that the guidelines laid down by the IPCC provide a basis for international agreement.

Although there are areas where errors can occur we recognise that the established protocols and international standards that have been developed are capable of providing an accurate measure of CO_2 emissions and therefore provide a base for economic instruments. We are, however, sceptical about the ability to measure accurately the quantities of carbon captured by land-based carbon sinks, such as forests.

---

[4] For example: containment in oil wells, either exhausted or used to facilitate oil extraction; injection of liquid CO_2 in to deep submarine saline aquifers.

7 Political and social obstacles to the use of economic instruments

In the past decade the UK has introduced several market-based instruments into environmental policy. Those policy instruments have been applied most effectively in the waste sector (landfill tax, recycling credits, tradable packaging recovery notes). The likely effectiveness of measures applied to the energy sector – the Climate Change Levy and associated energy efficiency agreements, the Renewable Energy Obligation, and the emissions trading scheme – is more controversial.

These market-based instruments must, however, be understood against a background dominated by regulation based on *technology-based* standards, where one seeks to control the level of emissions by insisting on the adoption of the 'best available technology' (BAT) – a phrase that leaves room for much ingenuity in interpretation. It is not helped by the use of another term: 'best available technology not entailing excessive cost' (BATNEEC).

The evidence that these command-and-control techniques have not fared well in sustaining and growing the economies of nations is overwhelming. Their application to the complex of the energy economy cannot be expected to yield any greater measure of success in minimising greenhouse gas emissions at minimum cost. Among the many problems faced in attempting to run the energy economy by regulation, there is the fact that those who devise such regulations are subject to many considerations of social policy and of pressure from various sectors of the economy. A key advantage of controlling greenhouse gas emissions by economic instruments is that it separates this particular aim from the myriad of other societal concerns. As just one example, a regulator controlling the electricity industry would have the reduction of the cost of electricity as a primary objective. Yet to encourage the reduction of CO_2 emission, one would take measures that would increase the price of electricity.

In Chapter 2 we considered the various types of economic instrument that could be brought to bear on the problem. Whether based on permits (with tradable options) or on a straight carbon tax, their essential role is to put a price on the emission of CO_2. For simplicity, we develop the following discussion in terms of a carbon tax while noting that the development of our theme would not differ greatly if one of the related forms of economic instrument were to be adopted. The form of carbon tax we shall bear in mind is one that is applied *universally*: to electricity generation, and industrial, domestic and transport uses of energy. It is a tax that would predominantly be collected up-stream, i.e. would be imposed on fuel depending on its carbon content. Because by far the greater part of greenhouse gas emission stems from the burning of fossil fuel, the collection of the tax would be relatively simple.

The tax revenue could be used for various purposes. Some suggestions have already been highlighted in Chapter 4, including the possibility that if appropriately used it could *enhance* national competitiveness. An interesting suggestion from Australia is that it could be used to increase individual pension resources (Hamilton 2002). This is not an issue that we pursue further, other than to note that the acceptability of a carbon tax would probably be improved if the use of the taxation income could be manifest rather than disappearing into the general exchequer.

Although economists differ on the precise manner of imposition of economic instruments, there is a clear consensus among them that the economic instrument route is by far the best and most economical for achieving whatever needs to be done to reduce greenhouse gas emission. Yet evidently there is no such unanimity in industry, government and other interested groups, a fact also evident in some of the communications we have received in response to our call for evidence and from views expressed at the seminar (see Appendixes A and B). In this chapter we touch on several reasons for these reservations, and how they might be overcome.

7.1 Corporate distrust

New taxes are not immediately welcomed by business any more so than by individuals. For an energy tax, there is also the specific concern that what may start out as an environmental tax could evolve into a general revenue-raising tax, with attendant uncertainty about future levels and scope. Uncertainty inhibits investment decisions.

Added to this legitimate concern there is also a more diffuse feeling that such taxes leave less scope for negotiation than is normal for conventional technology-based policies. There is less room for seeking favourable terms from the legislation or from its implementation (or both) through discussions with regulatory agencies.

Several measures are available to minimise the reservations expressed by some sectors of the business community: a clear environmental and economic justification for the tax; a tax starting at a low level but with some indication of the intended sequence of future increases. Introducing an economic instrument such as a carbon tax to replace the Climate Change Levy might also enhance its acceptability.

7.2 Loss of competitiveness

Probably the major concern contributing to reluctance to the introduction of economic instruments is the fear that such measures will harm international competitiveness. Economic analysis, as we have already noted in Chapter 4, demonstrates clearly that the aggregate compliance cost of economic instruments is less than that of alternative command-and-control measures. The perceived greater cost burden of economic instruments is an illusion, largely arising from the transparency of the measure[1].

The key concerns are first the possibility of reduced performance of net exports of goods affected by the economic instrument, and second the possibility of companies relocating to countries with less onerous economic instruments. In fact, net exports have not been found to be significantly affected by regulations (Jaffe *et al* 1995; Sorsa 1994). Corporations' location decisions are generally unaffected by environmental costs, primarily because they tend to be a small fraction of total costs (Jaffe *et al*. 1995; Eskeland & Harrison 1997). Firms do not invest more abroad in pollution-intensive industries to compensate for higher environmental costs at home (Eskeland & Harrison 1997; World Bank 1999). Most studies of productivity effects have found modest adverse effects, but it is noteworthy that even those effects tend to reflect the adoption of traditional regulatory policies rather than economic instrument-based policies.

This brief overview suggests that environmental policy, whatever form it takes, would have little or no impact on competitiveness. Concern over a loss of competitiveness has been seen as the major obstacle to reaching international accord. More roundabout impacts via productivity seem detectable at first sight, but the use of traditional measures of output, rather than measures incorporating the environmental benefit of the regulation, makes these findings suspect. None the less, what matters for policy is the *political perception* of these issues. Business is frequently and firmly of the view that regulations divert significant productive resources away from 'output' and towards 'environment'. The resulting lobbies reflect this view. As results of empirical studies are more widely disseminated we hope that the problem of reaching international agreements will be significantly eased.

7.3 The social impact of economic instruments

Impacts of economic instruments on socially disadvantaged groups define a second major concern of government. Economic instruments, which involve environmental taxes, are widely perceived as being regressive, i.e. the proportionate burden of the instrument is higher on poor than on rich groups. *Prima facie*, this will be so if the tax is on a commodity expenditure that forms a higher proportion of low incomes than high incomes. Energy would be a case in point. Tax on petrol appears to be regressive because it affects those who have to rely on motor vehicles most and who spend more of their income on private transport. Someone who cannot substitute public transport for private transport (e.g. most rural dwellers) and who has a low income, would appear to be the most affected by taxes on gasoline.

However, as with competitiveness, the political perception of this issue is often at odds with the available evidence. The OECD has conducted several reviews of the distributive incidence of economic instruments, with the main focus being on energy taxes (Harrison 1994; Smith 1995; OECD 1997) and concludes that the regressivity has been overstated.

There is no doubt though that there are important issues which a government would have to confront. A carbon tax will make domestic fuel, including electricity, more expensive. No government could contemplate adding to the number of the fuel-poor. But Government has other means to compensate those in need; indeed it already does so with the annual 'winter fuel' allowance to senior citizens. This could be enhanced to take care of the increased fuel costs (perhaps means tested) or incorporated into the state pension[2]. **It is important to appreciate that an individual who is fully compensated for the rise in fuel prices none the less has an increased incentive to avail themselves of all possible means, including those offered by government, to conserve energy.** The various schemes promulgated by the Government's Energy Savings Trust, the Carbon Trust, and the Local Government Associations would continue to play an absolutely key role.

---

[1] The inverse of a 'stealth' tax.

[2] While perhaps raising the anomalously reduced VAT on domestic fuel to the standard rate.

7.4 Reluctance to move towards harmonisation

There is a general reluctance among EU countries to move towards harmonisation of taxes, a reluctance that the UK appears to share with some fervour. Introducing a carbon tax system in one nation alone is not inconceivable, but clearly an agreement among all EU Member States to move in this direction would allay some of the fears[3] of damage by loss of competitiveness. Harmonisation of a carbon tax should be a key aim. This is particularly important as the EU is enlarged. There is evidence that governments, including our own, appreciate that for such an energy tax this would be necessary. The fear is that this could be the thin end of a wedge. We believe, however, that the case for a carbon tax is of such overriding importance – to all nations – that it can be treated as a separate and quite exceptional case. It need not inevitably lead to a wider tax harmonisation.

7.5 Experience within the European Union

We organized a seminar in which we learned of the experiences of introducing carbon taxes from representatives of five European countries: Sweden, Denmark, The Netherlands, Italy and France (see Appendix B).

The European Commission has in fact made a serious attempt at embarking on a carbon tax regime – it first presented a proposal at the Rio Earth Summit in 1992, and modified its provisions in 1995 – but abandoned it in 2001. The proposal met with substantial resistance, mainly because of the reluctance of some Member States to accept the transfer of tax competence, citing the fears noted in Section 7.4. Proposals are now being considered for the introduction of a European-wide emissions trading scheme.

All five of the countries represented at the seminar had some experience of imposing or trying to impose a carbon tax. One particularly pertinent example was the move in France to introduce a carbon tax in 1999. In the form first suggested it was a true *universal* carbon tax applicable to all fossil-fuel usage. In discussions with various stakeholders this concept was severely dented so that, for example, the tax was to be applied to all electricity consumption. At that point the matter was taken to the Courts, who ruled that the tax would be unconstitutional. The reason: 75% of electricity in France stems from the nuclear component. The tax would have impinged on householders who had only a minor responsibility for CO_2 emissions.

Sweden currently has a carbon tax that impinges on domestic consumers but – because of competitivity fears – is not applied to industry. The Netherlands has a complicated energy/carbon tax system that is imposed on domestic consumers above a certain level of usage regarded as ‘essential’, and on industry for usage *below* a certain level, to protect energy-intensive industry.

Italy has a carbon tax, with an intended gradual introduction over five years from 1999. But here too the situation is anything but simple. It is targeted at domestic as well as industrial and transport users, but designed to give some protection to the coal industry. It was ‘put on hold’ in 2000 because of a rise in international fuel prices, then re-instated in 2002. It is intended to be fiscally neutral.

Denmark has in the past depended predominantly on regulation. The country is intending to move towards more emphasis on economic instruments. Currently, there is a mixture of an energy and a carbon tax and other fiscal measures. Environmental taxes amount to 10% of the Danish tax revenues.

It is evident that there is a general recognition of the role of economic instruments, but so far the attempt to make a carbon tax the essential basis for controlling greenhouse gas emissions has not yet succeeded. There is one example of the imposition of a carbon tax that has had a *direct* effect on company policy – the decision by the Norwegian StatOil company to separate CO_2 from their natural gas supply and sequester it in underground repositories under the North Sea (Johnson 2000).

We hope that the economic advantages of a carbon tax will prevail and lead to the desired harmonisation – *for this tax* – between EU Member States.

---

[3] Not of course all of them – there remains the rest of the world.

8 Discussion and recommendations

There is an urgent need to reduce the emission of greenhouse gases into the atmosphere. The Kyoto accord is a valuable recognition of this need, though the aims, even if fully achieved, are very modest. The recent World Summit in Johannesburg has not achieved any advances on this situation. Much larger reductions will be needed, possibly as large as the 60% decrease in CO_2 emissions (by 2050) suggested by the Royal Commission for Environmental Pollution (RCEP 2000).

The achievement of emission targets is ultimately the responsibility of national governments. They can effect the reduction of emissions by advocacy, by regulation and by the application of economic instruments. There is, and will remain, an important role for advocacy and education. But there is also no doubt of the need for government to apply more direct means by *regulations* and/or by imposition of *economic instruments*. In practice, the UK Government and many others in the EU use a mixture of both. So, for example, in the UK the Government has introduced a tax – the Climate Change Levy – that is in fact a tax on energy usage. The Government has also imposed a Renewable Energy Obligation – a regulation that requires electricity generators to purchase 3% (rising to 10% by 2010) of their output from renewable sources.

The problem with Climate Change Levy as an economic instrument for greenhouse gas mitigation is that it is inefficient and partial. It is a tax on energy, not on greenhouse gases. And energy-intensive industries are allowed to pay low rates in exchange for signing agreements, each with a potential for tolerating reduced ambitions in performance. The Climate Change Levy does not directly cover the use of fossil fuels by the electricity industry, households or the transport sector. Looking beyond 2010, it is not clear how in its current form the Climate Change Levy could be used to bring about the substantial reductions in greenhouse gases likely to be required. It is a tax that involves Government in making detailed decisions on applicability and exclusion, which it is difficult to separate from other governmental aspirations.

We believe that the most cost-efficient way to reduce greenhouse gas emission is by a suitable economic instrument. We have reviewed the choices in Chapter 2. Broadly, they fall into two categories: a carbon tax imposed on all CO_2 emissions, or a system of tradable permits to allow the emission of a given quantity of CO_2. In the latter, possibly after an initial allocation scheme, the permits would be auctioned. A carbon tax and an auctioned permit scheme establish a price for the emission of CO_2. The EU is currently attempting to define such a scheme within the context of the Kyoto agreement. It would seem self evident that the wider the coverage of the scheme, the lower the overall costs. There might be advantages to using a permit scheme rather than carbon taxes, depending on circumstances and use of revenues. We believe, however, the key issue to be that the economic instrument should set a price on the emission of CO_2. As in previous chapters we shall, for simplicity, refer to the economic instrument adopted as a 'carbon tax'.

Although there is still room for debate on the exact form of carbon tax, there is none on the conclusion that control of total CO_2 emission can be effected at lower cost by relying on such an economic instrument than by regulation—the first of our specific recommendations:

1. Control of emission of CO_2 can be effected at lower overall cost by the application of an economic instrument, such as a carbon tax, than by a system based on regulation. (Section 4.1)

The form of the carbon tax should be the simplest that can be devised, so that it is comprehensible to all stakeholders, and equally importantly so that it facilitates international agreements.

2. We recommend that the achievement of maximal *simplicity* and transparency should be seen as a major and perhaps determining factor. (Section 2.6)

3. We recommend that the carbon tax should eventually be applied *universally*, to all sources of emitted CO_2 – industrial, domestic, transport (including aviation). (Section 3.4)

Some of the undesirable impacts of this policy – such as, for example, the risk of depriving vulnerable members of society of adequate heating – can be readily compensated by national government action.

4. Universal application of a carbon tax will require the Government to introduce or extend measures to avoid penalising the more vulnerable members of the community. They should be compensated but not shielded from the tax. (Section 7.3)

Others – such as the imposition of a carbon tax on aviation fuel – clearly need the widest possible international agreements

Intermediate situations are presented by industries whose energy costs amount to a large percentage of the total. We recommend that any special allowances for such industries should be temporary and based on direct subsidies rather than exemptions or low tax rates for such industries. The products from those industries will become more expensive; it is inescapably part of the purpose of the economic instrument to make a carbon-intensive industry less competitive.

5. We recommend that any measure to shield carbon-intensive industries from the impact of the tax should be time-limited, and that it should be transparent in the form of explicit subsidies. The tax is intended to make carbon-intensive products less competitive. (Section 3.4)

We have included some discussion on the magnitude of a carbon tax that would be required to reach the targets set by Kyoto and beyond. To set the value one would need to have knowledge of the price elasticity of various fuels and of the products produced by chemical industries, which generate emission from the process itself. However, one would also need to know the price barriers faced by various renewable energy sources – the rate at which their section of the energy market would grow with increase in the price of electricity. We have made some comment on the latter in Chapters 3 and 5. The impact of a carbon tax on renewables may turn out to exceed that arising from fuel price elasticities.

6. A carbon tax works in the first instance by making fossil fuel more expensive. It also makes renewables, nuclear and carbon sequestration more viable. These latter influences may turn out to be of equal or even greater importance. (Section 4.2)

Implementing a carbon tax would of necessity be a gradual process for two reasons. First, it would require many consequential changes in regulation, even though the end result would amount to a great simplification. Second, it would be highly desirable to evolve a trajectory of gradually increasing carbon tax rates which should be harmonised (though not necessarily synchronised) with the action of other nations. We do not underestimate the enormous problems in reaching the needed international agreements. They may take several decades, a time span that will see many successive administrations in each nation. What is most needed now is an agreement on a principle: that the control of emissions will be effected by the imposition of a carbon tax.

Although the impact on individual sectors of the economy will be substantial, the total change in GDP as detailed in Chapter 4 may be modest or, depending on the manner of recycling the carbon tax revenue, even positive. The conclusion derived from several economic analyses that a substantial long-term reduction in global emissions is, even in its narrowest sense, affordable is a result of key importance, and one that does not appear to have been more widely appreciated. It should be.

Economic analyses done by several different groups conclude that the overall cost of even drastic reduction in CO_2 emission is modest, with estimates in the range of 1% of long-term global GDP. This cost is negligible compared with the expected long-term growth in the global economy over the next 100 years of 1–3% a year.

7. A carbon tax should be introduced gradually and with the aim of eventual convergence with the nations of the EU, and beyond. The vital first step is to seek and reach an understanding *in principle* - that emission control would in future be based on the application of a carbon tax or related economic instrument. Reaching an agreement on as wide an international basis as possible is more important than the speed with which a fully-fledged scheme is implemented. (Sections 3.3 and 5.2.1)

A carbon tax implies the ability to measure the amount of CO_2 emitted. The technology for doing so is well established and can be put into place at modest cost. One advantage of a universal carbon tax is that the revenue can be collected 'up-stream'.

Because most of the emission arises from combustion of fossil fuels, the tax would be imposed on the purchase price of fuels. Emissions from the process industries require local measurement, but do not involve any major problems. If as the price of emission rises, carbon sequestration becomes commercially viable, it will be necessary to measure the amount of carbon sequestered. It is unlikely that carbon sequestration would be applied to any but large installations, so that there is no great additional complexity of collection.

8. A carbon tax should be collected up-stream on the purchase of fossil fuel, which results in 96% of the total emission. (Sections 6.1 and 6.4) It could be collected directly from process industrial units for emission other than that due to combustion of fossil fuel. The measurement of carbon content of fuels, of process emissions and subtraction of sequestered carbon is relatively straightforward.

The imposition of an economic instrument such as a carbon tax or the use of tradable permits, may not in the longer term, as we have seen in Chapter 4, have a detrimental impact on the GDP. However, it does have the immediate effect of removing the current cost-free right to emit CO_2. Industry must be given time to adjust to this change.

In the case of a carbon tax it implies that it should start at a low level, and with some indication by Government on the probable profile of future increases.

9. If the economic instrument to be adopted is that of introducing tradable permits, there is a case for initiating the scheme by grandfathering: i.e., allocating permits to individual companies reflecting their past emission records. We recommend that this stage should be strictly time-limited, with the aim of proceeding to a wholly auctioned permit system as soon as possible. (Section 2.3)

Appendix A List of respondents

We are very grateful to those organisations and individuals who responded to our request for information in support of our study. Those who agreed to be identified are listed below. We should stress that this report reflects our views only and that these respondents did not comment on the final statement or earlier drafts.

Ms Anna Beaumont	Advisory Committee on Business and the Environment
Mr Daniel Waller	Association for the Conservation of Energy
Mr David Porter	Association of Electricity Producers
Dr Jonathan Cobb	British Nuclear Fuels Limited
Mr Mark Akhurst	BP
Mr Paul Blacklock	Calor Gas
Mr Paul Allen	Centre for Alternative Technology
Mr Richard Jackson	Confederation of British Industry
Mrs Sara Eppel	Energy Savings Trust
Ms Faye Clamp	Federation of Small Businesses
Mr Robert Bell	Future Energy Solutions, AEA Technology
Ms Alison Miller	Local Government Association
Mr Neil Hornsey	Sustainable Development Commission
Mr Sean Cavendish	Sunpowered Energy Systems Ltd.
Mr Brian Samuel	TXU
Mr Bernard Abrams	Personal submission
Professor Philip Stott	Personal submission

Appendix B Programme for seminar on European experience

17 May 2002, The Royal Society, London

Many European countries have either introduced or considered a carbon tax, or other similar energy policies, or are currently trying to implement one. The aims of this seminar were to gather information for the Royal Society's study on *Economic Instruments for Climate Change Mitigation*, and in particular to learn from the experiences in designing and implementing a carbon tax in other European countries directly from policy makers involved in the process. The seminar allowed UK and European policy makers to discuss the possible roles of carbon taxation and other economic instruments such as emissions trading for climate change mitigation.

Speakers	
Mr Christophe Baulinet	Deputy Director General, Ministry of Finance, Economy and Industry, France
Mr Daniel Boershertz[1]	Directorate-General Taxation, European Commission, Brussels
Dr Mario Contaldi	Climate Change Unit, National Environmental Agency, Italy
Mr Thomas Dalsgaard	Head of Tax and Environment Policy, Finance Ministry, Denmark
Mr Kees Heiniken	Consumer Tax Legislation Directorate, Min. Finance, The Netherlands
Dr Bengt Johansson	Swedish Environmental Protection Agency, Sweden
Attendees	
Mr Mark Akhurst	Global Environmental Issues Team, BP
Dr Christopher Anastasi	Senior Environmental Analyst, British Energy
Sir Eric Ash	Royal Society, Working Group, Chair
Dr Mary Archer	Royal Society, Working Group
Dr Terry Barker	Royal Society, Working Group
Mr Robert Bell	Director, Future Energy Solutions, AEA Technology
Mr Richard Boyd	Environmental Tax Team, Customs and Excise
Mr John Costyn	Head of Environment Action Plan, OFGEM
Mr Jeremy Eppel	Divisional Manager of Sustainable Energy Policy, DEFRA
Mrs Sara Eppel	Head of Policy, Energy Savings Trust
Professor Ian Fells	Royal Society, Working Group
Mr Adrian Gault	DTI, Energy Group
Dr John Hassard	Royal Society, Working Group
Ms Rhian Hawkins	Environment: Risk and Atmosphere, DEFRA
Professor Geoffrey Hewitt	Royal Society, Working Group
Mr Richard Jackson	Environmental Taxes & Emissions Trading, CBI
Dr Bill Kyte	Head of Group Sustainable Development, Powergen
Professor Michael Laughton	Royal Society, Working Group
Mr Clive Maxwell	Environmental Taxation, HM Treasury
Mr Duncan Millard	DTI, Energy Group
Professor David Pearce	Royal Society, Working Group
Mr James Robertson	Environmental Tax Development Team, Customs and Excise
Mr Keith Wey	Chemical Industries Association

---

[1] Unable to attend on the day; presentation material submitted to the Working Group.

Appendix C Overview of current UK schemes

C.1 UK Emissions Trading Scheme

After several years of design and consultation, the UK's first emissions trading scheme for greenhouse gases was launched in April 2002 and attracted 34 participants. The scheme covers all greenhouse gases. It is an Emission Reduction Credit scheme where companies trade permits generated from reducing their emissions. This involves agreeing a baseline against which credits are calculated. The baseline is set by the average of emissions in 1998, 1999 and 2000. The compatibility with the proposed EU scheme is not obvious.

The UK emissions trading scheme is a voluntary scheme and is unique in offering financial incentives to join. Each participant can bid for a share of £215 million spread over 5 years. These payments to participants are intended to cover the risks they would bear in limiting their emissions. Electricity generation is excluded from the UK scheme, to prevent further switch to gas from the coal industry. The initial price determined in the auction was £53.40/tCO_2 (£195.80/tC). The main issue is what this price would have been without the subsidies[1]. Failure to achieve the agreed emission reduction in the UK emissions trading scheme will result in having to increase reductions in later years, along with a penalty factor, i.e. shortfalls must be more than made up in the future. Non-compliance also forfeits the subsidy. Once the first Kyoto compliance period (2008 onwards) is reached, these penalties are likely to take the form of a financial penalty of approximately £20 per tonne carbon equivalent.

The UK scheme has two classes of participant: those agreeing to absolute reductions in emissions, e.g. *X* tC by 2005, and those who operate with Climate Change Levy agreements who tend to have agreed 'per unit' reductions, e.g. *X* tC per unit output. The former is known as the 'absolute' sector and the latter as the 'unit' sector. The latter presents a problem because output expansion could raise absolute emissions even though 'per unit' emissions decline. Accordingly, the unit sector participates in the emissions trading scheme on a restricted basis and there is a 'gateway' that enables it to sell any credits to the absolute sector. It is this gateway that limits the sale of unit sector credits. The idea is to close the gateway altogether by 2008.

There is some suspicion that the UK emissions trading scheme embodies 'hot air'. Potential sources of hot air are: (a) the need to comply with other regulations, where compliance might be disguised as genuine reduction effort under the emissions trading scheme, especially if monitoring is weak. For example, the Integrated Pollution Prevention and Control (IPPC) which sets obligated companies pollution emission targets relative to the amount of activity; (b) securing a baseline based on past emissions but with future plant closures in the offing; (c) securing a baseline against a 'false' projection of economic activity which exaggerates output and hence emissions. The UK emissions trading scheme has safeguards against all these potential misuses, but it was noted earlier that hot air is an in-built risk of tradable permit schemes that embody emission reduction credit and/or grandfathering.

Both the UK and European schemes omit carbon sinks because, it is argued, of the difficulties of verification and measurement. Both schemes also try to address the problems of double counting. For example, emission reduction obligations under renewable energy policy must be met before any further emission reductions are counted as credits in either system. 'Projects' are allowed but their exact definition has yet to be confirmed. Projects relate to specific measures undertaken to reduce emissions, for example under the Clean Development Mechanism of the Kyoto Protocol.

C.2 The UK Climate Change Levy

The Climate Change Levy is effectively an environmental tax on the use of energy; it is not a carbon tax. From April 2001, business and public sector users were required to pay a levy in pence per kilowatt hours (p/kWh) of energy used with different tariffs for different fuels (Table 3). Domestic users are excluded. Electricity is dealt with as a whole because it was deemed too difficult to discriminate between electricity supplied from different primary fuels. Energy derived from renewable sources and 'good quality' Combined Heat and Power (CHP) are exempted from the levy, but because one of the aims is to stimulate new renewable sources, large hydroelectric plant (greater than 10 MW) is not exempted. In contrast, the European Renewable Energy Sources in the Internal Electricity Market (RES-E) directive accepts that large hydroelectric plants can be included in any tradable certificate scheme. The exemption is available only to supplies of electricity sold under contracts that are clearly identified as such. Suppliers are able to offer contracts containing renewable source declarations up to the limit of their

---

[1] The price was determined by a 'descending clock' auction. The auctioneer proposes a price and quantity bids are received. If these exceed the available subsidy (£215 million over 5 years), the price is lowered and bids are re-invited. The eventual price was determined after nine rounds of bids.

contracted purchase from generators using eligible renewable sources, provided they agree to abide by the conditions governing the scheme. Energy-intensive businesses are eligible to an 80% reduction in the Climate Change Levy rates providing they agree to certain energy efficiency measures.

Table 3. Climate Change Levy rates expressed as a carbon tax by taking account of the carbon content of fuels. (ECOTEC 1999)

Fuel	Pence per kilowatt hour	Pounds per tonne carbon
Coal	0.15	£16
Gas	0.15	£30
Petroleum	0.18	£22
Electricity	0.43	£31

The Climate Change Levy was expected to raise around £1 billion in 2000/01. It is intended to be revenue-neutral in operation, with most being fed back to business in the form of a 0.3% cut in employer's National Insurance reductions and £150 million providing support for energy-efficiency measures, promotion of renewable energy projects and low carbon technologies.

C.3 New Electricity Trading Arrangements (NETA)

NETA, which came into force on 30 January 2001, deals with how electricity is supplied to the distribution system (the National Grid), and how demand is balanced with supply. To supply electricity into the Grid, generators must sign and become party to the Balancing and Settlement Code. The trading arrangements consist of three separate 'markets':

- forwards and futures markets (including short-term power exchanges), which evolve in response to the requirements of participants, that will allow contracts for electricity to be struck over timescales ranging from several years ahead to on-the-day markets;
- a Balancing Mechanism in which National Grid Company, as System Operator, accepts offers of and bids for electricity to enable it to balance the system; and
- a Settlement Process for charging participants whose contracted positions do not match their metered volumes of electricity, for the settlement of accepted Balancing Mechanism offers and bids, and for recovering the System Operator's costs of balancing the system.

The financial penalties of a generator not being able to supply its contracted amount are heavy, and, in addition, oversupply is bought by the grid at a significantly reduced price. This places a significant burden on the competitiveness of variable renewable sources within the trading arrangements. However, renewable generators are given the option of not signing the Balancing and Settlement Code under NETA, and selling their electricity directly to one of the supply companies acting as a consolidator.

C.4 Utilities Act 2000 (Renewables Obligation)

Under the new Renewables Obligation and associated Renewables (Scotland) Obligation electricity suppliers must supply a proportion of their electricity from renewable sources. By 2010 this obligation will be 10% and is expected to remain at this level until 2025. To fulfill this obligation, suppliers must either physically supply the power from renewables generating stations or purchase 'green certificates' (either directly or indirectly) from others who have supplied such power. Any additional cost of supplying electricity from renewable sources must be met by the suppliers and may be passed on to their customers. However, under the terms of the Utilities Act, suppliers can 'buyout' part or their entire renewables obligation. This buyout payment has been set at 3 p/kWh above the current cost of electricity. The buyout option has been introduced to limit the cost to the consumer by setting a price cap on renewables. It is intended that the revenue from the buyout payments will be used to encourage suppliers to meet their obligation rather than continuing to buyout. This may be achieved by transferring the revenue from non-compliant suppliers to compliant suppliers although the method is yet to be decided.

Appendix D Outline of proposed European emissions trading scheme

The proposed European Union trading scheme is an allowance scheme, due, theoretically, for introduction in 2005. The proposal is for a mandatory scheme with wider coverage than the UK scheme. It will include the electricity generation sector, but will exclude the chemical industry and incineration. It is projected to cover some 40% of all EU carbon emissions in 2010. The long-term aim is that it will be extended to all greenhouse gases but, in the meantime, it is limited to carbon owing to perceived problems in monitoring and measuring non-carbon greenhouse gas emissions.

The EU proposal embodies grandfathering of the allowances. Financial penalties for non-compliance at the beginning will be set at €183/t carbon up to 2008 and €367/t carbon after that.

The EU proposal recognises the problem of absolute and unit emissions, but tends to dismiss it by saying that unit targets can always be converted into absolute targets by multiplying through by projected output. It is likely to be far more complicated than this.

Appendix E List of countries in Annex B of Kyoto Protocol

Country	Quantified emission limitation or reduction commitment (percentage of base year or period)
Australia	108
Austria	92
Belgium	92
Bulgaria*	92
Canada	94
Croatia*	95
Czech Republic*	92
Denmark	92
Estonia*	92
European Community	92
Finland	92
France	92
Germany	92
Greece	92
Hungary*	94
Iceland	110
Ireland	92
Italy	92
Japan	94
Latvia*	92
Liechtenstein	92
Lithuania*	92
Luxembourg	92
Monaco	92
The Netherlands	92
New Zealand	100
Norway	101
Poland*	94
Portugal	92
Romania*	92
Russian Federation*	100
Slovakia*	92
Slovenia*	92
Spain	92
Sweden	92
Switzerland	92
Ukraine*	100
United Kingdom	92
United States of America	93

* Countries that are undergoing the process of transition to a market economy. Source: Annex B of Kyoto Protocol to the Convention on Climate Change, p. 23.

The table shows countries in Annex B of the Kyoto Protocol and their agreed greenhouse gas emission reduction targets against a base line of 1990 emissions. Annex 1 of the United Nations Framework Convention on Climate Change identified a list of industrialised countries required to make reductions in their greenhouse gas emissions. The Kyoto Protocol specified emissions reduction targets for each of the countries and listed them in Annex B to the Protocol, with the exception of Turkey and Belarus.

Appendix F Glossary

Annex 1	Industrialised countries identified by, and signatories to, the United Nations Framework Convention on Climate Change (listed in Appendix E).
Annex B	Industrialised countries listed in Annex B of the Kyoto Protocol (full list in Appendix E). Emission reduction targets are allocated to each country.
Auction	Companies bid for a fixed number of permits based on their abatement costs.
CAC	Command-and-Control legislation
CCA	Climate Change Agreements. Negotiated exclusion or reduction in the Climate Change Levy for particular businesses, industries or technologies, granted in return for achieving efficiency targets.
CCGT	Combined Cycle Gas Turbine
CH_4	Methane. A powerful greenhouse gas but emitted in much smaller quantities than CO_2
CHP	Combined Heat and Power, also known as Cogeneration
CO	Carbon monoxide
CO_2	Carbon dioxide
DEFRA	Department for Environment Food and Rural Affairs
Elasticity	How one factor responds to changes in another, e.g., fuel demand against fuel price.
ERC	Emissions Reduction Credits
EU	European Union
Fugitive Emissions	Industrial emissions from unanticipated or spurious leaks in process systems.
GW	Giga Watt
Grandfathering	Allocation of emission permits based on past emission rates.
Hot air	Emission reductions that would have happened regardless of the company's efforts, e.g., a slump in productivity.
Landfill Levy	Tax applied to waste disposed of in landfill. Introduced in 1996.
IPCC	Intergovernmental Panel on Climate Change.
IPPC	Integrated Pollution Prevention and Control. Legislation enacted in response to the EU IPPC Directive.
kWh	Kilowatt hour
Kyoto Protocol	The protocol to the United Nations Framework Convention on Climate Change, agreed at Kyoto in December 1997, to return greenhouse gas emissions to their 1990 level by the year 2000.
MBI	Market-Based Instrument. Alternative name for Economic Instrument.
MtC	Million tonnes of Carbon
MW	Mega Watt
NETA	New Electricity Trading Agreement (see Appendix C)
NO_x	Nitrogen oxides (also known as oxides if nitrogen) is a collective term used to refer to two species of oxides of nitrogen: nitric oxide (NO) and nitrogen dioxide (NO_2).
OECD	Organisation for Economic Cooperation and Development
Permit	A fixed quantity of CO_2 emitted.
PIU	Performance and Innovation Unit, now part of the Strategy Unit
RCEP	Royal Commission on Environmental Pollution
SO_2	Sulphur dioxide
UKETS	UK Emissions Trading Scheme. Established April 2002 (see Appendix C)
VAT	Value-added tax

Appendix G References

AEA Technology (2002). UK Greenhouse Gas Inventory 1990 to 2000: Annual report for submission under the Framework Convention on Climate Change.

Barker T & Johnstone N (1998). *International competitiveness and environmental policies,* chapter 4, pp. 71–127). Edward Elgar, Cheltenham, UK.

Barker T & Rosendahl K E (2001). *Ancillary benefits of greenhouse gas mitigation in Europe: SO_2 NO_x and PM10 reductions from policies to meet the Kyoto Targets using the E3ME model and ExternE valuation.* Paper presented to the IPCC/OECD Expert Meeting on Ancillary Benefits, Washington DC, 27–29 March 2001.

British Wind Energy Association (2000). *Planning for wind energy, a guide for regional targets.* BWEA, London. http://www.bwea.com/pdf/planning.pdf

Chiesa P & Consonni S (2000). *Natural gas fired combined cycles with low CO_2 Emissions*. *ASME Journal of Engineering for Gas Turbines and Power* **122** (3), 429–436.

DEFRA (Department for Environment Food and Rural Affairs) (2001). *Guidelines for the measurement and reporting of emissions in the UK Emissions Trading Scheme' UKETS* (01) 05, August 2001.

DEPA (Danish Environmental Protection Agency) (1999). *Economic instruments in environmental protection in Denmark*. (87 pages.)DEPA/Ministry of Environment and Energy, Copenhagen.

DETR (Department of Environment Transport and the Regions)(2001). AEA Technology plc for DETR UK. *Greenhouse gas inventory 1990 to 2000: annual report for submission under the Framework Convention on Climate Change.* Available at http://www.aeat.co.uk/netcen/airqual/statbase/emissions/ghouse1.html

DTI (Department of Trade and Industry) (1997). *Richard Page turns up the heat for renewable electricity*. Press Release P/97/116, 6 February 1997.

DTI (Department of Trade and Industry) (2001). *Digest of United Kingdom energy statistics.* Table 5.10.

ECOTEC (1999). *Who gains from the Climate Change Levy?* Report to WWF UK. Birmingham: ECOTEC.

Ekins P (2000). *Economic growth and environmental sustainability: the prospects for green growth.* pp. 267-268. Routledge, London / New York

Ekins P & Barker T (2001). *Carbon taxes and carbon emissions trading*. Journal of Economic Surveys **15** (3).

Ekins P & Speck S (1999). *Competitiveness and exemptions from environmental taxes in Europe*. Environmental and Resource Economics, **13** (4), pp. 360-395.

Ekins P & Speck S (1998). *The impact of environmental policy on competitiveness: theory and evidence*. In International competitiveness and environmental policies (ed. T. Barker & J. Kohler), pp. 33–70. Edward Elgar: Cheltenham, UK.

Eskeland G & Harrison A (1997). *Moving to greener pastures? Multinationals and the pollution haven hypothesis.* Policy research working paper 1744, World Bank: Washington DC.

Hahn R (1984). *Market power and transferable property rights.* Quarterly Journal of Economics **99**, 753–765.

Hamilton C (2002). *The super-carbon scheme saving for retirement, saving the environment.* The Australia Institute. May. Available at http://www.tai.org.au/WhatsNew_Files/WhatsNew/carbon.pdf.

Harrison D (1994). *The distributive effects of economic instruments for environmental policy.* OECD: Paris.

Horlock J H (1995). *Combined power plants: past present and future* Journal of Engineering for Gas Turbines and Power **117** (4).

IAG (Inter-departmental Analysts Group) (2002). *Long-term reductions in greenhouse gas emissions in the UK*. DTI London.

IPCC (Intergovernmental Panel on Climate Change)(1996). *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories*, workbook vol. 2 (*Energy*). Available at http://www.ipcc-nggip.iges.or.jp/public/gl/invs5a.htm.

IPCC (Intergovernmental Panel on Climate Change) (2001*a*). *Climate Change 2001 – Mitigation The Third Assessment Report of the Intergovernmental Panel on Climate*. Cambridge University Press: Cambridge, UK, and New York, USA, USA. http://www.grida.no/climate/ipcc_tar/wg3/index.htm.

IPCC (Intergovernmental Panel on Climate Change) (2001*b*) *Climate Change 2001- Mitigation The Third Assessment Report of the Intergovernmental Panel on*

Climate. p. 55. Cambridge University Press: Cambridge, UK, and New York, USA. http://www.grida.no/climate/ipcc_tar/wg3/index.htm.

IPCC (Intergovernmental Panel on Climate Change) (2001c). *Climate Change 2001- Mitigation The Third Assessment Report of the Intergovernmental Panel on Climate*. p. 516–517. Cambridge University Press: Cambridge, UK, and New York, USA. http://www.grida.no/climate/ipcc_tar/wg3/index.htm.

Jaffe A, Peterson S, Portney P & Stavins R (1995). *Environmental regulation and the competitiveness of US manufacturing: what does the evidence tell us*? Journal of Economic Literature, **33**, pp. 132–163.

Johnson J W (2000). *A solution for CO_2 overload.* Science and Technology Review, December. Lawrence Livermore National Laboratory, University of California.

Koutstaal P (1999). Tradable permits in economic theory. In *Handbook of Environmental and Resource Economics* (ed. J. C. M.van den Bergh), pp. 265–274. Edward Elgar: Cheltenham, UK.

Kristensen J P (1996). *Environmental Taxes, Tax Reform and the Internal Market - Some Danish Experiences and Possible Community Initiatives in Environmental Taxes and Charges*. (126 pages.) National Experiences and Plans, European Foundation for the Improvement of Living and Working Conditions, Dublin, and Office for Official Publications of the European Communities, Luxembourg.

Larsen B M & Nesbakken R (1997). Norwegian Emissions of CO_2 1987–1994. A study of some effects of the CO_2 tax. *Environmental and Resource Economics* **9** (3), 275–290.

Marshall, Lord (1998). *Economic instruments and the business use of energy: a report by Lord Marshall*. HM Treasury: London.

Milborrow D (2001). *Performance and Innovation Unit working paper on penalties for intermittent sources of energy*. DTI: London.

Morgenstern R (1996). Environmental taxes. Is there a double dividend? *Environment* **38** (3), pp 16–20 and 32–34.

Norwegian Green Tax Commission (1996). *Policies for a better environment and high employment*. An English Summary (96 pages.) Oslo. Norway.

OECD (Organisation for Economic Cooperation and Development) (1997). *Environmental taxes and green tax reform*. OECD: Paris.

OECD (Organisation for Economic Cooperation and Development) (2000). *Behavioural responses to energy and transport-related taxes: a survey of price elasticity estimates*. OECD: Paris.

Oliveira-Martins J (1995) *Unilateral emission control, energy-intensive industries and carbon leakages*. OECD: Paris

OST (Office for Science and Technology) (2002). *Chief Scientific Adviser's Energy Research Review Group Recommendations to inform the Performance and Innovation Unit*. Energy Policy Review, March 2002.

Pearce D (2003). The Social Cost of Carbon and its Implications. *Oxford Review of Economic Policy.* (Submitted.)

Peterson & Fies (2002). Solar power to the people. *Physics World* **15** (7) 35–36.

Pigou A C (1920). *The economics of welfare*. Macmillan, London.

PIU (Performance and Innovation Unit) (2001). *Renewable energy in the UK: Building for the future of the environment*. Cabinet Office: London.

PIU (Performance and Innovation Unit) (2002). *The energy review*. Cabinet Office: London.

Repetto, R. & Austin, D. 1997. *The costs of climate protection: a guide for the perplexed*. World Resources Institute: Washington DC.

RAEng (Royal Academy of Engineering) (2002). *An engineering appraisal of the Policy and Innovation Unit's Energy Review*, pp 27–28. London.

RCEP (Royal Commission on Environmental Pollution) (2000). *Energy – the changing climate*. Twenty-second report, Cm 4749. (292 pages.)

Rodgers P (2002). Waiting for the power of the Sun. *Physics World* **15** (7) pp 44–45.

Royal Society (2001). *The science of climate change*. Joint statement by 16 of the world's scientific academies. Available from the Royal Society and http://www.royalsoc.ac.uk/templates/statements/StatementDetails.cfm?statementid=138.

Royal Society & The Royal Academy of Engineering (1999). *Nuclear energy – the future climate*. Document 10/99. Available from the Royal Society and http://www.royalsoc.ac.uk/templates/statements/StatementDetails.cfm?statementid=146.

Royal Society & The Royal Academy of Engineering (2000). *The role of the Renewables Directive in meeting Kyoto targets*. Document 11/00. Available from the Royal Society and http://www.royalsoc.ac.uk/templates/statements/StatementDetails.cfm?statementid=124.

Royal Society (2001) *The role of land carbon sinks in mitigating global climate change*. Document 10/01. Available from the Royal Society and http://www.royalsoc.ac.uk/templates/statements/StatementDetails.cfm?statementid=150.

Schwartz J & Repetto R (1997). *Non-separable utility and the double dividend debate: reconsidering the tax interaction effect*. World Resources Institute, mimeo. Washington DC.

SEPA (Swedish Environmental Protection Agency) (1997). *Environmental taxes in Sweden – economic instruments of environmental policy*, pp. 48–49. Report 4745. Stockholm

Smith S (1995). *Review of empirical evidence of distributional effects of environmental taxes and compensation measures*. OECD: Paris.

Sorsa P (1994). *Competitiveness and environmental standards*. Policy Research Working Paper 1249, World Bank: Washington DC.

STA (Solar Trade Association) (2002). *Frequently asked questions about renewable energy* Fact sheet. National Energy Centre, Milton Keynes

Thorpe T (2002). *Harvesting the waves*. Ingenia, September.Royal Academy of Engineering: London

Toft A J & Bridgwater A V (1997) *How fast pyrolysis competes in electricity generation market*. In Biomass gasification and pyrolysis; state of the art and future prospects, pp. 504–515. CPL Press.

World Bank (1999). *Greening industry: new roles for communities, markets and governments*. World Bank: Washington DC.

WEC (World Energy Council) (2002). Energy Info Centre – web site: http://www.worldenergy.org/wec-geis/.