SEEDS
Surrey Energy Economics
Discussion Paper Series

SURREY
ENERGY
ECONOMICS
CENTRE

Acid Deposition & Global Warming: simulating energy, environment, economy interactions in the UK with ENDAM2

David Hawdon and Peter Pearson

June 1993

SEEDS 65
ISBN: 1852370971

Department of Economics
University of Surrey

SEEC consists of members of the Department of Economics who work on energy and environmental economics. SEEC's aims include the promotion of research and teaching in the broad area of energy economics and policy. SEEC was founded in 1983. Its creation was intended to consolidate the research on energy economics which developed at the University of Surrey after the appointment of Colin Robinson to the Chair of Economics in 1968. Colin and the colleagues he attracted to the University built up Surrey's reputation, initially with pioneering work on North Sea oil and gas, and subsequently in all the other major areas of energy economics.

- Recent research covers the following areas: Electricity, gas and coal privatisation in the UK; privatisation in the Middle East; the structure of UK energy demand; North Sea oil and gas economics and policy: international oil markets; electricity economics; the transport of energy; environmental policy in the UK; energy and environmental policy in the Third World; global environmental issues.
- SEEC research output includes **SEEDS** - **S**urrey **E**nergy **E**conomics **D**iscussion **P**apers **S**eries (recent titles may be found on the back cover), as well as a range of other academic papers, monographs and books.
- Each year SEEC organises a range of energy conferences and workshops on energy themes. Specialist workshops include the meetings of the Third World Energy Policy Study Group, convened by Peter Pearson and Paul Stevens, and the joint SEEC/British Institute of Energy Economics Energy Modelling Group, convened by David Hawdon.
- Members of SEEC provide major inputs into the postgraduate energy courses run by the Economics Department - in particular, the M.Sc. courses on Energy Economics and Energy Policy, and the Diploma in the Economics of Energy and Development for Graduates.

Enquiries about SEEC may be made to:

Director of SEEC: Peter Pearson, **Secretary**: Isobel Hildyard

SEEC, Economics Department, University of Surrey,
Guildford GU2 5XH, UK.
Telephone: +44-483-509379 Fax: +44-483-303775

Surrey Energy Economics Discussion Paper Series
SEEDS No. 65

Acid Deposition & Global Warming: simulating energy, environment, economy interactions in the UK with ENDAM2

David Hawdon and Peter Pearson

ISBN: 1852370971
June 1993

British Library Cataloguing-in-Publication Data.
A catalogue record for this book is available from the British Library.

ACID DEPOSITION AND GLOBAL WARMING: SIMULATING ENERGY, ENVIRONMENT, ECONOMY INTERACTIONS IN THE UK WITH ENDAM2

David Hawdon and Peter Pearson
Surrey Energy Economics Centre, University of Surrey

1 INTRODUCTION

This paper shows how a number of the complex interrelationships between energy, environment and economic welfare can be investigated with the aid of a 10-sector input-output model of the U.K., with pollution emission coefficients and a European deposition vector for sulphur dioxide. The motivation behind the work was to develop both a teaching aid for demonstrating interactions between energy, environment and economic welfare and a practical tool that could be used to explore policy alternatives relating to key energy-environment problems like acid deposition and global warming.

The model seeks to avoid the usual shortcoming of simple open input-output models - that they tend to produce rather mechanical and often unenlightening solutions. Here the optional feedbacks from the semi-closure (between incomes generated in production and consumers expenditure) and the added energy and environmental components are intended to make the model much more effective in teaching the underlying economic modelling and policy problems in this area. Moreover, we have chosen, at this stage in the model's development, to work at a high level of aggregation. There are two reasons for this, one pedagogic and one pragmatic. The pedagogic reason is that it is exceedingly difficult for the user (in particular, the inexperienced student) to interpret the workings of a model with more than a very limited number of sectors, especially when the results relate not only to output but also to energy, environment and employment. By restricting the dimensions of the model, the program incorporates much of the complexity of the interrelationships without the obscurity of excessive disaggregation.

The pragmatic reason for working at a high level of aggregation is that it makes it possible to construct the model relatively quickly - this avoids the usual problem with I-O work, that the data work dominates, at the expense of analysis and interpretation. Moreover, the limitations of aggregation can be addressed, to some extent, by successive experimentation with different n-sector aggregations. The ability to assemble the data without a big input of resources is important in a wider context, since we intend to experiment with UK I-O tables of different vintages, and plan to extend the model to multi-country comparisons by using I-O tables from a range of countries, both industrialised and developing.

The spreadsheet medium permits the development of a practical tool which enables users to gain a deeper understanding of these interrelationships for themselves, through guided instruction and self-directed experimentation. Thus the user experiences both advanced input-output modelling and the sophisticated application of spreadsheet facilities. The system has been developed using Lotus 1-2-3 and is then compiled on BALER 5, which speeds up the running of the model, makes it possible to develop a more accessible front-end and enables the model to be run independently of the spreadsheet program.

The paper has six sections. Section 2 reviews the past applications of I-O analysis in the energy-environment area. In Section 3 we describe the model we have constructed. Section 4 explains the ENDAM2 program and its operation. Section 5 outlines the results of a set of simulation exercises performed with the model. Section 6 concludes the paper.

2 INPUT-OUTPUT ANALYSIS AND THE MODELLING OF ENERGY-ENVIRONMENT ISSUES[1]

2.1 Proactive Environmental Policy Strategies

Over the past few years governments have been urged to develop more proactive environmental strategies, in place of the reactive strategies that have characterised environmental policy in many countries. For example:

---

[1] This section draws on the review in Pearson (1989).

> The advanced industrial societies must start to do what they have all too often failed to do in the past; that is to anticipate the environmental consequences of their economic activities and to take measures to prevent them, not only within their own boundaries but also with regard to their neighbours and with regard to the global commons" (OECD, 1985, p. 23).

The kinds of problems that have led to pressure for more proactive strategies include several that are energy-related. They embrace pollutants such as sulphur and nitrogen oxides, carbon monoxide and dioxide, CFCs, methane and radioactive materials. Moreover, the environmental impacts of the externalities of energy production, transport and consumption can be not only uncertain but also distant over both time and space, with sometimes regional and global consequences (for example, acid rain, the fall-out from Chernobyl, damage to the ozone layer and the greenhouse effect).

There has been some debate whether the proactive or the reactive is the more appropriate approach, both in general and for particular problems. Much of the debate has been about the balance between the costs of controlling pollution now and the costs of experiencing and adapting to it in the future. In relation to global warming, for example, one of the key issues is how far governments should try to: (a) take proactive action now in the face of scientific and economic uncertainty and risk over-reacting, thus paying 'too much' now; or (b) postpone action and risk greater (and to some extent irreversible) damage as a result, thus paying 'too much' in the future. As Nordhaus (1991) puts it: 'The fundamental policy question involves how much reduction in consumption society should incur today to slow the consumption damages from climate change in the future.'

The balance of the debate between proactive and reactive strategies has been influenced more recently by the weight given to the interests of future generations in writings about 'sustainable development': ' ... future generations should be compensated for reductions in the endowments of resources brought about by the actions of present generations, '(Pearce et al., 1989, 3). However, proactive policy-making is neither easy nor uncontroversial. It requires consistency between environmental policies, energy policies and other policies, such as transport and agriculture. Moreover, as we have seen, it may imply action in advance clearly-established environmental damage and of scientific consensus about the relationships involved. It requires careful monitoring of current energy-environment relationships and modelling of future physical and socio-economic impacts, as well as evaluation of the costs and benefits of alternative policies. All this places heavy demands on data and knowledge. Reactive policy strategies, on the other hand, tend not to emphasise the forward-looking aspects nor to encourage such active speculation and data gathering.

Given the UK's history of reactive policy-making in the energy-environment area (Pearce, 1988), it is hardly surprising that until very recently the energy-environment database was limited and that little economic modelling should have been done. This has begun to change, partly as an accommodation to the increasing national and international pressures for policy change on trans-national and global issues.

2.2 Modelling Energy-Environment Relationships for Proactive Policies

If the exploration and evaluation of scenarios and policy strategies is a key input into proactive policy-making, the question arises as to what sort of modelling of energy-environment relationships might be helpful. Since energy-environment interactions lead to a wide range of policy issues, and of physical, social and economic impacts, it is not surprising to find that internationally a variety of modelling approaches and techniques has been employed in the past.

At the micro level, the approaches include the establishment and estimation of relationships between emissions and consequent physical damage, and of the private and social values of such damage and the benefits from reducing it. They also include the estimation of the private and social costs of abating emissions and of moderating pollution damage. The absence of scientific consensus on some of the important physical relationships (for example, dose-response relationships), and of appropriate market valuations of a number of the benefits and costs, is reflected in the range of estimation methods that abatement activities (see, for example: Leontief, 1970a, 1973; Leontief et al., 1977).

(ii) **Economic-ecologic models.**
This type of model extends the I-O system by incorporating ecological commodities that are inputs into or residuals from production and consumption processes. The basic I-O system is augmented by ecosystem sub-matrices that allow for flows within and between economic and ecological sectors in a manner similar to that of an inter-regional I-O model.[1] However, as Ayres (1978, p.118) has observed, "...despite major efforts it appears that the necessary theoretical understanding and data for a satisfactory "macro-economic-ecologic" model do not yet exist."

(iii) **Commodity-by-industry models**
This type of model incorporates ecological commodities into a commodity-industry I-O system by adding rows of ecological inputs and columns of ecological outputs. An operational example is the work of Victor (1972).

While the type (ii) economic-ecologic models seem highly appropriate for proactive policy-making, they are clearly not generally usable. Moreover,in view of the very heavy data requirements of both the type (ii) and (iii) models, it is not surprising that most applications of environmental I-O analysis have made use of the less ambitious and more restricted (but nevertheless still helpful) type (i) generalised I-O models.

Another useful line of development for I-O models has been the incorporation of a detailed and specific analysis of interindustry energy flows, often specified

---

[1] Examples of this type of model can be found in conceptual form in Daly (1986) and in partly operational form in Isard et al. (1972). For a critique of this kind of approach to ecological modelling, see James et al. (1978, ch. 10).

in physical terms.[1] Although environmental I-O models necessarily take account of the energy sectors and at least some of their residuals (for example, sulphur oxides feature in many studies), they are frequently not linked explicitly with energy I-O models.[2]

In the model described below, we deal explicitly with physical energy flows and emissions of air pollutants from the energy sectors.

The demands for data made by the basic I-O model are substantially increased when the model is augmented to incorporate the generation and abatement of pollutants. Also, there can be problems relating to the sectoral classification in the I-O table. I-O tables are not usually designed with the analysis of energy-environment issues as a priority and are thus likely to over-aggregate important energy sectors and industries with significantly different pollution characteristics (Kohn, 1975, p. 348). Moreover, as we note below, there is some evidence that the degree and method of sectoral classification selected for an I-O table can influence the sensitivity of the model. In our model, although we decided to adopt a high level of aggregation (for the reasons explained in Section 1), within this we have chosen to disaggregate energy into five sectors.

Where possible, the regional aspects of the energy-environment problem need to be considered in the design of the model. On the one hand, a number of pollution problems are most appropriately analysed at a local rather than a national level, while on the other, there are aspects which may need to be analysed at a multi-regional or even global level. Sulphur and nitrogen oxides and carbon dioxide offer good examples of these different aspects. Input-output analysis has in fact been carried out for pollution generation at regional level (e.g. Miernyk & Sears, 1974; Kohn, 1975), at national level (Gay & Proops, 1990) and at multi-regional level (Leontief et al., 1977). However, it should be

---

[1] For reviews of I-O models applied to energy flows, see Casler & Wilbur (1984) and Miller & Blair (1985); for examples of theoretical and applied studies, see: Casler & Hannon (1989); Reardon (1973); Herendeen (1974); Wright (1975); Bullard & Herendeen (1977); Denton (1977); Al-Ali (1979); Common & McPherson (1981, 1982); Park (1982); Behrens (1984), Hoch & Carson (1984), Leung & Hsu (1984).

[2] For examples of linked models see: Muller (1977); James (1982); and Pearson (1984). See also Harris et al. (1984) and James et al. (1985)

noted that the majority of I-O models do not also deal with the transport and dispersion of pollutant emissions.[1]

In the model described below, we make some attempt to deal with dispersion, by using a vector of sulphur oxide dispersion coefficients to estimate the UK's depositions of sulphur oxide on a set of European countries and on North Africa. The coefficients are based on EMEP (European Monitoring and Evaluation Programme) data, reproduced in Newbery (1990). As Newbery explains, EMEP, set up in 1978, now tracks both SO_2 and NO_X across Europe. The map of Europe is split into 150 km grid squares. Meteorological data allows the track of air which arrives at 820 'arrival points' to be traced backwards for 96 hours. An air parcel can then be tracked forwards in time, as it accumulates and deposits pollutants (the model records pollutants emitted by each country), and reaches its arrival point 96 hours later. In this way a substantial proportion of depositions can be traced back to an identifiable source that emitted the pollution up to 96 hours earlier.

Newbery's Table A2 is a matrix whose column elements list sulphur emissions for each of 30 countries or regions, while the row elements indicate emissions received by them (in thousands of tonnes of sulphur per year). From these EMEP data we have calculated a vector of coefficients of UK sulphur deposition per unit of total UK sulphur emissions. This vector is then used to analyse the impacts on other countries of changes in UK sulphur emissions. In future applications, we intend to use I-O tables for other European countries to explore alternative patterns of sulphur 'exports' and the possibilities for different abatement strategies.

2.4 Policy Problems and Strategies

We turn now to consider how I-O models have been used to investigate energy-environment policy problems and policy strategies. The range of available policy strategies includes:

---

[1] For an example of a model with dispersion, see Muller, 1975; for a brief review of dispersion models, see Miller & Blair, 1985.

(a) Influencing the level and pattern of final demand. This might involve a low growth scenario, for example, or the policy might be specifically targeted at particular energy sectors, such as electricity generation.

(b) Altering the mix of technologies used for specific purposes; for example, changing to a mix of energy technologies that produce an alternative pattern of discharges. Possibilities here include changing from high to low sulphur coal, to reduce sulphur emissions, or from coal to oil or gas, or switching from fossil fuels to nuclear, hydro, wind or wave-generated electricity, to reduce carbon dioxide emissions.

(c) Investing in measures that increase the efficiency with which energy is produced and/or used (for example, electricity generation, transmission and distribution, or fuel-efficient appliances and vehicles).

(d) Influencing the discharge of residuals by treating them - for example, through flue-gas desulphurisation.

(e) Reducing the impact of pollutants at receptor points, through remedial or protective measures (for example, liming lakes to reduce their acidity, installing double-glazing to moderate the impact of noise).

(f) Changing the spatial location of pollution-generating activities, through zoning.

There is, of course, a wide range of policy instruments that can be used to implement these strategies, including government expenditure, market-based instruments including various forms of taxation and the use of tradeable emissions permits, command and control regulations and moral suasion. Aspects of the listed policy strategies can be investigated with the aid of I-O models. Moreover, although standard I- O models are not directly usable for constrained optimisation (for example, minimising the abatement costs of meeting a set of emissions standards), when combined with other techniques, such as linear programming, I-O can be used to explore policy strategies set in a framework of optimisation (see, for example, Kohn, 1975, or Muller, 1977).

2.5 Pollution Coefficients and Projections of Residuals

The most direct method of augmenting an I-O model to account for the generation of pollutants is to add an extra row to the I-O system for each pollutant, where element j in a row represents the physical quantity of that pollutant emitted by sector j in a given time period (Leontief, 1970a). Then, carrying over the assumption of linearity to the relationship between each sector's output and the quantity of pollutant emitted, coefficients of pollutant per unit of sectoral output can be calculated. For any given vector of final demands, the augmented I-O model can then be solved to find the gross output of each sector and then the quantities of pollutants generated by each sector in the production of that sector's output.

This approach has been applied to emissions of energy-related pollutants, such as sulphur oxides and nitrogen oxides from the combustion of fossil fuels. An I-O system extended in this manner can be used to investigate a variety of scenarios. These can include alternative projections of final demand and changing technology, based on analyses of likely economic, demographic and technical developments which will affect the future level and pattern of energy use and pollution generation.[1]

The advantage of the I-O method, of course, is that it enables not only the direct but also the indirect environmental repercussions of different patterns of final demand to be taken into account. Frequent use has been made of the direct plus indirect ('cumulated') pollution-output coefficients (or 'intensities'), which indicate how much of each pollutant is emitted directly and indirectly in all sectors per unit of final demand in each sector. These coefficients are obtained

---

[1] For examples of energy-related projection studies, see: Leontief & Ford (1972) and Cumberland and Stram (1976), both for the USA; Forsund and Strom (1974), for Norway; Leontief et al. (1977), for the world economy, using a multi-regional model; and Harris et al. (1984), for the USA, who link an I-O model to an energy supply network model.

for each pollutant by post-multiplying its vector of direct pollution-output coefficients by the inverse inter-industry matrix from the I-O model.[1]

In a recent working paper, Gay and Proops (1990) examined carbon dioxide emissions in the UK, with aid of estimated carbon dioxide coefficients and an aggregated 38-sector version of the 1984 UK I-O tables. They estimated intensities per unit of total output and cumulated intensities per unit of final demand. This enabled them to rank industries by intensities and total emissions, and to make suggestions for carbon dioxide reduction strategies. In a related paper, Symons, Proops & Gay (1992) used the UK I-O tables to assess the impacts that carbon taxes on fossil fuels would have on the prices of consumer goods (since the production of such goods implies direct and indirect fossil fuel use). These price changes were used, through a simulation model based on Family Expenditure Survey data, to estimate the effects on consumer demand. The new structure of demand then allows the estimation of fossil fuel use and associated carbon emissions. They experimented with different levels of carbon tax and tried out different ways of implementing a revenue-neutral policy, including a reform designed to offset the adverse distributional effects of carbon taxation on low-income households.

Hughes (1990) explored the possibility of structural change in the composition of final demand in Poland. He replaced the actual final demand vector by alternative vectors based on data for Spain and Portugal. Spain was chosen because it is the Western European country most similar to Poland in population and industrial structure, although its per capita income is three times greater. Portugal, on the other hand, has a per capita income only 50 per cent greater than that of Poland, but with an industrial sector more oriented to light industrial goods. Hughes concluded that the energy and environmental problems of Poland cannot be blamed on the structure of production and final demand: policy should be oriented towards greater energy efficiency and lower pollutant emissions in all sectors, since a switch from heavy to light industry will simply shift the burden of emissions from air pollutants to water pollutants.

---

[1] For studies that estimate cumulated pollution intensities, see: Leontief and Ford (1972), for the USA; Victor (1972), for Canada; Miernyk and Sears (1974), at a sub-regional level, for West Virginia, USA; James et al., (1978), for the Netherlands; James (1982), for Australia; and Forsund (1985) for Norway.

This study is a good example of how I-O analysis can provide useful inputs into the policy-making process.

Two other examples of studies that explore the relations between final demand and environmental impacts are those of Forsund (1985) and Victor (1972). In Forsund's study of Norway, he compared the patterns of discharges of more than 30 residuals, which would result from unit increases in four categories of final demand vector: exports; government consumption; gross fixed asset formation; and private consumption. He found that exports had the highest unit discharges of the majority of the residuals, with the Pulp and Paper, Chemicals and Metals sectors being responsible for some of the major discharges.[1] Victor (1972, pp. 200-209) examined the implications for his "index of ecologic cost" if private car use in Canada were reduced by 50 per cent and replaced by public transport.

A different use for pollution intensities involves estimating cumulated intensities per unit of consumption spending or income for different income or population groups. This indicates the ways in which alternative income levels and distributions, consumption patterns and lifestyles can lead to variations in the environmental implications associated with satisfying these final demands (Pearson, 1984). Such information would be helpful to the framing of a variety of social and economic policies, particularly if combined with estimates of the distributional incidence of pollution abatement costs (Robison, 1985; Ketkar, 1984). A related application, much more demanding both theoretically and empirically, involves the construction of coefficients relating the impacts of pollutants to separate income or population groups. Ultimately this is needed if the benefits from pollution control strategies are to be thoroughly explored by I-O models.

In a valuable review of pollution intensities and their uses, James et al. (1978, ch. 7) raised a number of important questions. They concluded that: (a) it is likely to be risky to use "international" pollution coefficients in situations where

---

[1] In his view: "The strength of the I-O approach is to reveal unexpected results due to interactions in the economy. We may note when splitting up Private Consumption that the category Schooling, etc. generates substantial amounts of Sulfur oxides, Dust, and Hydrocarbons due to intermediate deliveries from Pulp and paper, and that "Medical care" generates more dust than, for instance, "Tobacco" (Forsund, 1985, p 337).

domestic residual discharge data are unavailable;[1] (b) the choice of the number of sectors in an I-O table and the method of classifying them can exert a potentially critical impact on a model's sensitivity; and (c) the usefulness of I-O as a predictive tool may depend on which residuals are of concern: "The findings suggest that input-output methods are highly appropriate in the case of sulphur oxides, which are emitted by a wide range of industries and seem to involve quite significant indirect pollution effects. The case seems fairly strong also in the analysis of carbon monoxide. For nitrogen oxides, particulates and hydrocarbons, the use of input-output may not be so easily justified" (p. 151).

Apart from the pollution intensities, direct plus indirect energy intensities per unit of final demand can be calculated, with the energy being calculated in physical or value units. These cumulated coefficients can be valuable when assessing the impact over time of changing energy prices and changing technology. Al-Ali (1979) used the 1973 I-O tables for Scotland to estimate the cumulated coefficients for four energy industries, enabling him to rank the ten most important energy-purchasing sectors, some of which were not identified when only the direct intensities were considered. He was also able to estimate the sensitivity of all sectors to changes in prices in the energy sector.

In a similar study for the UK as a whole, Common & McPherson (1981, 1982) examined how the cumulated primary energy intensities and the 'roundaboutness' of electricity use in different commodities changed between the 1968 and 1974 UK I-O tables (see also Wright, 1975). They concluded that while overall there had been primary energy-conserving technical change, with the incidence varying across commodities, it had not been on a substantial scale.[2] Although there was considerable stability in relative energy intensities, "It is clear, however, that using the 1968 input-output technology to predict the

---

[1] For examples of the use of 'international' coefficients, see the multi-regional model of Leontief et al. (1977, p.25), and the Australian model of James (1982, p.139); in both cases, many of the emission factors are derived from USA sources.

[2] This, of course, was before the effects of the first oil price shock of 1973-74 had worked their way through; we need to know more about what has happened since then, in the light of the second oil shock of 1979-80, the dramatic decline in oil prices in 1985-86 and other subsequent developments in energy markets.

impact of a given set of primary fuel increases in 1974 on relative commodity prices would have been seriously misleading" (Common & McPherson, 1982, p. 47).

2.6 Abatement Costs and the Treatment of Emissions

The strategy of abating pollution through the treatment of emissions has been widely explored. Leontief (1970a; see also 1973, 1974) proposed the extension of the I-O model by adding columns to represent pollution reduction processes, as well as rows to represent pollution generation. The augmented model can then be used to investigate the generation and abatement of pollution under a variety of assumptions about technologies (particularly abatement technologies), environmental quality standards and final demand.

One of the interesting uses which has been made of I-O models is the estimation of abatement costs. As an example, the world study by Leontief et al. (1977) estimated the costs of achieving a variety of abatement standards between 1970 and 2000 in terms of the total current plus annualised capital costs of abatement procedures as a percentage of gross domestic product. For regions in which the 1970 US standards of pollution abatement were to be applied (regions with a per capita gross product of more than 2,000 US dollars, at 1970 prices), the total costs of all abatement activities were in the range of 1.4 to 1.9 per cent of gross domestic product, while the share of the capital stock used for abatement purposes was between 2.5 and 4 per cent. As the authors point out, however, these projections have to be interpreted carefully, in view of the data limitations of the study.[1]

A different approach to estimating the costs of meeting pollution standards is that of Miernyk and Sears (1974). The aim of their study was to investigate what effects compliance with the U.S. Clean Air Act of 1970 would have on programmes intended to stimulate regional development in the USA. The work was based on a dynamic regional I-O model for West Virginia. Miernyk and

---

[1] "No information exists , for example, on the costs of pollution abatement for medium- or low-income countries; hence it was necessary to assume that abatement involves the same technology throughout the world as it does in the United States of America. Similarly the pollution coefficients were based primarily on United States data" (Leontief et al., 1977, p. 25).

Sears adjusted the elements of the basic matrices in the I-O model to reflect the extra costs of complying with prescribed emission standards for particulates and sulphur dioxide. The authors concluded that although the cost increases implied by compliance were significant, this would not place West Virginia industry at a competitive disadvantage, as long as compliance standards remained national and did not vary by location or establishment.

2.7 Price Impacts

The system of price equations that underlies the I-O system can be used to explore the cost implications of pollution abatement. For example, it is possible to estimate the impact on the prices of all sectors' outputs of making individual sectors pay all or part of the cost of reducing pollution (Leontief, 1970a). For example, Ketkar (1984) adjusted the technical I-O coefficients for abatement cost. He found that the effect of meeting U.S. controls on pollution in the early 1970s was to raise prices on average by 1.4 per cent. However, in the major polluting industries, more substantial price increases occurred, ranging from 3 per cent to more than 12 per cent.

Ketkar also estimated the impact on the level and distribution of incomes of meeting the controls, using a semi- closed I-O system based on Miyazawa's (1976) approach. This procedure, employed in the model described below, involves closing the loop between personal incomes generated in production and incomes spent on consumption, and is necessary if the full impacts of abatement costs are to be followed through (see also: Hawdon & Pearson, 1990, 1992; Pearson, 1984; Rhee & Miranowski, 1984). Ketkar found that the pollution control expenditures generated substantial amounts of extra income and employment and led to increases in gross output in most industries.

Another aspect of abatement costs concerns the distribution of the burden of these costs across different groups in the population, an important policy consideration (Robison, 1985). Studies also have been carried out to explore the direct and indirect impacts on all sectors' prices of higher prices in the energy sectors. In these cases, the energy price increases are assumed to be triggered by causes such as exogenous oil price shocks or changes in fuel taxation, rather than by increases in pollution abatement costs. Apart from Al-Ali's (1979) Scottish study, mentioned earlier, two sets of studies of the impacts in the UK of exogenous fuel price increases are by the National Economic Development Office (NEDO, 1974, 1975a, 1975b) and Common (1985).

The 1974 NEDO study used the 1968 UK I-O tables. They applied a set of postulated fuel price increases to cumulated energy intensities (in value terms) in order to estimate the repercussions on the prices of 90 industrial commodities. The results were compared with a reference case, a projection for 1977 as the situation might have been in the absence of the energy price increases. The work was inspired by the 1973-74 oil price shocks and was completed rapidly. Revised estimates of the price increases and energy-intensiveness estimates were soon published (NEDO, 1975a). The strikingly large revisions in the percentage commodity price increases (many were more than doubled) offered a clear illustration of the sensitivity of the model, and may well have encouraged scepticism in the UK about the value of this kind of I-O modelling.

In a much later paper, Common (1985), using the 1974 UK I-O tables, investigated the distributional impacts of higher energy prices on households. Common calculated the price propagation effects of packages of primary fuel price increases (assuming, like the NEDO studies, that prices are set everywhere to cover costs).[1] The results were consistent with the claim that higher energy prices are regressive in their impact on households in the UK, although Common argues that the regressiveness was less severe than some commentators had implied.

2.8 Changing the Mix of Technologies, and Improvements in Energy Efficiency

Changing the mix of technologies employed offers significant possibilities for acid deposition and carbon dioxide abatement strategies. As an example, Miernyk and Sears (1974) simulated three different processes of converting coal to gas for use in electricity generation. In a somewhat different approach,

---

[1] The appropriateness of the "cost plus pricing rule" has been challenged by Hughes, in a series of studies of fuel taxes in less-developed countries (Hughes, 1984, 1985a, 1985b, 1985c, 1986a, 1986b).

Harris et al. (1984) examined the hypothetical impact of offshore oil and gas discoveries on air pollution.

In an application which compares both a change in the mix of technologies and investment in energy conservation, Common (1983), in a speculative paper, compared the costs of a low energy strategy for the UK, involving industrial energy conservation, with an alternative "benchmark" strategy involving replacing the 1974 electricity generation technology with an all-nuclear generation technology. He adjusted the coefficients relating fuel inputs to industrial sectors for assumed fuel conservation, and replaced the electricity coefficient column in the absorption matrix by a column intended to represent the technology of all-nuclear generation. Common concludes that, "Substantively, it has been shown that in 1974 conditions the industrial energy conservation measures claimed in the IIED's [International Institute for Environment and Development] low energy scenario to be technically feasible as of 1976 would have been worth as much, in terms of avoided primary input costs, as the complete nuclearization of the electricity industry ..." (p. 236).

2.9 Optimisation Approaches

The fact that I-O analysis can be set within a framework of constrained optimisation makes it possible, to investigate the cost-effectiveness of different strategies for achieving predetermined sets of environmental quality targets in the form of emission standards. A good illustration is the work of Kohn, which combines linear programming and regional I-O analysis in a study of the control of five separate air pollutants in the St Louis airshed in the U.S.A. The efficient set of control methods is, "that set which eliminates excess pollution, including the incremental pollution associated (directly and indirectly) with pollution control itself, at the least cost ....' (Kohn, 1975, p. 326).

Kohn finds that the result of incorporating the input-output feedbacks to the vector of polluting activities is to alter the optimal set of control methods, an option not available within the standard Leontief approach. Moreover, Kohn's model has the advantage that it allows for increasing marginal costs per unit of pollution control. Kohn suggests also that the shadow prices implied by his linear programming solutions, which provide information about marginal costs of abatement, could be useful inputs into the process of setting emission charges that might be used to achieve target levels of pollution control.[1]

2.10 The Limitations of I-O Modelling

The principal advantage of I-O analysis, despite its drastic simplifications, is that as long as appropriate data are available, it offers a workable tool of general equilibrium analysis, making it possible to explore the complex direct and indirect repercussions of economic changes. However, a number of significant simplifications and limitations need to be borne in mind. These have been reviewed more fully in Pearson (1989).

The most important simplification relating to general use is, of course, the linearity of the basic model, with the assumptions of fixed proportions of inputs and constant returns to scale. This inevitably results in a somewhat distorted picture of a non-linear world. Moreover, the distortions are likely to increase with the size and duration of the changes that are analysed, although their extent remains difficult to predict. Linearity also carries penalties when pollution generation and abatement are represented as linear processes. However, there is in principle little difficulty in relating emissions to sectoral output in a non-linear fashion. Pollution abatement is perhaps more of a problem. The validity of assuming constant marginal abatement costs has rightly been questioned. However, abatement processes can be treated as effectively non-linear, as the work of Kohn (1975) and Muller (1979) shows.

The limited extent of the environmental coverage of most energy-environment I-O models needs to be borne in mind when interpreting their results and using them to aid policy formulation. In most I-O models only a restricted set of residuals is covered, while resource inputs from the environment are rarely accounted for, except in the hitherto largely non-operational "economic-ecologic" models mentioned earlier. Nor have there been many

---

[1] For further comments on shadow prices, see: Lowe (1979); Hawdon (1986). Other models that combine linear programming and I-O include those of Victor (1972), Muller (1979), and James et al. (1986).

attempts to follow the "materials balance approach" (Kneese, Ayres and D'Arge, 1970; Ayres, 1978; James, 1985).

I-O's undoubted appetite for data is clearly exacerbated when I-O is extended to incorporate pollution emissions and abatement at a sectoral level. Furthermore, to the extent that the data are inappropriately-classified, inaccurate, unavailable or replaced by poor proxies, the results will be wrong or misleading; this will damage the effectiveness of the model. This, of course, is true of all models, but for I-O the errors can be multiplicative and thus, in some circumstances, particularly serious.

2.11 Reactive Strategies and the Use of I-O in the UK

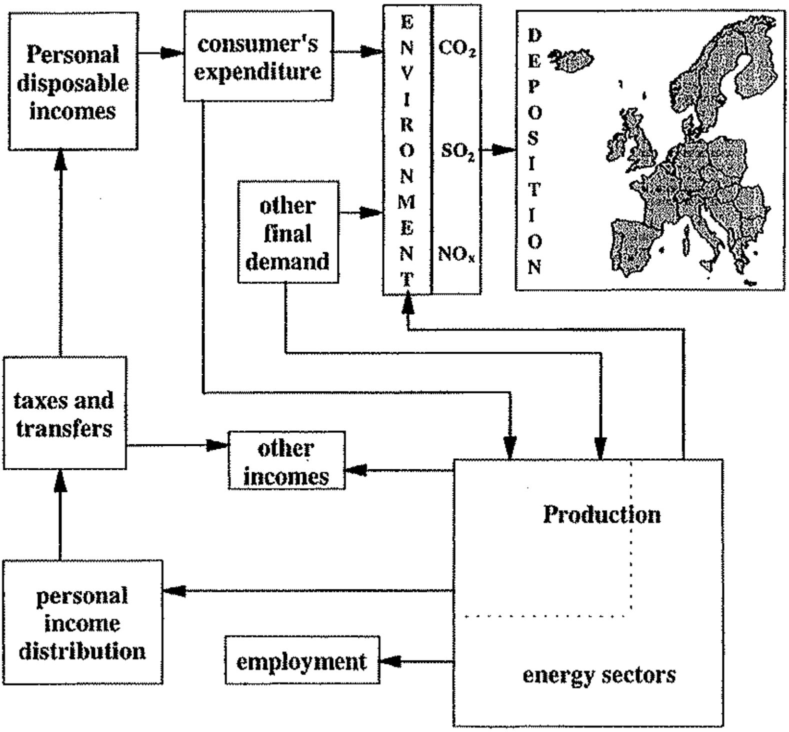
As this review has indicated, there is a substantial international literature on the use of I-O in the analysis of energy and environment issues. However, although these types of I-O models have been applied fairly widely in a number of countries, it is worth considering why they have rarely been applied in the UK. The contributory factors have included: (a) reservations about the usefulness of this kind of modelling approach (partly founded on the limitations just discussed); (b) insufficient demand for forward-looking studies; and (b) a shortage of up-to-date, appropriately-classified data on the structure of production, on emissions, and on abatement and damage costs. The reactive approach to policy-making that has been followed in the UK (and many other countries) tended not to encourage the kinds of speculative modelling studies that are an essential adjunct to proactive energy-environment policy-making. However, perceptions of the seriousness of energy-environment issues are leading to a rightward shift in the demand for both modelling activity and data. It is here that I-O, despite its limitations, may have a useful part to play.

3 THE STRUCTURE OF THE MODEL

3.1 The Features of the model

The model described below represents the major elements in the income-expenditure-output-income cycle. It can be operated either as a semi-closed Leontief system, with personal consumption endogenously determined (Hawdon & Pearson, 1990; Hawdon & Pearson, 1992; Pearson, 1984), or as an open system. As an aid in identifying the key features of this integrated model, the flowchart (Figure 1) depicts the income, expenditure, output and environmental flows. What is modelled is in effect a simultaneous system in which changes in one set of variables trigger a complex series of (often obscure and counterintuitive) repercussions. The model is driven by four main structural features. It is the interaction between these features that determines the nature of the system's response to changes in any exogenous variables or parameters.The features are: (a) the pattern of consumer spending by income groups (via expenditure coefficients); (b) the interindustry production structure, including appropriately disaggregated energy sectors (via input-output coefficients) - there are five energy sectors - coal, oil extraction, oil processing, electricity and gas - plus agriculture and forestry, construction, manufacturing, transport and services); (c) the distributions of personal disposable incomes by income group, generated in each production sector (via value added distribution coefficients); and (d) the structure of environmental effects from production, consumption and use of energy (via coefficients for sulphur and nitrogen oxides and carbon dioxide and for European deposition). In addition personal consumption is partially determined by relative prices.

Figure 1: Outline of Principal Flows



energy sectors. D^x is a matrix of coefficients of environmental effects per unit value of gross output, while D^c and D^f are matrices of coefficients of environmental effects per unit value of personal consumption and of non-personal final expenditure, respectively (D^c could be disaggregated to distinguish between the effects of the consumption activities of different social groups). L' is a row vector of employment coefficients per unit of gross output.

The model can thus be used to simulate the effects of a variety of policies and possibilities, not only through changes in exogenous variables (final demand and income taxes and transfers) but also through changes in the structural matrices and their coefficients. In each case the full effects, direct, indirect and income-induced, can be traced and the changes in comparative static equilibrium values discovered. In this way, policy issues connected with energy use and environmental impacts, employment, and economic welfare can be investigated.

4 ENDAM2 AND POLICY SIMULATION

4.1 The program's objectives.

Development of the program went through two major phases. Initially a four-sector version was created under LOTUS 123. This was partially menu-driven and offered wide opportunities for user interaction with the contents of virtually any of the component matrices (Hawdon & Pearson, 1990). ENDAM2 is a spreadsheet implementation of the model on a slightly larger scale. The original aims of the program were: (1) to provide a teaching aid to enhance the understanding of economy/energy/environment interactions; (2) to enable the user to explore in a fairly flexible way the impacts of expenditure and fiscal policy decisions on output and income distribution via the technology and production structure of the economy and (3) to preserve the important national income accounting identities and ensure consistency in model outputs. Aims 1 and 3 were retained in the new version but aim 2 was focused more sharply on energy and environmental policy issues. The most important difference between the versions lies in the desire to begin to develop the model into a genuine tool for investigating policy issues.

4.2 Data

The original ENDAM model was purely a teaching device with 4 production sectors designed for ease of use at a student level. ENDAM2 is more ambitious and offers the scope for genuine if limited experimentation. As we have seen, it covers 10 sectors, five energy sectors (coal, oil extraction, oil processing, electricity and gas) together with agriculture and forestry, construction, manufacturing, transport and services. Interindustry data was obtained from the latest UK Input Output tables (CSO (1990)) using the commodity by commodity sales analysis. Energy data was obtained from the Digest of Energy Statistics. Information on environmental emissions and costs was more difficult to identify. The UK Digest of Environmental Protection and Water Statistics provides a statistical analysis of emissions of the major airborne pollutants. We decided to focus on the three gases - sulphur dioxide (SO_2), nitrogen oxide (NOx) and the main contributor to global environmental change, carbon dioxide (CO_2) - whose output could be most clearly related to economic activity. Although it is not possible to identify the exact contribution of each fuel to total emissions the data is sufficient to identify the major components of Dx, the industry emissions matrix, and it was possible to construct Dc and Dy from other available information on heating and motor vehicle use.

The model adopts a very simple representation of price and income effects in determining consumer expenditure. As in the previous version, Family Expenditure survey data was used to split total consumers expenditure between the income categories. Total expenditure was divided in proportion to relative income levels of the two major groups. Analysis of upper and lower income quartiles in the FES was used to allocate expenditure between individual sector outputs. Adjustments to these allocations were required to balance the given row (sales) totals since no satisfactory breakdown of expenditure patterns between income groups is provided in the national income statistics. Income was separated into income from employment (YL) and gross profits,etc (YU) in an attempt to identify lower and upper income groups earnings. Price elasticities were needed in order to compute the effects of carbon taxes on energy consumption. In the absence of any satisfactory model of price transmission throughout industry sectors it was decided not to incorporate price effects on interindustry demands for fuels. Instead the burden of any carbon taxes is borne by final demand and in particular by personal consumption. This is also an assumption made recently by Symons et al (1992).

Compensated demand elasticities were derived from current econometric analysis of UK energy demand over the period 1960 to 1991. Based on an error correction model, the long run residential energy demand elasticities estimates were as follows:-

TABLE 1 - RESIDENTIAL ENERGY DEMAND ELASTICITY ESTIMATES

Fuels	Long Run Cross Elasticities of Demand - UK.			
	Coal	Oil	Electricity	Gas
Coal	-2.30	0.14	1.13	0.97
Oil	0.04	-0.80	0.41	0.35
Electricity	0.07	0.07	-1.20	0.52
Gas	0.06	0.07	0.56	-1.10

Source: Surrey Energy Economics Centre estimates.

The implied income elasticity for each expenditure category is unity, a restriction which will be relaxed in future versions of the model.

Two types of atmospheric pollution costs are calculated in the model. The first is the cost of the damage done to human health, buildings and other structures and plant life by acid rain. Such costs are likely to be proportional not simply to emissions but to the product of emission quantities and economic activity. Pearce, Markandya and Barbier (1989) present estimates varying between 0.5 and 6% of GNP for various developed countries. We have adopted a value within this range for the UK but it is clear that any costs derived in this way must be heavily qualified since no detailed direct estimates exist as yet for the UK.

The second type of cost is the 'clear up' cost of reducing emissions by specified amounts, usually referred to as abatement costs. Here we have used information presented by Newbery in his survey article (Newbery (1990)). Abatement can be achieved by installation of capital equipment like Flue Gas Desulphuration units in power stations which extract sulphur and directly lower emissions, or by using lean burn engines in motor vehicles. These processes incur high capital costs and in addition require increased fuel consumption to make up for lost output. We have chosen an annualized cost per tonne of SO_2 removal from power stations of $783 and an increased fuel cost of around 10%. The model could be extended to include other ways of reducing sulphur emissions e.g. by increasing imports of low sulphur fuels, by using fluidised bed combustion in coal stations or by switching to gas. Some investigators comment on the rising marginal cost of emission reduction but we do not incorporate this feature in the model both because of a lack of agreement on costs and because of the cost reducing effect of technical progress in the longer term. In regard to NOx we incorporate both extra capital costs and increased fuel consumption by vehicles and stationary sources alike. For CO_2 we have not estimated the direct abatement costs since abatement is induced by fuel switching or improvements in energy efficiency.

4.3 The Structure of the Program.

The user is presented with input tables providing the opportunity to alter basic assumptions regarding energy intensity, SO_2 and NOx unit emission levels, final demand and taxation rates. Carbon taxes can be set for up to four fuels. Within each table there is no restriction on numerical input so that a wide variety of simulations can be performed. The structure is inevitably a compromise between freedom to experiment and the need for minimal guidance in the face of complexity.

Program flow is controlled entirely by menus and help is available at each stage. The user can view the basic matrices which make up the program data base and can read interpretative text. The main menu presents the user with 6 options including the quit option. Option 1 presents a statement of the problem to be tackled by the program together with information on levels of emissions and their potential effects for the UK. Option 2 provides some additional explanation of the program itself which can be ignored after the first run. The entire data base is open to view using option 3 (Economy) which provides access to data relating to transactions, coefficients, and the augmented inverse of the model. The most important option is option 4 which permits the assessment of policy changes. Selecting 4 installs an impact menu with choices between changing technologies (option 1), changing sector spending and taxes (option 2), and introducing carbon taxes (option 3). A fourth option on this menu permits the complete resetting of all policy variables to their initial (zero) levels together with automatic recalculation of model parameters so that further incremental policy investigations are not contaminated by previous choices. Resetting is optional so that the effects of policy combinations can be assessed. Each policy choice invokes policy tables for inserting desired parameters. The model then calculates the equilibrium effects on output, expenditure, emissions, European SO_2 depositions, energy use and abatement costs and benefits, all of which can be inspected graphically.

5 EXPERIMENTS USING ENDAM2

Apart from exploring the structure of the economy, the model can be used as a tool for performing straightforward but revealing simulations. Here we describe the results of studies involving efficiency changes, alterations in final expenditures, changing the structure of the electricity industry, mixed spending and tax changes and finally the imposition of an energy tax.

5.1 Simulating efficiency and emission changes.

Technical efficiency improvements in the use of any input can be represented in the form of reductions in the value of input coefficients along a row of the coefficients matrix (Matrix A in equation (1)). The first two simulations compared the impact of a uniform 10% improvement in efficiency of coal use throughout all sectors with that of a similar improvement in electricity use. As might be expected the improvement in electricity efficiency had a greater overall direct and indirect effect on industry output (see Table 2). Indeed when electricity intensity was reduced the effect on coal demand was equivalent to half the fall resulting from a direct reduction in coal intensities. The main difference, however, occurs in emission output. The reduction in SO_2 emissions from the change in electricity intensities was 7 times greater than that achieved by the change in coal intensities. In addition, reducing electricity intensities had a relatively small effect on employment and income. It is worth pointing out, however, that it would require a 50% improvement in efficiency of electricity use to secure a 20% reduction in total SO_2 from electricity efficiency improvements alone. This gives some idea of the magnitude of the task involved in attaining international targets for emission reduction.

TABLE 2 - EFFECTS OF CHANGES IN ELECTRICITY AND COAL INTENSITIES ON GROSS OUTPUT, INCOMES, EMISSIONS AND EMPLOYMENT

SECTOR/ INCOMES/ EMISSIONS/ EMPLOYMENT	ORIGINAL OUTPUT	10% CHANGE IN	
		Electricity Intensity	Coal Intensity
AF (£billion)	154	0	0
COAL "	49	-2	-5
OILE "	225	0	0
OILP "	151	0	0
ELEC "	123	-7	-1
GAS "	73	0	0
CONST "	452	0	0
MANU "	1967	-4	-5
TRANS "	201	0	-1
SER "	2548	-7	-7
YU "	867	-4	-3
YL "	1538	-7	-8
SO_2 (thousand tonnes)	3676	-145	-21
NOx "	2274	-45	-9
CO_2 (mn tonnes)	157	-3	-1
W (0,000)	2079	-6	-7

5.2 Changing structure of electricity.

Substantial changes in the nature of UK electricity generation have been set in train by the privatisation of the industry in 1991. From our point of view the most significant development has been the reduction in coal generated electricity and the introduction of new, more efficient, gas fired capacity. This is a process whose future is not at all clear and is dependent to a large extent on political decisions about the future size of the UK coal industry. In these circumstances the model can fulfil a useful role in exploring the consequences of specified alterations in input structure. Introducing more gas power generation at the expense of coal involves changing the input output coefficients in the electricity column of the input output coefficients matrix, A. The effect of any such change is, unfortunately, to unbalance the coefficient matrix. It is necessary to compensate any absolute change in one coefficient by opposite changes in other coefficients. This ensures that impacts on the rest of the economy come from changes in the composition of the inputs rather than from changes in total input requirements. The SO_2, NOx and CO_2 coefficients for electricity have also to be altered to allow for the changed average pollutant output effect resulting from changes in input structure. An experiment was carried out which involved reducing the coal in electricity coefficient from 0.3 to 0.2 and increasing the gas in electricity coefficient from 0 to 0.1. Emission coefficients for electricity were reduced by 20% (CO_2), 35% (SO_2) and by 17.5%(NOx). As may be seen from Table 3, required coal output falls by £14 billion (28%), and there are reductions in all other industry gross output levels except for gas, oil exploration and production and construction. Emissions of SO_2 are particularly affected, falling by 25.8% (950 thousand tonnes). The impacts on CO_2 and NOx are also significant at 7% and 6.6% respectively, with the difference largely reflecting the fact that both fuels are carbon based (CO_2) and the importance of activities other than electricity generation in the production of NOx emissions.

TABLE 3 - EFFECTS OF CHANGING STRUCTURE OF ELECTRICITY SUPPLY ON GROSS OUTPUT, INCOME, EMISSIONS AND EMPLOYMENT

SECTOR/INCOMES/ EMISSIONS/ EMPLOYMENT	ORIGINAL OUTPUT	EFFECTS OF STRUCTURAL CHANGE
AF (£billion)	154	-1
COAL "	49	-14
OILE "	225	4
OILP "	151	-1
ELEC "	123	-2
GAS "	73	12
CONST "	452	0
MANU "	1967	-8
TRANS "	201	-1
SER "	2548	-8
YU "	867	-1
YL "	1538	-11
SO_2 (thousand tonnes)	3676	-950
NOx "	2274	-151
CO_2 (million tonnes)	157	-11
W (0,000)	2079	-104

5.3 Changing expenditure levels.

Final non consumption expenditure (F) includes government expenditure, exports and fixed capital formation. A simulation was carried out in which expenditure on coal was decreased by £1 billion (Table 4). Coal output fell by 2.2% but the effect on other industry output was less than 1%. By contrast a similar reduction in electricity expenditure is seen to impact on coal, as well as electricity, output reducing it by around 1%. Reductions in electricity expenditure are around 6 times as effective in lowering SO_2 emissions, 8 times as effective for NOx and 5 times as effective for CO_2, given unchanged technology. The effects on total SO_2 emissions deposited outside the UK on Europe and North Africa are shown in the bottom row of the table.

TABLE 4 - REDUCTIONS IN GROSS OUTPUT, INCOMES, EMISSIONS AND EMPLOYMENT FROM £1 BILLION CHANGES IN FINAL EXPENDITURE IN EACH ENERGY SECTOR

SECTOR/INCOMES/ EMISSIONS/ EMPLOYMENT	COAL	OIL	OILP	ELEC	GAS
		(x 10^1)			
AF (£ billion)	1	1	0	1	0
COAL "	11	0	0	4	0
OILE "	1	11	5	0	4
OILP "	1	0	10	1	0
ELEC "	2	1	0	11	1
GAS "	1	0	0	0	11
CONST "	0	0	0	0	0
MANU "	11	6	4	7	5
TRANS "	1	1	0	1	
SER "	15	11	8	12	9
YU "	7	12	7	7	7
YL "	6	8	6	11	8
SO_2 (th. tonnes)	4	16	46	241	13
NOx "	9	9	8	75	7
CO_2 (mn. tonnes)	1	1	1	5	1
W (0,000)	5	8	6	11	8
External SO_2 Deposition (th. tonnes of sulphur)	30.2	10.6	31.1	163	8.96

5.4 The effect of energy taxes.

In three experiments the residential prices of coal, electricity and gas were independently raised by 10% to simulate the effects of an energy tax (Table 5). The effect of the coal price increase was to lower slightly the level of overall industrial output, incomes, emission levels and employment. Increasing the price of electricity on the other hand led to significant interfuel substitution and to substantial reductions in emissions. The effect of increasing the price of gas is, as might be expected, quite different. The substitution of other fuels for gas leads to an increase in overall pollution levels. Since very different percentage changes in emissions result from given changes in fuel prices, it is interesting to calculate what changes are required to achieve a given level of emission reduction. The effect of a 10% increase in coal prices is achievable by a 2% subsidy on gas or a 0.67% increase in electricity prices. This suggests that selective changes in fuel prices may be more efficient in attaining environmental goals than blanket tax changes.

TABLE 5 - EFFECTS OF 10% TAX ON SPECIFIC FUELS ON GROSS OUTPUT, INCOMES, EMISSIONS AND EMPLOYMENT

	SECTOR	COAL	ELEC.	OIL	GAS
Gross output (£ billion)	AF				
	COAL	-1	-2		1
	OILE		1	-1	-1
	OILP			-2	1
	ELEC		-7		2
	GAS		2		-5
	CONST				
	MANU	-4	-5	-4	-3
	TRANS	-1	-1	-2	-1
	SER	-12	-14	-12	-10
Incomes (£ billion)	YU	-4	-5	-4	-4
	YL	-8	-10	-7	-8
Emissions (thou. tonnes)	SO_2	-10	-151	-4	52
	NOx	-22	-47	-12	18
	CO_2	-1	-3	-1	0
Employment (10,000)	W	-8	-10	-8	-6

6 CONCLUSION

ENDAM2 offers the opportunity for assessing a wide range of hypothetical policy stances. However the current version is limited by its inability to take into account the demand responses of intermediate producers to price movements and by its relatively crude approach to abatement costs and damage costs. The incorporation of such effects would make it possible to examine in more detail the relative merits of market based and command instruments for pollution control. Future versions are intended to improve and develop the database and enhance the opportunities for investigating domestic and international policy issues and trade-offs.

Despite its current limitations, ENDAM2 remains, in our view, a useful teaching tool that provides an interactive introduction to the complexity of sectoral interrelationships and energy-environmental issues in a modern economy. It also shows some promise as a research tool to assist in the examination of energy-environmental policy questions.

APPENDIX A - SECTOR DEFINITIONS

ENDAM	S.I.C.	SECTOR
AF	(1-2)	Agriculture & Forestry
COAL	(3)	Coal
OILE	(4)	Oil Extraction
OILP	(5)	Oil Processing
ELEC	(6)	Electricity
GAS	(7)	Gas
CONST	(88)	Construction
MANU	(8-87)	Manufacturing (d)
TRAN	(91-94)	Transport
SERV	(89,90,95)	Services/Distribution
IMP	(104)	Imports
OTHER	(105,106)	Sales by final demand /Taxes on expenditure
VU	(108)	Gross profits,etc
VL	(107)	Income from employment
GROSS	(109)	Gross Inputs, gross output
CU	(104pt)	Consumers expenditure (Upper Group)
CL	(104pt)	Consumers expenditure (Lower Group)
YU		Income Upper
YL		Income Lower
TU		Tax Upper
TL		Tax Lower
W		Employment

REFERENCES

Ahmad, Y.J., Dasgupta, P. and Maler, K-G. (1984), **Environmental Decision-Making, Volume Two**, Hodder and Stoughton, London.

Al-Ali, H.M. (1979), "Input-output analysis of energy requirements: an application to the Scottish economy in 1973", **Energy Economics**, October, pp. 211-218.

Ayres, R.U. (1978), **Resources, Environment and Economics**, Wiley, New York.

Barde, J.-P. & Pearce, D.W. (1991), **Valuing the Environment: Six Case-Studies**, Earthscan, London.

Behrens, A. (1984), "Energy and output implications of income redistibution in Brazil", **Energy Economics**, April, pp. 110-116.

Baker,P, Micklewright, J., and Blundell, R.(1987) 'Modelling Energy Demand and Household Welfare using Micro-Data'. **Paper No 141**, Queen Mary College, London.

Blundell, R. 'Consumer Behaviour: Theory and Empirical Evidence - A Survey'. **Discussion Paper No 88-05**, University College, London.

Boero, G, Clarke, R & Winters, LA (1991), **The Macroeconomic Consequences of Controlling Greenhouse Gases: A Survey**, HMSO, London.

Braden, J.B. & Kolstad, C.D. (1991), **Measuring the Demand for Environmental Quality**, North-Holland, Amsterdam.

Bullard III, C.W. and Herendeen, R.A. (1977), "The energy cost of goods and services: an input-output analysis for the USA, 1963 and 1967", in Thomas, J.A.G. (ed.) **Energy Analysis**, IPC Science and Technology Press, Guildford, pp. 71-81

Casler, S. & Hannon, B. (1989), Readjustment Potentials in Industrial Energy Efficiency and Structure', **Journal of Environmental Economics and management**, 17, 93-108.

Casler, S. & Wilbur, S. (1984), "Energy Input-Output Analysis: a simple guide", **Resources and Energy**, 6, pp. 187-201.

Central Statistical Office (1990), 'Input Output Tables for the United Kingdom 1985', **Central Statistical Office**, London.

Common, M.S. (1983), "The IIED industrial energy conservation programme: an order of magnitude assessment", **Energy Economics**, October, pp. 232-236.

Common, M.S. (1985), "The distributional implications of higher energy prices in the UK", **Applied Economics**, 17, pp. 421-436.

Common, M.S. & McPherson, P. (1981), "The Energy Intensities of Commodities: 1968 and 1974", University of Stirling Discussion Papers in Economics, Finance and Investment, Stirling.

Common, M.S. & McPherson, P. (1982), "A note on energy requirements: Calculations using the 1968 and 1974 UK input-output tables", **Energy Policy**, March, pp. 42-48.

Cumberland, J.H. & Stram, B.N. (1976), "Empirical Results from Application of Input-Output Models to Environment Problems," in Polenske, K.R. & Skolka, J.V. (eds), **Advances in Input-Output Analysis**, Ballinger, Cambridge, pp. 365-382.

Daly, H. (1968), "On Economics as a Life Science," **Journal of Political Economy**, 76, pp. 392-406.

Deaton, A. and Muellbauer, J. (1980) **'Economics and Consumer Behaviour'** Cambridge University Press, Cambridge.

Denton, R.V. (1977), "The energy cost of goods and services: an input-output analysis for the Federal Republic of Germany, 1967", in Thomas, J.A.G. (ed.) **Energy Analysis**, IPC Science and Technology Press, Guildford, pp. 82-87.

Economic Commission for Europe (1984), **Air-Borne Sulphur Pollution: Effects and control**, Air Pollution Studies 1, United Nations, New York.

Fisher, A.C. (1981), **Resource and Environmental Economics**, Cambridge University Press, Cambridge.

Førsund, F.R. (1985), "Input-Output Models, National Economic Models, and the Environment", ch. 8 in Kneese, A.V. & Sweeney, J.L. (eds.) (1985), pp. 325-341.

Førsund, F.R. & Strøm, S. (1974), "Industrial Structure, Growth and Residual Flows," in Rothenberg, J.G. and Heggie, I.G. (eds), **The Management of Water Quality and the Environment**, Macmillan, London, pp. 21-69.

Freeman III, A.M. (1979), **The Benefits of Environmental Improvement**, Johns Hopkins, Baltimore.

Freeman III, A.M. (1985), "Methods for Assessing the Benefits of Environmental Programs," in Kneese,A.V. & Sweeney, J.L. (eds) (1985), pp. 223-70.

Gay, P.W. & Proops, J.L.R. (1990), 'Carbon Dioxide Production by the U.K. Economy: An Input-Output Assessment', **Working Paper No. 89-22**, Department of Economics and Management Science, University of Keele.

Hanley, N (1990), 'Are there Environmental Limits to Cost-Benefit Analysis?', **Discussion Paper 90/6**, Department of Economics, University of Stirling.

Harris, C.C., McConnell, V.D. & Cumberland, J.H. (1984), "A model for forecasting the economic and environmental impact of energy policy", **Energy Economics**, July, pp. 167-176.

Hawdon, D. (1986), "Linear Programming, Shadow Prices and Environmental Taxes", **Surrey Energy Economics Discussion Paper No. 31**, University of Surrey, Guildford. To appear in: Gossling, W.F. (ed) (1991, forthcoming), **The Greenhouse Effect,the Environment and Input-Output Analysis**, Input-Output Publishing Company, Lowestoft.

Hawdon, D & Pearson, PJG (1990), in Welford, R (ed), **Information Technology for Social Scientists**, European Research Press, 187-204.

Hawdon, D & Pearson, PJG (1992), 'A Model of Energy-Environment Interactions in the UK', **Proceedings of the 15th Annual Conference of the International Association for Energy Economics, 'Coping with the Energy Future: Markets and Regulations, Volume II**, Tours, France, L-129-32.

Herendeen, R.A. (1974), "Use of Input-Output Analysis to Determine the Energy Cost of Goods and Services", in Macrakis, M.S. (ed.) **Energy: Demand, Conservation and Institutional Problems**, MIT Press.

Hoch, I. and Carson, R.T. (1984), **An Energy-Oriented Input-Output Model**, Resources for the Future,Washington D.C.

Hope, C. and Owens, S. (1986), "Frameworks for Studying Energy and the Environment", **Environment and Planning A**, 18, pp. 851-64.

Hufschmidt, M.M. and Hyman, E.L. (eds) (1982), **Economic Approaches to Natural Resource and Environmental Quality Analysis**, Tycooly International, Dublin.

Hughes, G.A. (1984), "The Impact of Fuel Taxes in Thailand", **World Bank Staff Working Paper**, Washington, D.C.

Hughes, G.A. (1985a), "The Incidence of Fuel Taxes: A Comparative Study of Three Countries", **Discussion Papers Series, XIII**, Department of Economics, University of Edinburgh.

Hughes, G.A. (1985b), "Fuel Prices, Taxes and the Distribution of Income in Thailand", **Discussion Papers Series, XIV**, Department of Economics, University of Edinburgh.

Hughes, G.A. (1985c), "Substitution Effects and the Impact of Fuel Taxes in Thailand",**Discussion Papers Series, XV**, Department of Economics, University of Edinburgh.

Hughes, G.A. (1986a), "The Impact of Fuel Taxes in Tunisia", Department of Economics, University of Edinburgh (mimeo).

Hughes, G.A. (1986b), "Substitution and the Impact of Transport Taxation in Tunisia", Department of Economics, University of Edinburgh (mimeo).

Isard, W., Choguill, C.L., Kissin, J., Seyforth, R.H. & Tatlock, R. (1972), **Economic-Ecologic Analysis for Regional Development**, Free Press, New York.

James, D.E. (1982), "General Equilibrium Modelling of Environmental Damage: Energy Use and Combustion Emissions in Australia", in Hufschmidt, M.L. & Hyman, E.L.(eds.) **Economic Approaches to Natural Resource and Environmental Quality Analysis**, Tycooly International, Dublin, pp. 124-145.

James, D.E. (1985), "Environmental Economics, Industrial Process Models, and Regional Residuals Management Models", in Kneese, A.V. & Sweeney, J.L. (eds) (1985), pp. 271-324.

James, D.E., Jansen, H.M.A. & Opschoor, J.B. (1978), **Economic Approaches to Environmental Problems**, Elsevier, Amsterdam.

James, D.E., Musgrove, A.R. deL. & Stocks, K.J. (1986), "Integration of an economic input-output model and a linear Programming technological model for energy systems analysis", **Energy Economics**, April, pp. 99-112.

Jones, M. (1989), "The Potential of Decision Analysis as a Means of Integrating the Environment into Energy Policy Decision-Making", **Environment and Planning A**, 21.
Ketkar, K.W. (1984), "Environmental protection policies and the structure of the U.S. economy", **Applied Economics**, 16, pp. 237-256.

Kneese, A.V. & Sweeney, J.L (eds) (1985), **Handbook of Natural Resource Economics**, Vol. I, North-Holland, Amsterdam.

Kneese, A., Ayres, R.V. and D'Arge, R. (1970), **Economics and the Environment**, Resources for the Future, Johns Hopkins, Baltimore.

Kohn, R.E. (1975), "Input-Output Analysis and Air Pollution Control", in Mills, E.S. (ed.) **Economic Analysis of Environmental Problems**, N.B.E.R., Massachusetts. Reprinted in Ahmad et al. (1984).

Leontief, W. (1966), **Input-Output Economics**, First Edition, Oxford University Press, Oxford.

Leontief, W. (1970a), "Environmental Repercussions and the Economic Structure: An Input-Output Approach" in **Review of Economics and Statistics**, 52, pp. 262-77. Reprinted in Leontief (1977, 1986).

Leontief, W. (1973), "National Income, economic structure and environmental externalities", in Moss, M. (ed.) **The Measurement of Economic and Social Performance**, Studies in Income and Wealth, Vol, 38, N.B.E.R., New York, pp. 565-76. Reprinted in Leontief (1977, 1986).

Leontief, W. (1974), "Structure of the World Economy: Outline of a Simple Input-Output Formulation". **American Economic Review**, 64, pp. 823-34. Reprinted in Leontief (1986).

Leontief, W. (1977), **Essays in Economics**, II, Basil Blackwell, Oxford.

Leontief, W. (1986), **Input-Output Economics**, Second Edition, Oxford University Press, Oxford.

Leontief, W., Carter, A.P. and Petri, P. (1977), **The Structure of the World Economy**, Oxford University Press.

Leontief, W. & Ford, D. (1972), "Air Pollution and the Economic Structure: Empirical Results of Input- Output Computations", in Brody, A. and Carter, A.P. (eds.), **Input-Output Techniques**, North-Holland, Amsterdam, pp. 9-30.

Leung, P. & Hsu, G.J.Y. (1984), "An integrated energy planning model for Hawaii", **Energy Economics**, April, pp. 117-121.

Lowe, J., Lewis, D. & Atkins, M. (1982), **Total Environmental Control**, Pergamon Press, Oxford.

Lowe, P.D. (1979), "Pricing Problems in an Input-Output Approach to Environment Protection", **Review of Economics and Statistics**, 61, pp. 110-117.

McCutcheon, R. (1979), **Limits of a Modern World**, Butterworths, London.

Meadows, D.H, Meadows, D.L. and Randers, J (1992), **Beyond the Limits: Global Collapse or a Sustainable Future**, Earthscan, London.

Miernyk, W.H. and Sears, J.T. (1974), **Air Pollution Abatement and Regional Economic Development**, Lexington Books, D.C. Heath.

Miller, R.E. and Blair, P.D. (1985), **Input-Output Analysis: Foundations and Extensions**, Prentice-Hall, Englewood Cliffs.

Mitchell, R.C. & Carson, R.T (1989), **Using Surveys to Value Public Goods: The Contingent Valuation Method**, Resources for the Future, Washington, D.C.

Miyazawa, K. (1976), **Input-Output Analysis and the Structure of Income Distribution**, Springer- Verlag, Berlin.

Muller, F. (1979), **Energy and Environment in Interregional Input-Output Models**, Martinus Nijhoff, Boston.

NEDO (National Economic Development Office) (1974), **The increased cost of energy - implications for UK industry**, HMSO, London.
NEDO (National Economic Development Office) (1975a), **The increased cost of energy - supplementary calculations**, HMSO, London.

NEDO (National Economic Development Office) (1975b), **Price propagation in an input-output model - determining the implications of higher energy costs for industrial prices**, HMSO, London

Newbery, D. (1990)'Acid Rain' **Discussion paper No 442**. Centre for Economic Policy Research, London.

Nordhaus, W.D. (1991), 'To Slow or Not to Slow: the Economics of the Greenhouse Effect', **Economic Journal**, 101 (407), 920-937.

OECD (Organisation for Economic Co-operation and Development) (1981), **The Costs and Benefits of Sulphur Oxide Control**, OECD, Paris.

OECD (Organisation for Economic Co-operation and Development) (1985), **Environment and Economics**, Organisation for Economic Co-operation and Development, Paris.

OECD (Organisation for Economic Cooperation and Development) (1987), **Energy and Cleaner Air: Costs of Reducing Emissions**, OECD, Paris.

Park, S. (1982), "An input-output framework for assessing energy consumption", **Energy Economics**, 14, pp. 105-110.

Pearce, D.W. (1976), **Environmental Economics**, Longman, London.

Pearce, D.W. (1988), "Energy Policy and Environmental Policy in the UK", chapter in Pearson, P.J.G. (ed) **Energy Policies in an Uncertain World,** Macmillan, London.

Pearce, D., Markandya, A.,and Barbier, EB (1989) **Blueprint for a Green Economy**. Earthscan Publications, London.

Pearce, DW (ed.) (1991), **Blueprint 2: Greening the World Economy,** Earthscan, London.

Pearson, P.J.G. (1984), "Energy Policy, Environment and Income Distribution in LDCs: an Input-Output Approach", **Surrey Energy Economics Discussion Paper No. 15,** University of Surrey, Guildford.

Pearson, P.J.G. (1986), "Input-Output Analysis and Air Pollution", **Surrey Energy Economics Discussion Paper No. 30,** University of Surrey, Guildford.

Pearson, P.J.G. (ed) (1989), **Energy Policies in an Uncertain World,** Macmillan, London.

Pearson, P.J.G. (1989) 'Proactive Energy-Environment Policies: a Role for Input-Output Analysis?' **Environment and Planning: A**, 21, 1329-48.

Peterson, F.M. (1975), "Comment" on Kohn (1975), reprinted in Ahmad et al. (1984), pp. 351-58.

Reardon, W.A. (1973), "Input-Output Analysis of U.S. Energy Consumption", in Searl, M.F. (ed.), **Energy Modeling,** Resources for the Future, Washington, D.C.

Rhee, J.J. & Miranowski, J.A. (1984), "Determination of Income, Production and Employment under Pollution Control: an Input-Output Approach", **Review of Economics and Statistics,** 66, pp. 146-150.

Robison, H.D. (1985), "Who Pays for Industrial Pollution Abatement?" **Review of Economics and Statistics**, 67, pp. 702-706.

Simpson, D & Walker, J (1987), 'Extending Cost-Benefit Analysis for Energy Investment Choices', **Energy Policy**, June, pp 217-227.

Symons, EJ, Proops, JLR & Gay, PW (1992), 'Carbon Taxes, Consumer Demand and Carbon Dioxide Emissions: A Simulation Analysis for the UK', **Working Paper Series, No. W92/6**, Institute for Fiscal Studies, London.

Victor, P.A. (1972), **Pollution: economy and environment**, Allen and Unwin, London.

Wright, D.J. (1975), "The natural resource requirements of commodities", **Applied Economics**, 7, pp. 31-39.

SURREY ENERGY ECONOMICS DISCUSSION PAPER SERIES

SEEDS Number

International Bargaining and the EC Large Combustion Plant Directive
Roger Fouquet (forthcoming)

69 Fuels for Electricity Supply after the UK Coal Review
Peter Pearson (Ed): Anthony Baker, Nigel Evans, PMS Jones and Colin Robinson ISBN 1852371099 May 1993

68 Electricity in the Third World
Peter Pearson (Ed): Andrew Barnett, Gerald Foley, Francis McGowan and Peter Pearson ISBN 1852371080 May 1993

67 The Economics of Pit Closures in the UK
Peter Pearson (Ed): 3 papers by Anthony Baker et al
ISBN 1852371064 January 1993

66 The Political Economy of Energy Privatisation
Colin Robinson ISBN 1852371056 Dec. 1992

65 Acid Deposition and Global Warming: Simulating energy, environment, economy interactions in the UK with ENDAM2
David Hawdon and Peter Pearson ISBN 1852370971 June 1993

64 Electricity Pricing: Current Practice and Future Developments
D Hawdon, E Marshall and R Orson
ISBN 1852370807 June 1992

63 Prospects for Oil Prices in 1992 and Beyond
P Caddy, D Hawdon, R Jordan, P Stevens and J Toalster
ISBN 1852370777 May 1992

62 The Results of UK Electricity Privatisation
Colin Robinson ISBN 1852370769 March 1992

61 Energy Trends and the Development of Energy Policy in the United Kingdom
Colin Robinson ISBN 1852370750 February 1992

(Continued overleaf)

SURREY ENERGY ECONOMICS DISCUSSION PAPERS (Contd.)

60 Environment, Energy Efficiency and the Third World
P J G Pearson (Ed): 4 papers by M Bell et al
ISBN 1852370734 October 1991

59 Prospects for Oil Prices
P Caddy, P Davies, D Hawdon, P Stevens and J Toalster
ISBN 185237070X July 1991

58 A Model for Passenger Car Gasoline Demand in Canada
M N Eltony ISBN 1852370696 June 1991

57 Time of Day Pricing Schemes for Electricity Utilities in Developing Countries
B Ram ISBN 1852370688 June 1991

56 Aid and Energy in the Third World
P J G Pearson (Ed): 3 papers by J Cochrane et al
ISBN 1852370645 March 1991

55 Soviet Energy Prospects and Problems: The Energy Sector in the USSR 1985-1990 Supplement: February 1991
B P Pockney ISBN 1852370629 December 1990

54 Energy Efficiency in the Third World
P J G Pearson (Ed): 6 papers by K Bennett et al
ISBN 1852370602 October 1990

53 Prospects for Nuclear Energy in the UK and Europe
M Barrett et al ISBN 1852370599 September 1990

52 Oil Prices in 1990 and Beyond
D Hawdon et al ISBN 1852370580 July 1990

51 Nuclear Power, the Greenhouse Effect & Social Costs of Energy
P M S Jones ISBN 1852370572 May 1990

Details of 1-50, order form, prices & Subscription Scheme on request