DEFRA

Impact of the Climate Change Programme on Industrial Carbon Dioxide Emissions

Final Report

August 2003

Entec UK Limited
Cambridge Econometrics

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Report for

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Executive Summary

Introduction

The UK has a legally binding target under the Kyoto Protocol to reduce its greenhouse gas emissions to 12.5% below 1990 levels by 2008-2012. The UK government has also set a domestic goal of a 20% reduction in carbon dioxide (CO_2) emissions below 1990 levels by 2010. A key requirement of the Kyoto Protocol is that countries show *demonstrable progress* in meeting their commitments. The work presented in this report contributes to meeting this requirement by providing estimates of the likely impact of selected policies and measures aimed at reducing the direct and indirect emission of CO_2 resulting from industrial energy consumption. The report also extends the availability of industrial sectors for which technologically disaggregated carbon abatement cost curves exist. Entec UK Ltd and Cambridge Econometrics have worked together to undertake this study.

Modelling Techniques

In order to estimate the likely impact of the policies and measures to be analysed, a combination of 'bottom-up' and 'top-down' modelling was employed. ENUSIM (Industrial Energy End-Use Simulation Model), a technology-based, 'bottom up' industrial energy end-use simulation model, was used to partially evaluate the effect of the Climate Change Levy (CCL) on selected industrial sectors. ENUSIM is designed to model the uptake or retrofit of energy saving and/or fuel switching technologies in selected industrial sectors, taking into account both economic factors and assumptions about investment in new technology. The industry-specific abatement cost curves contained in ENUSIM do not, however, include combined heat and power (CHP) stations. The estimated impact of the selected policies and measures on CHP, and the resulting emissions savings, thus had to be estimated using the MDM-E3 (Multi-sectoral Dynamic Model Energy-Environment-Economy) model, which is a 'top-down' model of the UK economy, with fully integrated energy-environment sub-models. Likewise, the impact of the Climate Change Agreements (CCAs) on carbon emissions was calculated 'off-model' using ENUSIM data. Every effort was made to ensure consistency between the different modelling approaches, but care should still be exercised when aggregating the estimates from the different policy measures.

Results

The table below presents the estimated impact of policies and measures simulated in this project. Estimates of the carbon saving from the selected policies and measures are presented for 2010 only. The results are presented in the form of 'end user' emissions of CO_2 expressed as Millions of tonnes of Carbon (MtC). End user emissions include the allocation of power station emissions to electricity consumers.

The overall effect of the policies and measures modelled to date is anticipated to be about a 4.5 MtC reduction in 2010 from a baseline (with none of these policies in place). CHP contributes approximately 1.7 MtC to this figure. To put these estimates in context, the estimated impact of a similar set of policies and measures targeted at reducing carbon emissions from business, as presented in the Climate Change Programme (CCP) and Third National Communication (3NC), were 7.0 MtC and 5.8 MtC, respectively. However, for the following reasons, these two estimates are not strictly comparable with the results of this study:

- The contribution of the CCL to the CCP/3NC carbon saving estimates is evaluated over all industrial sectors (including some not included in ENUSIM), as well as the commercial, service and public sector. The latter sectors alone account for over 38 per cent of the total, combined energy use.
- The price effect of the levy as reported in the CCP/3NC is based on the full rates of CCL applied to all businesses liable to pay the levy. The modelling in this study applies the discounted rate to those sectors covered by climate change agreements.
- The estimated impact of the CCL provided in the CCP/3NC is based on 'top-down' modelling, explicitly incorporating the CHP fuel input and renewable generation exemption, whereas the price effect of the levy estimated in this study is based on 'bottom-up' modelling, with the impact of the CHP exemption estimated 'off-model'. The models have different mechanisms for modelling behaviour, and differ in coverage and approach to baseline definition. 'Top-down' models also capture indirect/feedback effects, whereas 'bottom-up' models do not.
- The base case assumptions adopted in forecasting the levy impacts for the CCP/3NC are also different to those used in this study.

The carbon savings estimate for the Emissions Trading Scheme (ETS) relates solely to the additional up-take of CHP. However, our cost curve work has indicated further capacity for savings. For example, if the market price of permits was £5 per tonne of carbon dioxide (equivalent to £18.33 per tonne of carbon), a potential reduction of 5.8 MtC appears feasible under current policies (assuming a discount rate of 3.5% and all sectors included in the cost curves participate in the trading scheme). In theory, this is equivalent to saying that a carbon tax of £18.33 per tonne would achieve the same saving, although the rate at which this saving could be achieved depends on the way in which the markets respond to the price signal. For electricity, this corresponds to an additional cost of 0.215p per kWh compared to the climate change levy rate of 0.43p per kWh, and for natural gas the cost is 0.095p per kWh compared to the CCL rate of 0.15p per kWh. Higher permit prices could allow a reduction of up to 7.0 MtC, including a contribution of 0.8 MtC from the energy industries' own energy use, which includes ancillary plant at power stations and all oil refineries.

Simulated Policy Contributions to Carbon Reductions from Business as Usual by 2010 (MtC)

Policy Measure	Carbon reduction from policy simulation
Climate Change Levy (CCL) plus Climate Change Agreements (CCA)	>3.4
CCL Package, predominantly Enhanced Capital Allowances (ECAs)[1]	0.6
Business rate exemption on Combined Heat and Power (CHP)[2]	0.1
Emissions Trading Scheme (ETS)[3]	>0.5
Interaction effects of CHP policies[4]	-0.1
Total	**4.5**

Notes:

[1] ECA on CHP contribution only. Includes contribution from sectors both with and without CCAs.

[2] No estimate of the policy impact is provided in the CCP or 3NC.

[3] This study has only estimated the contribution from CHP. 0.8 MtC/yr is the 3NC estimate of the impact of the initial scheme in 2010; savings of 1.1 MtC/yr are already committed, some of which will be from CHP.

[4] Not estimated in CCP/3NC.

The following table and accompanying figure summarise available industrial carbon emissions estimates from Energy Paper 68 (EP68), 3NC and the modelling carried out through this project. The modelling conducted in this study also includes the energy industries' own use. However, since the majority of this relates to sectors other than industry, for the purpose of comparison this is shown separately in the table. So the overall reduction in industrial carbon emissions from 1990 to 2010 of 11.8 MtC in EP68/3NC is comparable to the 11.3 MtC from our simulation.

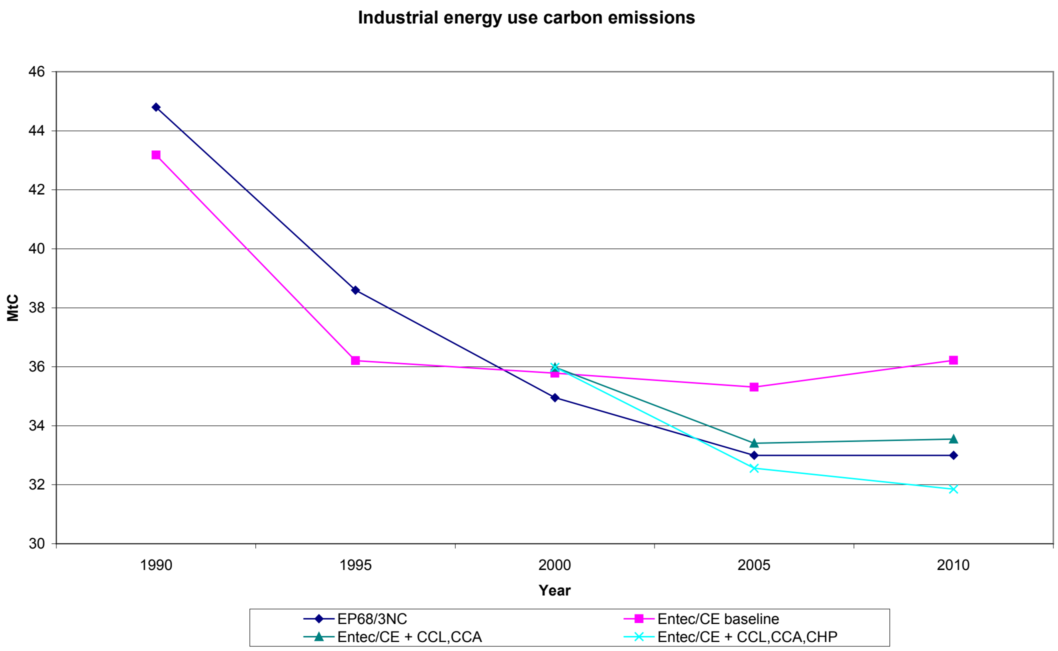
Carbon Emission Estimates (MtC)

Source	1990	1995	2000	2005	2010
EP68/3NC industry baseline with measures	44.8	38.6	34.95	33.0	33.0
Entec/CE policy simulation: baseline, no measures excluding energy industry own use	43.18	36.21	35.78	35.31	36.22
Entec/CE policy simulation: baseline, no measures energy industry own use	13.62	11.35	10.58	10.27	10.19
Entec/CE policy simulation: including CCL and CCA impact excluding energy industry own use[1]	43.18	36.21	35.98	33.41	33.55
Entec/CE policy simulation: including CCL and CCA impact for energy industry own use[1]	13.62	11.35	10.58	10.23	10.13
Entec/CE policy simulation: including CCL and CCA and CHP policies excluding energy industry own use[1]	43.18	36.21	35.98	32.56[2]	31.85

Notes:

1. Does not include price effect of CCL exemptions regarding CHP
2. By interpolation

Trend of Carbon Emissions from Industrial Energy Use



It is clear from the work undertaken during this study that the UK's policies and measures focussing on industrial CO_2 emissions will make *demonstrable progress* towards meeting the UK's obligations under the Kyoto Protocol. Together with reducing energy intensity, energy consumption and CO_2 emissions, the policies and measures put in place provide UK industry with cost-effective opportunities to reduce CO_2 emissions.

Drivers for Changes in Energy Demand

Changes in energy demand are often explained in terms of output growth, technical change (which is usually leads to greater energy efficiency) and structural change. Structural change refers to a change in the mix of output produced; it is commonly measured by changes in sectors' share of total output. It is distinguished from technical change, which refers to a change to the input mix of production.

A common way to measure technical change and structural change effects on energy consumption is to examine the change in the ratio of energy to output or 'energy intensity'. According to the DTI in its recently published *Energy Consumption in the UK*, between 1990 and 1999, the overall decline in industrial energy intensity was 13%. Of this overall decline, the DTI estimated that 11% was due to changes in intensity of the component sectors of industry and changes in structure are estimated to contribute 2%.

The Effect of Fuel Price on Structural Change

To undertake an analysis of the effects of fuel price changes on structural change, a MDM-E3 model run was performed whereby a shock to fuel prices was applied. The shock consisted of a tripling of the full CCL rate from 2002 onwards. The effects of the fuel prices shock are measured in terms of differences in sectors' share of gross output with and without the fuel price shocks.

For all industry sectors, the percentage point change is very small at less than 0.1 percentage points. The results indicate that fuel price changes are not likely to be a driving force behind the structural change. It is more likely that globalisation of production, i.e. increasing imports and changes in consumers' tastes are the main drivers of structural change in the future as they have been in past.

Future Opportunity

Further development of the policy response through the CCP could be assisted through the following:

- Evaluation of the effect of a carbon-based levy rather than one based on the energy content of the taxable fuels;
- Analysis of the outcomes of the joint Confederation of British Industry – Engineering Employers' Federation, and the Policy Studies Institute – Green Alliance surveys of businesses' response to the CCL;
- Analysis of CCA reporting data when this becomes available in 2003 to facilitate evaluation of the actual performance resulting from the measure;

- Validation of the behavioural function of ENUSIM using CCA 2003 reporting data;
- Further work to evaluate the impact of the ETS as the scheme develops and companies come under pressure to meet stated reduction commitments;
- From the review of international policies addressing industrial sector CO_2 emissions[2], areas identified that are not currently covered by UK policy measures which may warrant investigation are:
  - Grants and low interest loans for energy saving equipment;
  - Investment subsidies for large-scale demonstration projects;
  - Tax exemption for renewables projects (other than that afforded by the CCL); and
  - Regulations on the performance of boilers (small scale).

Future work on the assessment of the potential for such policies and measures is required to complement existing policies and measures of the CCP. This may be particularly important for the impact of grants and low interest loans for energy saving equipment.

Future work should also undertake a review of the energy efficiency technologies and techniques included in the ENUSIM model. Investigation of the impact of scenarios surrounding step-changes in energy consumption and generation should also be considered.

[2] Industrial Sector Carbon Dioxide. Review of International Policies Addressing Industrial Sector Carbon Dioxide Emissions, Entec UK Ltd, June 2002

Contents

1. Introduction

1.1 Background

The UK has a legally binding target under the Kyoto Protocol to reduce its greenhouse gas emissions to 12.5% below 1990 levels by 2008-2012. The UK government has also set a domestic goal of a 20% reduction in carbon dioxide emissions below 1990 levels by 2010. Policies implemented to reduce emissions of greenhouse gases affect the energy supply sector, business sector, transport sector, domestic sector, agriculture, forestry and land use sector and the public sector. The business sector incorporates both manufacturing and commercial activities. The work presented in this report examines the impact of those policies affecting manufacturing activities of the business sector[3].

Together with continuing to evaluate and develop its policy response regarding climate change, the UK has reporting obligations under the Kyoto Protocol and European Union (EU) Monitoring Mechanism. A key requirement of the Kyoto Protocol is that countries show *demonstrable progress* in meeting their commitments. The work presented in this report contributes to meeting this requirement through analysis of the impact of climate change policies focussing on energy consumption by industry. Entec UK Ltd and Cambridge Econometrics have worked together to undertake this work.

[3] The following nineteen sectors are considered: brick manufacture, cement, lime and plaster manufacture, ceramics manufacture, chemicals manufacture, construction, electrical engineering, energy industry (own energy use), food and drink industry, glass and glassware manufacture, iron and steel manufacture, mechanical engineering, non-ferrous metals manufacture, non-metallic minerals and mineral products manufacture, other industries, paper manufacture and utilisation, plastics and rubber manufacture, textiles, leather and clothing manufacture, vehicle manufacture, water industry (purification and distribution only).

1.2 Policies and Measures

The UK's Climate Change Programme[4] (CCP) (November 2000) sets out policies and measures addressing climate change in the UK. The Third National Communication under the United Nations Framework Convention on Climate Change[5] (3NC) (October 2001) presents an update of the policies and measures together with an assessment of progress against their estimated effect. Table 1.1 presents the estimated effects of the climate change policies and measures detailed in the CCP and the 3NC affecting industry.

Table 1.1: Estimated Effects of the Climate Change Policies and Measures by 2010

Document	CCL[1]	CCAs and IPPC[2]	Energy efficiency under the CCL package[3]	Emission trading	Total
Climate Change Programme	2 MtC[4]	2.5 MtC	0.5 MtC	2.0 MtC	7.0 MtC
Third National Communication	2 MtC[4]	2.5 MtC	0.5 MtC	0.8 MtC	5.8 MtC

1. Climate Change Levy
2. Climate Change Agreements and Integrated Pollution Prevention Control
3. Carbon Trust, Enhanced Capital Allowances, etc.
4. Includes exemption of the Climate Change Levy (CCL) on combined heat and power (CHP) and renewable energy generation. Includes consideration of the commercial sector and the public sector.

Table 1.2 presents the CCP policies and measures affecting industry. In addition to those listed in Table 1.2, CHP also receives a business rate exemption. Full analysis of the Emissions Trading Scheme (ETS) has not been included in this policy assessment due to the early stage in the ETS's development.

All of the policies and measures listed in Table 1.2 are classified as *existing* policies and measures rather than *additional* policies measures by the Kyoto Protocol definitions as they are *implemented*[6]. There are currently no *additional* policies and measures to those listed in Table 1.2.

[4] http://www.defra.gov.uk/environment/climatechange/cm4913/index.htm

[5] http://www.defra.gov.uk/environment/climatechange/3nc/default.htm

[6] Existing policies and measures are those either *implemented* (i.e. for which one or more of the following applies: national legislation is in force; one or more voluntary agreements have been established; financial resources have been allocated; human resources have been mobilised.) or *adopted* (those for which an official government decision has been made and there is a clear commitment to proceed with implementation). Additional policies and measures are those *planned* (i.e. are under discussion and having a realistic chance of being adopted and implemented in future).

Table 1.2: Summary of UK Policy and Measures Affecting Industry

Policy Measure	Description
Climate Change Levy	Application of levies to fossil fuels and electricity (liquid petroleum gas: 0.07 p/kWh; natural gas, coal, lignite and coke: 0.15 p/kWh; electricity: 0.43 p/kWh). Renewable energy (with the exception of large-scale hydroelectricity) and fuel used by and energy supplied by Good Quality Combined Heat and Power are exempt from the CCL.
Climate Change Agreements and Integrated Pollution Prevention and Control	Forty-two CCAs have been established with industry sectors which commit industry to reduce energy use by agreed amounts at specified time periods to 2010 in return for an 80% reduction in the CCL. Energy efficiency measures required under IPPC will extend energy efficiency measures to those outside CCAs through regulatory control.
Energy efficiency under the Climate Change Levy package	Enhanced Capital Allowances (ECAs) (100% first year capital allowances) are available for approved energy saving investments (e.g. boilers, CHP, lighting, motors and drives, pipework insulation, refrigeration and heating and compressor equipment). The Carbon Trust will also take-over, develop and extend the activities of the Energy Efficiency Best Practice Programme.
Emissions trading	Development of an Emissions Trading Scheme (ETS) whereby businesses can meet their CCA commitments through trading CO_2 credits or whereby businesses enter trading directly following identification of baseline emissions, commitment to reduce emissions and bidding for the ETS incentive fund.

1.3 Project Work Programme

The project involved the following principal work areas:

- Domestic and international policy analysis;
- Data gathering; and
- Model development.

Table 1.3 summarises the principal project issues and the approach to addressing them. Due to limitations and uncertainties surrounding model capabilities and data availability, the project required a high degree of flexibility and innovative thinking to enable the issues to be addressed.

1.4 Reporting Requirements

Both the Kyoto Protocol and the EU Monitoring Mechanism require reporting of the effect of existing and additional policies and measures. The reporting requirements are essentially the same, although the EU Monitoring Mechanism also requires an assessment of the economic impact of policies and measures where possible. The Kyoto Protocol and EU Monitoring Mechanism require that projections of the effect of existing and additional policies and measures are provided from the latest year for which comparable inventory data are available in the national communication. The analysis of the effect of policies and measures presented here contributes to developing such projections.

Table 1.3: Summary of Project Issues and Approach

Issue	Approach
Domestic and international policy analysis	
Formulate modelling scenarios and model the effect of policies.	Scenarios developed with reference to UNFCCC policy and measure definitions. CCL effect (excluding CHP) represented in the ENUSIM model. CCA's effect calculated off-model using ENUSIM data. CHP contributions to various other policies and measures modelled using MDM-E3 model.
Quantify the effect of additional policies and measures, i.e. non-CCP related.	Significant policies identified. Evaluation made of the effect on energy consumption and CO_2
Quantify the effects of policies by using ex-post data or to identify quantifiers that will be suitable for this purpose in due course.	Data from the Digest of UK Energy Statistics proposed for ex-post data validation in the future. Anecdotal information from industry also explored regarding the likely impact of policies and measures.
Assess progress by other EU Member States, the US and Japan in abating industrial sector emissions.	Policy profiles of selected countries compiled and implications for the UK assessed.
Assessment of cost abatement curves by sector illustrating emissions abatement as a function of cost.	Extensive review of the cost curve function in ENUSIM carried out. Cost curves in ENUSIM used to perform this evaluation following updating of model data.
Data gathering	
To collect information on energy intensive sectors using feedback from monitoring of CCAs.	No information available until formal reporting date in 2003.
To improve data on historical structural change and how these might continue into the future.	Modelled output data imported from MDM-E3 into ENUSIM to improve robustness of output projections through to 2020. These take into account projected fuel price changes together with a wide range of macroeconomic influences. The link between energy consumption and output was also examined from new DTI data available for the 1990s.
Develop new sectors in ENUSIM: construction, energy industries own energy use and the water supply industries.	Sectors fully developed and integrated.
Improve data on projected uptake of energy efficient technologies taking on board new data sources. Develop data for the non-metallic minerals sector which has no energy efficiency technologies included.	Data reviewed and improved for sectors accounting for 70% of industry energy demand. Data developed for the non-metallic minerals sector.
Model development	
Establish the effect of induced structural change on fuel price sensitivity (i.e. shift into or out of energy intensive industry as the fuel price rises or falls).	Assessment made of changes in energy intensity through the 1990s and the impact of fuel price on structural change through modelling in MDM-E3.
Extend the modelling to include output elasticity.	Modelled output data imported from MDM-E3 into ENUSIM to improve robustness of output projections through to 2020. These take into account projected fuel price changes together with a wide range of macroeconomic influences.
Include the marginal effects of electricity savings.	Assumption made that the supplied energy to CO_2 ratio of gas fired power and that of the average ratio across all fuels are similar hence effects not considered further.
Review the scope of CO_2 savings as a function of cost.	Cost curves used from ENUSIM to perform this evaluation following updating of model data.

2. Modelling Techniques

2.1 Introduction

This section presents the modelling strategy used to analyse the impact of CCP policies and measures regarding industrial CO_2 emissions. It also sets out the central assumptions and judgements used in the modelling work.

Two models were used to undertake the analysis. The primary model used was ENUSIM but it was necessary to supplement the analysis through the use of Cambridge Econometrics' MDM-E3 model, since ENUSIM is unable to simulate the impact of changes in prices and economic activity. A further limitation of ENUSIM is that it does not permit the user to carry out the analysis of certain policies and measures. The impact of a number of policy measures had, as a result, to be determined by the use of MDM. Some of the properties for each model are examined in this section.

2.2 ENUSIM

The Model

ENUSIM, the Industrial Energy End-Use Simulation Model is a technology-based, "bottom up", industrial energy end-use simulation model. It is designed to model the uptake or retrofit of energy saving and/or fuel switching technologies in industry, taking into account both economic and behavioural factors affecting investment in new technology.

The core methodology used within ENUSIM calculates future energy consumption (E) for each of the 110 industrial sub-sectors, according to the following equation:

E = UED x SEC

where UED (useful energy demand) is a factor expressing the change in useful energy demand relative to the base year, taking sub-sectoral growth into account, but assuming constant energy efficiency for each process. SEC is the specific energy consumption representing the energy required per unit output, relative to the base year, under three behavioural assumptions: Business as Usual; All Cost Effective and All Technically Possible. These three cases show the effects of potential changes to investment patterns arising from external influences such as national or international energy policies. The results generated by the cases are broad projections conditional on the assumptions on which they are based and should not to be regarded as forecasts.

The ENUSIM model disaggregates the industrial sector into sectors, sub-sectors, devices and device technologies. Sectors and sub-sectors are used by ENUSIM to identify where devices are used. Device technologies (energy saving technologies) are then applied or retrofitted to these devices in various combinations to save energy. Once new technologies are applied, the SEC value is changed accordingly. SEC projections are normally performed over a period of between twenty to thirty years, although the user can vary this to be any time period. Projections are performed year by year rather than solving all years simultaneously, as is normally the case in optimisation models.

Energy demand projections also depend on projections of future activity, UED. In ENUSIM, these are input at the sub-sector level, since using projections at the sector level could lead to incorrect results from the model. UED is measured by output; gross commodity output, physical units or gross valued added.[7]

2.2.1 Key Assumptions

Only foreseeable available energy efficiency technologies and techniques are included in the model. Innovations which may occur through initiatives such as the Carbon Trust resulting in Low Carbon Technologies are not considered; consequently, any step-change that may result through technologies such as hydrogen sourced power and fuel cells are not considered.

Before a simulation can be performed, ENUSIM needs to be supplied with:

- Fuel price assumptions;
- Sub-sector output (throughput) assumptions;
- A discount rate; and
- A behavioural assumption.

Base assumptions need to be defined for these inputs. This section outlines the assumptions used in this modelling work.

Fuel Price Assumptions

ENUSIM requires historical data and forecasts for 21 fuel prices. Fuel price data for 2000 were obtained from various sources including the DTI's *Digest of United Kingdom Energy Statistics 2001* (DUKES), and *Quarterly Energy Prices* and also unpublished information (Appendix A Table A1). Forecasts for the various fuel prices were based on Cambridge Econometrics' energy price projections contained in the January 2002 *UK Energy and the Environment* report. They were derived by applying the changes in energy price forecasts to the historical information for 2000. The fuel prices classifications used in ENUSIM do not exactly match those in Cambridge Econometrics' energy price classifications hence only a close matching could be applied. The same method was also used to construct historical time-series back to 1995. Appendix A Table A2 presents the assumed inflation profile for the various fuel prices. A sensitivity analysis of fuel prices was performed and the result of which can be found in the Section 2.2.3.

Sub-sector Output (Throughput) Assumptions

The ENUSIM database contains 'throughput' data on each sub-sector for the base year, 1995. In most cases, throughput is measured in terms of tonnes of production. In a small number of cases, other units are used such as valued added. ENUSIM requires the model user to provide it with a growth profile for each throughput. For the base case, these growth profiles were based

[7] Refer to previous AEA Technology reports for further information regarding ENUSIM: 'Industrial Sector Carbon Dioxide Emissions: Projections and Indicators for the UK, 1990-2020' April 1999 and June 2000.

on gross output projections from the MDM-E3 model. The industrial classifications used in ENUSIM do not exactly match those in MDM-E3 therefore, assumptions for ENUSIM's sub-sector throughput forecasts were based on average annual growth rates for broadly comparable sectors within MDM-E3 (See Appendix A Table A3 which summarises the growth information used in MDM-E3).

Discount Rate

Before each simulation, ENUSIM requires the user to select a rate of discount to be applied in the payback calculations. These calculations determine whether or not an energy-saving technology is implemented. The higher the rate of discount, the greater are the extent of future energy savings needed for a technology to be implemented. ENUSIM's interface allows three discount rates to be applied: 6%, 15% and 25%. A sensitivity analysis of the extreme rates was performed and the results of this sensitivity are presented in the next section. A discount rate of 25% was used in the modelling of the fuel price effect of the CCL.

Behavioural Assumptions

Before each simulation run, ENUSIM also requires the user to select a 'scenario'. These scenarios define the way in which energy-saving technologies are implemented. ENUSIM's interface allows three types of behaviour: business as usual (BAU), all cost effective (ACE) and all technically possible (ATP).

The BAU assumption is intended to characterise a continuation of recent trends, with industry continuing to take up energy efficient technologies and energy management procedures in the way it has done in the past. There is however, presumption of no step change in the implementation of energy saving technologies. The mechanisms (or variables) used in ENUSIM to represent this behaviour are twofold:

- The speed with which a technology is taken-up (i.e. 'the time taken to reach the 50% penetration level'), and;
- The extent to which a technology is taken-up (i.e. 'the maximum penetration of a technology').

However, it should be noted that these variables are set by the user by assumption, rather than estimated by experience and are set at very low levels for the BAU simulation, which is intended to be consistent with a continuation of recent trends. Generally, for the ACE and ATP simulations, they are set at a much higher level or at the maximum level. The BAU assumption was used in the modelling of the fuel price effect of the CCL.

The ACE simulation shows what will happen if each sector adopted all available cost-effective management and technical, energy-efficiency measures. In common with all such bottom-up approaches, this scenario places no limits on the overall available management time or capital needed for implementing all the possible measures. It is therefore inherently optimistic.

2.2.2 Sensitivity and Dynamics

To ensure understanding of the sensitivity and dynamics of ENUSIM, a number of tests were performed that enabled the model's response to parameter changes to be evaluated. These tests examined the responsiveness of ENUSIM to changes in fuel prices and discount rate. The aim was to establish whether ENUSIM key outputs, energy demand and CO_2 emissions, respond to changes in these parameters in an intuitive and consistent way, and whether the magnitude of response is plausible in relation to other modelling findings. The results of these findings are presented in Appendix B.

The analysis is limited to two sectors, the chemicals industry and iron and steel industry[8]. These sectors were selected because they are large final energy consumers and carbon emitters. In the base year, 1995, the chemicals industry accounted for 15% of energy demand and carbon emissions in ENUSIM, while iron and steel accounted for 16% of energy demand and 18% of carbon emissions.[9]

The analysis suggested that the responsiveness of energy demand and carbon emissions to changes in fuel prices and in the discount rate are low. Reasons for this include:

- The choice of behavioural assumption: the business as usual assumption does not allow large step movements in the take-up of energy savings technologies;
- Alternative fuel price sensitivities such as relative fuel price sensitivities may lead to larger movements than when all fuel prices are adjusted by the same degree (i.e. if all fuels increase by same percentage, fuel switching is never going to be profitable); and
- The model does not capture important energy-saving technologies such as CHP.

We are not aware of other modelling work that tests the sensitivities of fuel prices (and the discount rate) on the energy demand and carbon emissions in the same manner as indicated in Appendix B. It is therefore, difficult to assess whether these estimates are reasonable. One possible comparison, however, is with the projections from the DTI's Energy Paper 68 (EP68) 'Energy Projection for the UK' (pp 53)[10].

EP68 provides projection bands for carbon emissions. These projection bands are based on high and low (real) fuel price assumptions (difference between high and low is not uniform across fuel prices). Table 2.1 presents the impact of these assumptions of high-low fuel price relativities on carbon as reported for 'industry' in EP68 against those bands modelled in ENUSIM. The EP68 range is 2%. For the two industry sectors examined in ENUSIM, the range is between 1% and 2% for the level shift and 1% and 3% for the growth shift suggesting that ENUSIM's modelled fuel-price response is within a reasonable range when compared with EP68.

2.2.3 New Industry Development

Three new industries have been incorporated into ENUSIM; the energy, construction and water industries. The result of adding these industries is to increase the total energy consumption modelled by ENUSIM by approximately 31%, or 24% in terms of carbon. This is almost entirely attributable to the inclusion of the energy industry's own energy use, which accounts

[8] In Cambridge Econometrics' classification, iron and steel includes non-ferrous metals. Non-ferrous metal is not included in ENUSIM's definition of iron and steel.

[9] Only the energy sector was larger than these sectors, accounting for 30% of energy demand and 23% of CO_2 emissions.

[10] http://www.dti.gov.uk/energy/inform/energy_projections/ep68_final.pdf

for an increase in energy consumption of 30%, or 23% in terms of carbon. Summaries of the structures of the new industry sectors are presented in Appendix C.

Table 2.1: EP68 and ENUSIM Sensitivities - Carbon Emissions

Model	Variable	Settings	High-Low Range Relative to Base Year Level (%)
EP68	Carbon 'industry'	Various Real Price Sensitivities	2
ENUSIM	Carbon 'chemicals industry'	20% Nominal Price Levels Sensitivities (25% discount rate)	2
ENUSIM	Carbon 'chemicals industry'	Growth shift to 20% price increase at 2010	3
ENUSIM	Carbon 'iron and steel'	20% Nominal Price Level Sensitivities (25% discount rate)	1
ENUSIM	Carbon 'iron and steel'	Growth shift to 20% price increase at 2010	1

2.2.4 Reviewing and Updating Model Data

A review of data in ENUSIM was performed for selected sectors and with regard to certain technologies. There were three aspects to the review:

- **Reviewing technology coverage and accuracy for key sectors:** sectors reviewed were iron and steel, paper, chemicals, cement and energy industry use. This ensured that device technology data for sub-sectors accounting for 70% of total energy demand were reviewed and updated;
- **Enhanced capital allowances:** existing device technologies were screened for all devices to assess whether any of the technologies available to receive ECAs (except CHP) are relevant but absent from the model. Data was collected accordingly to remedy omissions; and
- **Device technologies for the non-metallic minerals sector:** no device technologies for the non-metallic minerals sector (concrete crushing and stone processing) had previously been developed. Data regarding relevant device technologies for the sector were investigated and integrated into the model.

The reviews entailed extensive contacts with industry and thorough review of documents such as the best available techniques reference notes (BREFs) produced by the EU as guidance for implementation of the Pollution Prevention Control Directive (PPC Directive). BREFs incorporate information regarding energy efficiency technologies for the sectors. The review resulted in a number of new device technologies being developed (eight for the cement sector, two for the energy industry sector, four for the iron and steel sector and four for the paper sector) and twenty significant corrections to capital costs and energy efficiency data for the chemical industry being made. The result of the review was a 4% increase in modelled carbon emissions reduction due to the CCL (discussed in Section 3) approximately equivalent to an additional 0.05 MtC.

2.3 Multisectoral Dynamic Model

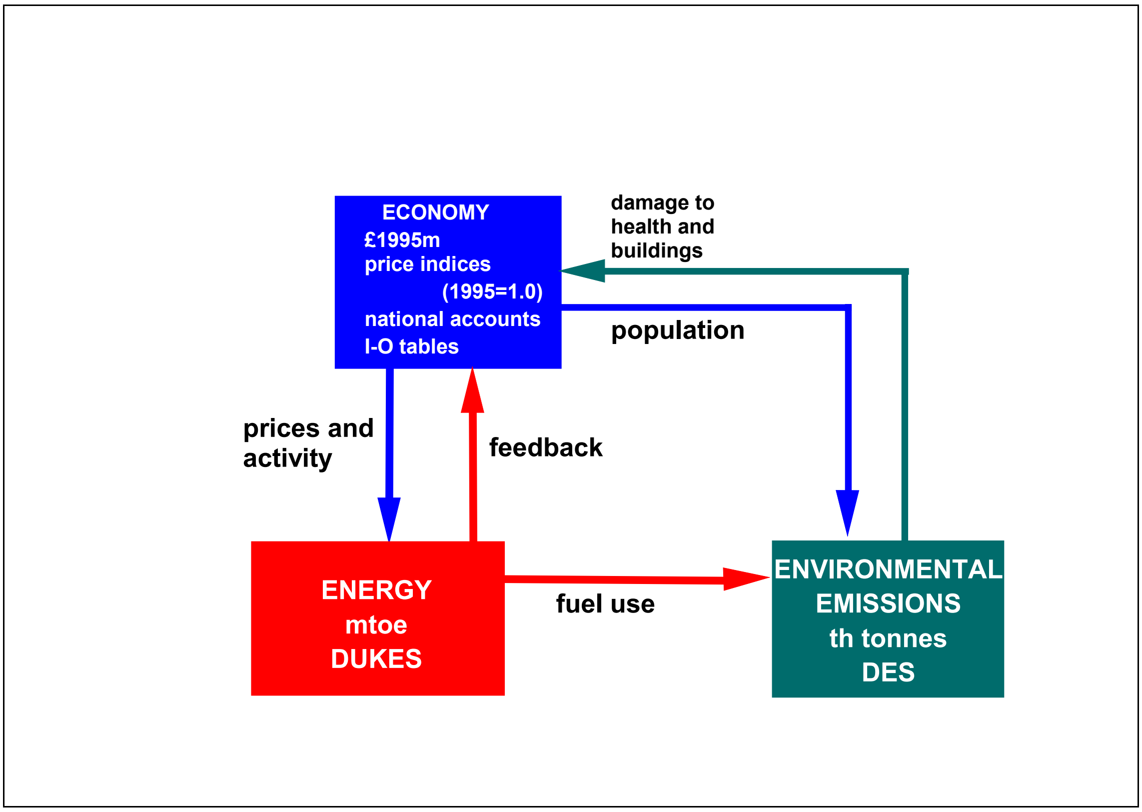
The MDM-E3 model is the UK's most detailed integrated energy-environment-economy model. It has been designed to analyse changes in economic structure, energy demand and resulting environmental emissions. MDM was used for a number of purposes in the policy analysis including:

- To evaluate the contribution of combined heat and power (CHP) to reducing energy demand and CO_2 emissions within the context of the various policies and measures;
- To update and improve throughput changes in ENUSIM to 2020; and
- To compare/cross-check ENUSIM modelling results.

The latest version of MDM-E3 is based on the 1992 Standard Industrial Classification, with 1995 as the price-base year, and uses input-output tables for 1995. A comprehensive account of an earlier version of the economic model is given in Barker and Peterson (1987). The model has since become a regionalised energy-environment-economy model and most of the equations have been respecified, but the basic structure of the model has remained unchanged.

Flows in the economic model are generally in constant prices, while the energy-environment modelling is performed in physical units. This modelling is described in Barker et al (1995). Energy-environment characteristics are represented by sub-models within MDM-E3. The coverage includes energy demand (primary and final), environmental emissions, the electricity supply industry and domestic energy appliances. The energy industries are included within the basic input-output structure and MDM-E3 is a fully integrated single model, allowing extensive economy-energy-environment interaction. Figure 2.1 summaries the energy-environment-economy linkages within MDM-E3.

Figure 2.1: Modelling the Economy, Energy, and the Environment



3. Policy Impacts

3.1 Introduction

This section presents the findings from the modelling of impacts of the various CCP policies and measures on carbon emissions. The modelling work regarding the CCL and CCA reported in April 2002 has been updated following a review of the model's technologies. The effects of the CCL and CCA are presented followed by an assessment of the contribution of CHP under various policies and measures.

3.2 The Climate Change Levy

The fuel price response[11] of industry (including the energy industries' own energy use) to the introduction of the CCL was modelled using ENUSIM. For information regarding the modelling technique and key assumptions regarding fuel price, sub-sector output, discount rates and behavioural issues, refer to section 2.2.2. In modelling the CCL, the 80% CCL discount was applied to sectors with CCAs. The result suggested a reduction of about 0.1MtC/yr, with a possible additional 0.05 MtC/yr due to extension of ENUSIM's technology database and further small additions from exemption of renewables and good-quality CHP from the CCL. However ENUSIM is known to have low fuel price responsiveness; the effect of the CCL at full rate for all sectors as modelled by AEA Technology using the earlier version of ENUSIM[12], was 0.25 MtC/yr for CCL at the full rate, compared to 2 MtC/yr from EP68 which indicates greater take-up of the low cost abatement options available. The response would also be increased by consideration of :

- exemption for CHP and renewables from the CCL;
- energy consumption of the commercial sector; and
- energy consumption of the public sector

Because of these uncertainties the CCL and CCA results are shown together in the summary tables of this report.

[11] Fuel price response is the reaction, in terms of uptake of energy efficiency techniques, that sectors have resulting from a response to an increase in energy price due to the CCL.

[12] See ETSU (October 2001) 'Climate Change Agreements - Sectoral Energy Efficiency Targets'.

3.3 The Climate Change Agreements

The impact of the CCA was modelled by imposing implied percentage reductions of the CCA on the participating industries. These calculations involved imposing the implied percentage reduction in the target variable (e.g. relative energy use, relative carbon emissions, absolute energy use or absolute carbon emissions) on a comparable ENUSIM output variable (SEC or energy). Essentially, this calculation tells us what energy demand and carbon emissions would be if an industry met its target by reducing its demand for each fuel equally. The assumption that the fuel mix will remain constant at a base period may slightly bias our results for carbon emissions. One of the desired effects of the climate change levy is to encourage a switch from more to less carbon intensive fuels. Earlier ENUSIM modelling showed however, that change in the fuel mix was very small, suggesting that this bias is likely to be negligible.

Results from the off-model calculations show that carbon saving could be as high as 2.7 MtC if the firms participating in the CCAs were to achieve their targets. This finding is broadly in line with the Government's own estimates of the carbon saving in 2010. In the 3NC, the Government estimated that the CCA would save 2.5 MtC in 2010.

The estimate of the impact of the CCA on carbon savings is largely unchanged, following the updating of ENUSIM devices and technology databases.

3.4 Policy Effects on Combined Heat and Power

3.4.1 Introduction

This section builds on work carried out by Cambridge Econometrics for the DTI and DEFRA, to project the level of Good Quality CHP (GQ CHP) capacity. It presents estimates of additional generating capacity and carbon savings arising from the Government's support measures for CHP including exemption of CHP fuel inputs and the recently announced exemption of certain types of CHP power export.

Cambridge Econometrics, working in association with AEA Technology, undertook a study for the DTI and the DEFRA to model the growth of CHP in the UK to 2010[14]. The key objective of the study was to project the level of capacity and the preferred measure of CHP capacity in 2010 under baseline conditions which include the effect of a number of the Government’s support measures for CHP. The study also assessed the contribution of selected support measures to the growth in capacity including the contribution of the exemption of the fuel input from the CCL and the ECAs for CHP.

Key to achieving the study's objectives was the MDM-E3 model. MDM-E3 was previously used to study the economic and environmental implications of achieving the Government’s CHP target for the Combined Heat and Power Association (CHPA). A key innovation of the modelling was that it extended MDM-E3 to incorporate a detailed representation of CHP technologies and cost-benefit decisions. This new part of the model is referred to as the ‘CHP sub-model’.

[14] http://www.dti.gov.uk/ energy/chpfinalreport.pdf

3.4.2 Assumptions Used in CHP Report

MDM-E3 and the CHP sub-model require a set of assumptions describing the state of the economic environment in the future. These can be classified into three types:

- Energy prices;
- Government policy measures; and
- Macroeconomic variables.

Energy Prices

The assumptions about the future levels of energy prices, particularly the prices for electricity and gas, have been critical to the results arising from the modelling analysis. As central fuel price assumptions, it has been assumed that gas market prices decrease slightly in the short run while the wholesale price of electricity is assumed to be stable for a number of years before increasing slightly. These slightly differ from the assumptions underlying the modelling work undertaken in ENUSIM.

Government Policy Measures

The policy assumptions in the base case capture the effects of a number of policy measures. These include:

- Exemption of the fuel input to CHP from the CCL;
- Exemption of direct sales of electricity generated by CHP from CCL;
- Exemption of exports of electricity via licensed suppliers generated by CHP from CCL as announced in the 2002 Budget;
- The CCL, CCAs and the lower CCL rates (20% of the standard rates) for industrial sectors with a CCA (affecting the fuel prices of alternatives to CHP);
- ECAs for CHP Schemes;
- Certain exemptions from Business Rates for CHP power generating equipment and machinery;
- The effects of the ETS (assuming a permit price of £15/tonne carbon);
- The effects of the Community Energy Programme; and
- The effects of the Quality Improvement Programme through incentives to improve non-qualifying CHP so that it becomes eligible as qualifying CHP.

The baseline policy assumptions differ from those used in the ENUSIM work, which assumes no policy measures. This modelling of CHP contains a scenario however, which does correspond closely with the policy assumption of the ENUSIM work (see below).

Macroeconomic Variables

Assumptions have been made on a range of macroeconomic variables exogenous to the MDM-E3 model. These include, for example, the rate of economic growth and inflation in the UK's trading partners, exchange rates, interest rates and UK tax rates and government expenditures.

These assumptions, discussed in Cambridge Econometrics' January 2002 *UK Energy and the Environment* report, are consistent with those used in the ENUSIM modelling.

3.4.3 Key Findings

The work undertaken for the DTI and DEFRA were based around a baseline and fuel price assumptions slightly different from those used in the ENUSIM modelling. They are comparable enough nonetheless, to augment the ENUSIM modelling findings.

GQ CHP Capacity

Table 3.2 presents results from the scenario "base case without support measures", which most closely corresponds with the baseline "no measures" scenario used in the ENUSIM modelling. It shows that without government support measures, GQ CHP capacity in the UK is expected to rise from a little over 4.5GWe in 2000 to around 7.5 GWe in 2010.

Table 3.2: Capacity (MWe), Base Case without support measures

Sector	1995	2000	2005	2010
Chemicals	1058	1574	1741	1762
Other Industry & Power Generation	1085	1713	1839	1956
Own Use	656	987	1214	1542
Commerce & Households	176	237	851	2041
Iron and Steel	105	77	94	111
Minerals	17	55	57	57
Total	3097	4642	5795	7468

Table 3.3: Capacity (MWe), Difference from the Base Case

Sector	1995	2000	2005	2010
Chemicals	0	0	56	1053
Other Industry & Power Generation	0	0	300	693
Own Use	0	0	124	475
Commerce & Households	0	0	128	213
Iron and Steel	0	0	16	41
Minerals	0	0	1	2
Total	0	0	626	2477

Taken together, the Government measures - those implemented and those recently announced - are expected to add almost a further 2.5 GWe of GQ CHP capacity. Table 3.3 shows how the expected additional capacity relative to the Base Case is distributed across the sectors, while Table 3.4 shows the contribution of each of the support measures to additional capacity.

Table 3.4: Capacity (MWe): Contribution of Selected Measures

Sector	2010
CCL Fuel Input Exemption for CHP	196
Extension of the CCL exemption to exported energy	752
Enhanced Capital Allowances for CHP	744
Business Rates Exemption for CHP	117
Emissions Trading - CHP contribution	622
Quality Improvement Programme[1]	750
Community Energy Programme[1]	130
Interaction effect[2]	-834
All Support Measures in Base Case	2477

Notes:

1. Based on Government estimates
2. Contributions are measured by taking the difference between the Base Case with and without each of the support measures. See Chapter 6 of the CHP report (http://www.dti.gov.uk/ energy/chpfinalreport.pdf) for further details on the interaction (double-counting) effects.

Placing these results on the same sector classification basis as ENUSIM modelling is not straightforward (refer to Appendix E for summary discussion of this issue). The economic sector classifications used in CE's CHP report do not match those used in ENUSIM. ENUSIM has 19 sectors, which are largely contained in five MDM classifications: iron and steel, minerals, energy sectors' own use, chemicals, other industry. The ‘other industry’ classification contains most of the 19 ENUSIM sectors. Due to reasons of confidentiality with CHP data, the 'other industry' grouping was merged with ‘power generation’, another MDM sector grouping which is not covered by ENUSIM[15]. Power generation accounted for 13% of total GQ capacity of "other industry and power generation" group in 2000. This proportion was fairly stable over the period 1995-2000 and so assuming an unchanged proportion over the forecast period would be quite reasonable. Placing the results on the same sectoral basis, the impact of support measures is expected to add around 2 GWe of GQ CHP capacity.

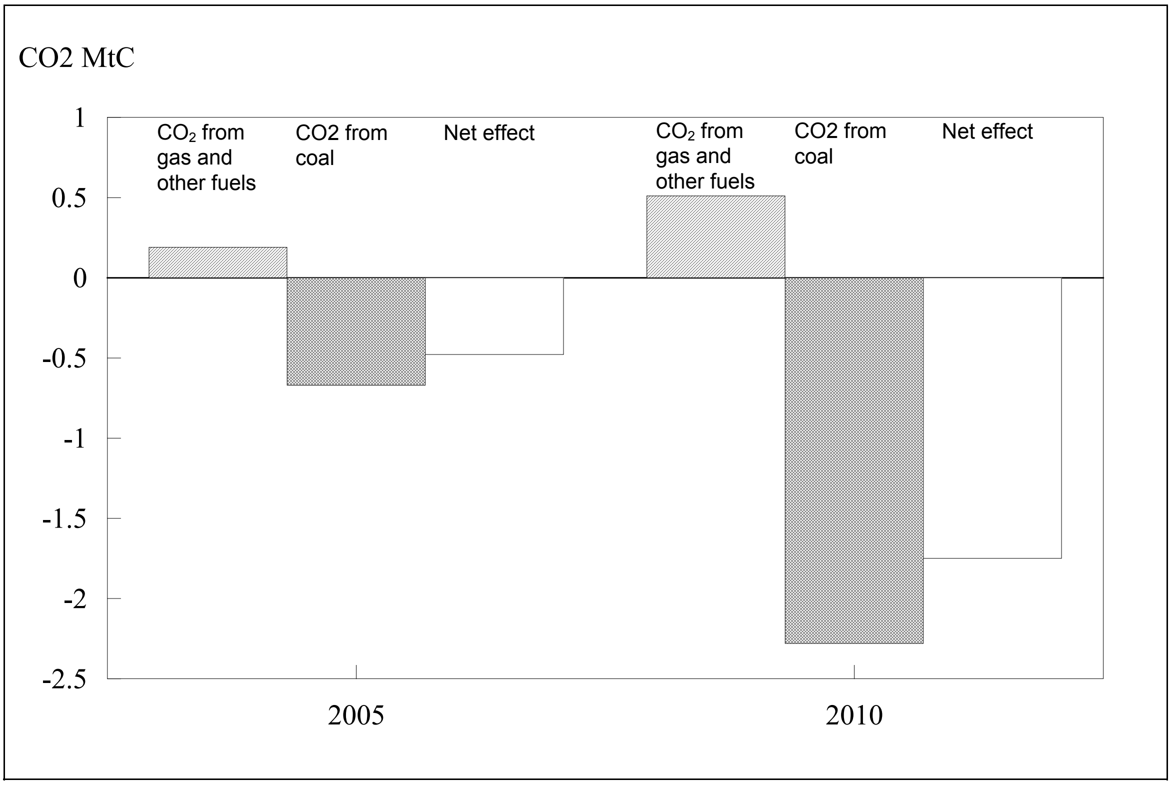
[15] A further yet trivial complication is provided the inclusion of Construction in Commerce and Households in the MDM-E3 model. On a slightly related issue, Water (Sewage Treatment) also should have been included into this grouping, but due to reasons of confidentiality was included in Other Industry.

Carbon Emission Savings

The carbon saving arising from additional capacity is expected to be around 1.7 MtC in 2010. The extra CHP capacity from the support measures is expected to displace coal-fired and gas-fired generation by the major power producers. UK carbon emissions will be reduced as a result, because new CHP (compared to a conventional system of gas-fired heating and electricity from the distribution network) is more efficient and uses fuels with much lower average carbon content to generate electricity. The support measures are estimated to reduce UK CO_2 emissions at an annual rate of 1.7 MtC by 2010, i.e. 0.7 MtC for each 1 GWe of new CHP installed[16]. This estimate is dependent to a certain extent on the assumption regarding the level of fuel prices and the relative prices of the different fuels. In contrast, the overall effect on UK CO_2 emissions of changing the fuel price assumptions in the base case is much larger.

Figure 3.1 shows the changes in CO_2 emissions divided into the changes in emissions from burning coal and those from burning gas and other fuels, with the net figure for emissions from all fossil fuels. As a result of the support measures, the higher CHP capacity displaces coal burning mainly by conventional power stations. There is, in comparison, an increase in gas burning by the extra CHP, that is partly offset by a decrease in gas burning by conventional gas fired power generation.

Figure 3.1: Effect of CHP Support Measures on UK CO_2 Emissions



[16] This estimate is almost identical to that calculated by the DTI in the October 2000 edition of Energy Trends.

Table 3.5 presents a breakdown of the contribution of each support measure to carbon savings. The exemption of CHP fuel inputs provides very little additional carbon savings. The low contribution seems to stem from the assumption in the modelling that a large percentage of firms with CHP (or potential installers of CHP) are also party to a climate change agreements. They therefore receive an 80% discount on the CCL, which reduces the benefits of the exemption from the CCL.

Table 3.5: Implied Carbon Savings: Contribution of Selected Measures (MtC)

Sector	2010
CCL Fuel Input Exemption for CHP	<0.05
Extension of the CCL exemption to exported energy	0.6
Enhanced Capital Allowances for CHP	0.6
Business Rates Exemption for CHP	0.1
Emissions Trading - CHP contribution	0.5
Interaction effect and other measures	-0.1
Total carbon savings from support measures	1.7

Since publishing the 3NC, the Government has announced a further CCL exemption for CHP. In the April 2002 Budget, the Government announced the CCL exemption for electricity exported from GQ CHP via licensed suppliers. This exemption provides (potentially) large financial benefits to CHP operators, as they will be able sell on any excess electricity output to licensed suppliers, who in turn can sell that electricity onto an end-user free from the CCL. It is estimated that this will deliver carbon savings of 0.6 MtC in 2010. Taken together, the CCL and CCL exemptions on CHP fuel and energy exports is estimated to contribute a reduction of 0.7 MtC, this increases to 0.8 MtC if the Business Rates exemption on CHP noted in the CCP is included.

Finally, it is useful to highlight that the ECAs measure is expected to deliver around 0.6 MtC savings in 2010 via CHP. In the 3NC, the Government estimated that all energy efficiency measures for business, announced as part of the climate change levy package, will save 0.5 MtC in 2010. In addition, the ETS is expected to deliver around 0.5 MtC carbon savings via CHP. In the 3NC, the Government estimated that emissions trading could save between 0.8 MtC and 2 MtC in 2010.

3.5 Other CCP Policies and Measures

The ETS has not been modelled as part of this project. This is due to the early stage at which the Scheme is currently at and the unsuitability of ENUSIM to model the measure[17]. In addition the

[17] The interaction of sectors can not be modelled since sectors are modelled individually. This has particular significance when attempting to model ETS whereby the advantage of sectors adopting energy efficiency measures may vary depending on the relative value of CO_2 ETS credits to sectors.

ECA measure has only been modelled in part. For the ECA, only the contribution from CHP has been examined. The estimates from the CHP modelling can be used as a lower-bound estimate of the contribution to carbon savings of the ECAs.

3.6 Non-Climate Change Programme Policies

Policies set out in the CCP aim to reduce greenhouse gas emissions. Outside the CCP policy framework, there are other policies that have the potential to influence energy consumption and hence greenhouse gases, particularly CO_2. The influence of these policies may be either to reduce or increase CO_2 emissions. A review of key policies was carried out to establish which ENUSIM industry sectors and sub-sectors may be affected by such policies. The results of this review are presented in Appendix D.

Two non-climate change policies were considered to have a potential to affect industrial sector energy use. These are the Large Combustion Plant Directive (LCPD) and the Sulphur Content of Certain Liquid Fuels Directive (SCLFD). The impact of these polices on the relevant sectors has been investigated and the conclusions are summarised in the table below.

Table 3.6 Summary of LCPD and SCLFD Impacts

Policy Measure	Industrial sectors/sub-sectors affected	Change in energy use	Effect on energy/fuel use
Large Combustion Plant Directive	Electricity generation, petroleum refining, coke manufacture, iron & steel, cement	Estimated net increase of ~400 TJ/year (0.02% of UK total) by January 2008	Some operators will have to install additional abatement equipment. The main impact is on coal-fired power stations.
Sulphur Content of Liquid Fuels Directive	Petroleum refining	No significant change	Most refineries will switch to low-sulphur crude or are already producing low-sulphur fuels. Some refineries will switch to natural gas for internal energy use.

It is concluded that non-climate change policies will lead to an increase in industrial sector energy use of around 0.02% of the UK industrial sector total. Considering that total UK primary energy demand for all sectors (i.e. industrial, domestic, transport, etc.) in 2000 was around 102,220 PJ (DUKES 2001), the impact of non-climate change policies is to increase total UK energy use by around 0.004%. This marginal effect on energy demand was not considered further in the policy analysis.

4. Cost Curves and Structural Change in the Economy

4.1 Introduction

This chapter examines findings from two off-model exercises:

- Examination of cost curves as implied from the latest ENUSIM simulations; and
- Examination of the role of structural change on energy consumption.

The aim of the cost curve work was to establish the overall scope of economically feasible energy efficiency improvements possible. The aim of the structural change work was to examine historical trends of production and energy consumption ratios and to examine the nature of the relationship between fuel price changes and the effect such changes may have on structural change in the economy.

4.2 ENUSIM Cost Curves

4.2.1 Introduction

A detailed examination of the costs curve function in ENUSIM was presented in the April 2002 report. The method of calculation and limitations of the costs curve function were explored. Despite a number of limitations, the cost curve function has been used to provide an overall assessment of the scope for energy savings and implied CO_2 emission reductions as a function of cost.

4.2.2 Method

The cost curve is built up as follows:

1. The available technologies on a given device are ordered by cost-effectiveness (defined by annual financial savings taking into account annualised capital costs, running costs and energy and other savings). These technologies are then applied to the device in that order, up to the level of the remaining cost-effective potential in the year for which the curve is being calculated;
2. The actual energy saving associated with any given technology depends on its position in the list of available technologies, since there is a diminishing return associated with adding multiple technologies to a given device. This also affects the annual saving associated with the technology via the financial impact of the energy saving; and
3. Once the effect of all technologies in the sector has been calculated, the full list of technologies is then ordered in terms of the specific annual saving (i.e. the annual saving per unit of energy or CO_2 saved). This is used as the y-axis data for the cost-supply curve, and the energy or CO_2 saving is used as the x-axis data.

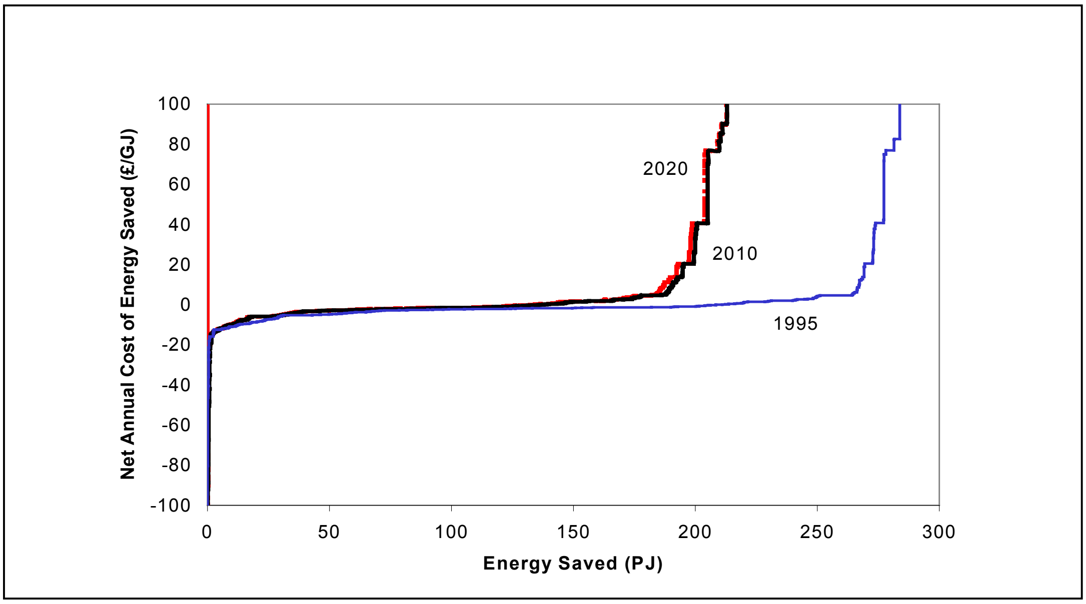
4.2.3 Results

Appendix F presents sectoral cost curves for both energy saved and CO_2 saved using calculations from the latest ENUSIM simulations, (which includes the revision to device technologies, capital costs and efficiency savings undertaken as part of this contract). A discount rate of 25% was used for these cost curves.

To understand the potential supply of energy saved from the industrial sector and its potential cost, aggregate 'supply' curves were constructed using discount rates of 3.5% and 25.0%. These differ from the cost curves in that they map the average cost of energy saved (or carbon emission reduction) against the cumulative energy saved (or carbon emission reduced) from all cheaper technologies[18]. This type of curve is broadly consistent with the concept of a supply curve, which shows the amount of a good supplied (in this case, energy saved) for given prices (in this case, specific energy savings).

Figures 4.1 to 4.4 plot an aggregated energy and carbon saving supply curves derived from sectoral cost curves using discount rates of 3.5% and 25.0%. The aggregated curve is a mapping of the specific energy savings of all technologies across all industries with the cumulative energy saved from all cheaper technologies. The curves include all the industrial sectors covered by ENUSIM, including the energy industries' own use.

Figure 4.1: Potential National Energy Savings (3.5% discount rate)



[18] One shortcoming of these curves is that they do not take account of the order in which technology will need to been implemented. Hence, low-cost technologies may be needed to be implement following high cost technologies.

Figure 4.2: Potential National Carbon Savings (3.5% discount rate)

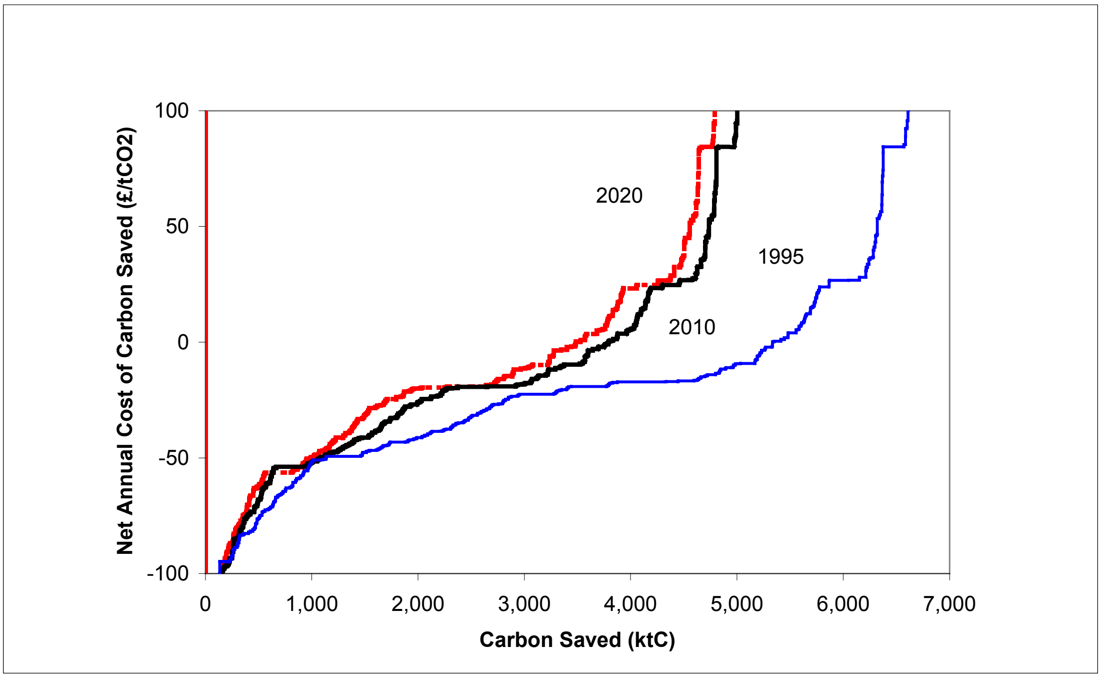


Figure 4.3: Potential National Energy Savings (25.0% discount rate)

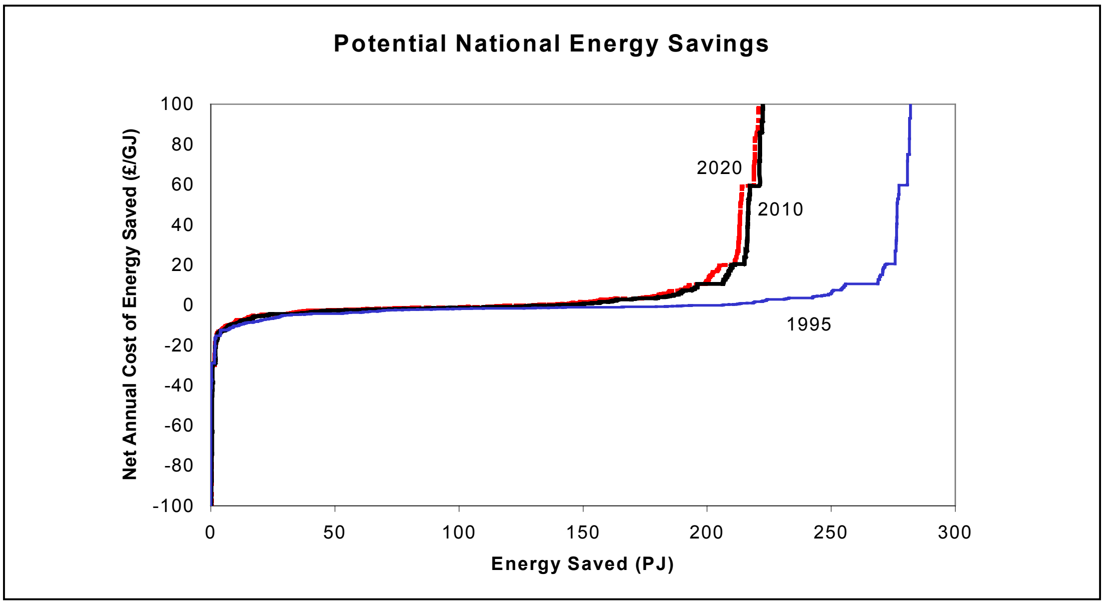
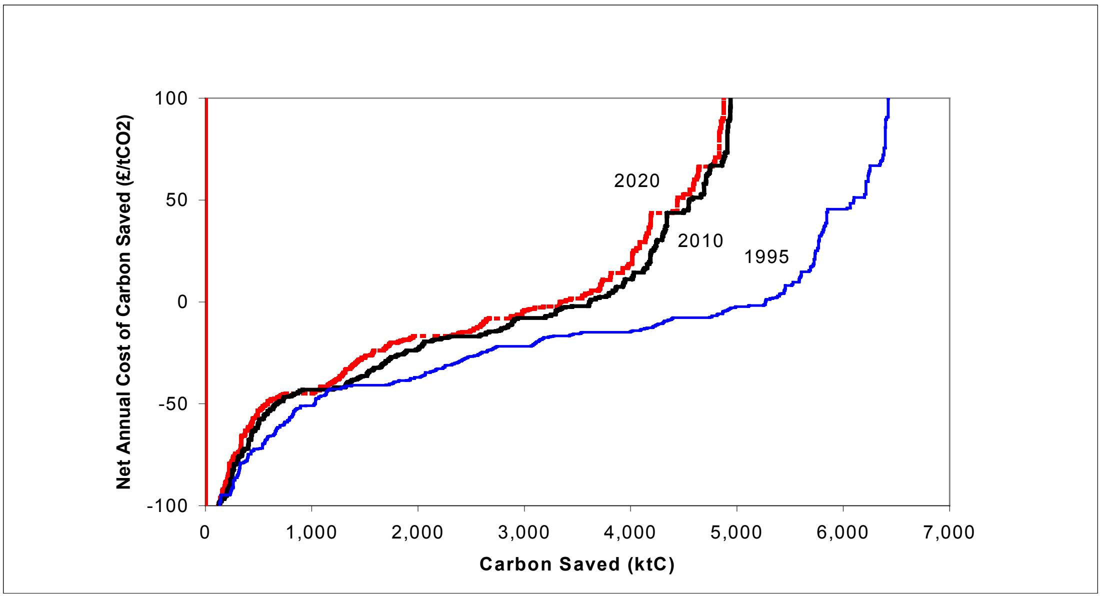


Figure 4.4: Potential National Carbon Savings (25.0% discount rate)



The upward-sloping curve is consistent with standard microeconomics theory. The energy-saved supply curves begin at negative prices, indicating that these savings are made at a negative cost (i.e. reduced overall cost) to industry. The leftward shift in the energy supply curve means that by 2020 there is a smaller amount of 'no regrets' energy savings that can be achieved than was possible in 1995. It should be noted that this is because this curve does not incorporate yet-to-be invented energy-saving technologies that could provide a greater scope for energy savings, off-setting the leftward shift in the supply curve between 1995 and 2020.

The carbon-saved supply curves differs in shape and length from the energy-saved supply curve. While these carbon-saved supply curves are essentially implied from the energy-saved curves, there is not a one-for-one correspondence between the charts, as energy-technologies will have different fuel mixes.

Under certain conditions, the carbon-saved curve can provide insight into the size of annual carbon-savings from different permit prices of the ETS. For instance, a permit price of £5 per tonne carbon dioxide could deliver around 3.8 MtC in 2010 at a discount rate of 25%, or 4.0 MtC at a discount rate of 3.5%, if all cost effective technologies are taken up. Carbon abatement costs increase sharply above about 4.6 MtC (2010, 3.5% discount rate). This includes a contribution of about 0.8 MtC from savings in the energy industries' own use, mainly in refineries.

4.3 Structural Change

This section comprises two parts. The first looks at the historical structural change of the industrial sector and what impact it has had on energy consumption patterns. The second examines the impact of a fuel price shock on structure of industry using simulation runs performed in MDM-E3. The data to assess historical structural change became available in July 2002. It has not yet been possible to assess whether the new information will improve ENUSIM's historical data.

4.3.1 Historical Structural Change

Introduction

Structural change refers to a change in the mix of output produced; it is commonly measured by changes in sectors' share of total output. It should be distinguished from technical change, which refers to a change to the input mix of production. Structural change occurs for various reasons including changes in household consumption patterns, changes in market conditions due to increased import penetration and to a lesser extent, changes in cost of inputs such as fuels. Further, structural change can provide impetus for technical changes and technical change can in turn drive structural changes.

Changes in energy consumption are often explained in terms of output growth, technical change (which is usually leads to greater energy efficiency) and structural change. A common way to measure technical change and structural change effects on energy consumption is to examine the change in the ratio of energy to output or 'energy intensity'. This method assumes a constant elasticity between energy consumption and output through time, and assumes that technical and structural change does not affect output growth. Changes in energy due to technical and structural changes however, are largely unobservable or difficult to measure.

According to the DTI in its recently published *Energy Consumption in the UK*[19], between 1990 and 1999, the overall decline in industrial energy intensity was 13 per cent[20]. Of this overall decline, the DTI estimated that 11 per cent was due to changes in intensity of the component sectors of industry. Changes in structure are estimated as contributing 2 per cent. The fall in energy intensity, however, was partly attributable to a change in the way energy statistics were collected in the period. In 1996, there was a change in the definition used to classify the industrial sector - energy used in transformation activities, for example, manufacturing coke or generation of electricity was excluded from 1996 onwards.

Historical Energy Consumption Dynamics

The DTI have also recently published disaggregated industrial-sector energy consumption statistics. These enable for the first time examination of the historical dynamics of energy consumption at a very disaggregated level. Appendix G contains charts of the energy consumption disaggregated on an ENUSIM sectoral basis. These charts also contain sectoral data on gross output (in volumes) from the Office for National Statistics input-output database and implied ratio of energy intensity. It should be highlighted that due to classification problems with the energy data, these charts may over- or under-state the actual change in the energy intensity in a particular sector; although direction of the movements should be broadly correct.

Of the 19 ENUSIM sectors, 18 sectors show a decline in their energy intensity ratio between 1992 and 1999. The largest fall occurred in the Non-Metallic Minerals sector, which fell almost 60% between 1992 and 1999. The only sector to exhibit a rise in its energy ratio was the Energy

[19] http://www.dti.gov.uk/energy/inform/energy_consumption/index.shtml

[20] See page 33, DTI (2002) 'Energy Consumption in the UK'.

Industries sectors. This rise however, is complicated by definitional problems with data, as the DTI energy data do not cover oil, gas and coal extraction.

Two parts of the industrial sector that have undergone substantial change, both technical and structural, are the engineering, and plastics sectors. Developments in these two areas are examined in detail below.

Engineering Sector

Engineering comprises two sectors in the ENUSIM classification, electrical engineering and mechanical engineering. The electrical engineering sector experienced considerable change in the 1990s. The composition of this industry is mixed, including activities ranging from manufacture of typewriters and calculators to printed circuit board manufacture, machining and assembly. Table 4.1 presents a summary of output and energy consumption statistics for the sub-sectors underlying electrical engineering.

Table 4.1: Electrical Engineering: Energy Consumption and Gross Output

Sub sectors	Change in energy	Changes in output	Change in energy intensity	% share of output in 1999	Change in output share, 1992-99	% share of Energy in 1999	Change in energy share, 1992-99
Office machinery & computers	0	15	-15	24	-2	11	2
Electric motors and generators etc	-15	16	-31	13	-1	22	2
Insulated wire and cable	-65	-14	-52	3	-1	5	-3
Electrical equipment NEC	-8	16	-24	10	-1	16	2
Electronic components	0	35	-35	9	1	18	4
Transmitters for TV, radio and phone	-23	83	-107	17	7	7	0
Receivers for TV and radio	-51	22	-73	7	0	3	-1
Medical and precision instruments	-57	6	-62	19	-4	17	-7
Total electrical engineering	-24	23	-46	100	-	100	-

These data show that the 24% decline in energy consumption for electrical engineering between 1992 and 1999 was broadly based across the sub-sectors, with only two sub-sectors, *office machinery & computers* and *electronic components*, not recording a fall; the largest fall in energy consumption was recorded in *insulated wire and cable*. Despite the decline in energy consumption, output grew by 23% between 1992 and 1999, implying a 46% fall in the energy intensity. Of this decline in energy intensity, it is estimated that 4% was due to changes in the output mix of electrical engineering.[21]

Mechanical engineering comprises two SIC industries: *manufacture of fabricated metal products* and *manufacture of machinery and other equipment*. As with electrical engineering, mechanical engineering covers many activities, with very different output growth histories. Table 4.2 presents output and energy consumption statistics for the sub-sectors underlying mechanical engineering.

Table 4.2: Mechanical Engineering: Energy Consumption and Gross Output

Sub sectors	Change in energy	Changes in output	Change in energy intensity	% share of output in 1999	Change in output share, 1992-99	% share of Energy in 1999	Change in energy share, 1992-99
Structural metal products	-19	61	-80	11	1	7	0
Metal boilers and radiators	-54	1	-55	3	-2	3	-1
Metal forging, pressing, etc	26	75	-50	17	4	32	11
Cutlery, tools etc	-20	33	-54	4	-1	4	0
Other metal products	-24	24	-47	10	-3	13	-1
Mechanical power equipment	-36	30	-67	12	-2	11	-3
General purpose machinery	-30	57	-87	17	2	11	-2
Agricultural machinery	-14	34	-47	3	0	2	0
Machine tools	-57	48	-105	4	0	2	-1
Special purpose machinery	-53	66	-119	11	2	6	-3
Weapons and ammunition	29	33	-4	3	0	4	1
Domestic appliances NEC	-21	41	-62	4	0	3	0
Total mechanical engineering	-15	48	-62	100	-	100	-

These data show that the 15% decline in energy consumption between 1992 and 1999 was broadly based, with only two sub-sectors, *metal forging, pressing, etc.* and *manufacture of* w*eapons and ammunition,* recording rises. The largest falls in energy consumption were

[21] This estimate was derived by applying the same method used in the DTI publications 'Energy Consumption in the UK' (2002) and 'Energy Paper 66' (1997).

recorded in *manufacture of machine tools* and *manufacture of metal boilers and radiators.* Despite the decline in energy consumption, output grew by 48% between 1992 and 1999, implying a 62% fall in the sector's overall energy intensity. Had the output mix of mechanical engineering stay the same over this period, the decline in energy intensity would have been 66%; hence, the output mix of mechanical engineering become more energy intensive between 1992 and 1999.

Plastics and Rubber Products Sector

The plastics and rubber products industry is covered by the SIC code 25. The plastics industry converts a wide range of polymer into a host of finished and semi-finished products, while the rubber products industry largely consists of the manufacture of tyres for the vehicles industry and manufacture of general rubber products.

Table 4.3 presents output and energy consumption statistics for the sub-sectors of *plastics & rubber products*. Due to lack of detailed data on output, this sector could only be divided into two parts. These data show that the 9% decline in energy consumption for plastics and rubber between 1992 and 1999 reflects an 18% decline in energy consumption in plastics that was partly offset by a 23% rise in energy consumption in rubbers products. Despite the decline in energy consumption, output grew by 42% between 1992 and 1999, implying a 50% fall in the overall sector's energy intensity. Of this decline in energy intensity, it is estimated that 1% was due to changes in the output mix of plastics and rubber products industry.

Table 4.3: Plastics and Rubber Products: Energy Consumption and Gross Output

Sub-sectors	Change in energy	Changes in output	Change in energy intensity	% share of output in 1999	Change in output share, 1992-99	% share of Energy in 1999	Change in energy share, 1992-99
Rubber products	23	31	-8	18	-2	26	7
Plastic products	-18	44	-62	82	2	74	-7
Total plastics and Rubber	-9	42	-50	100	-	100	-

Table 4.4 presents more detailed energy statistics for these industries. These data show that the 18% decline in energy consumption for plastics was entirely driven by a 76% fall in energy consumption for *plastic plates, sheets, tubes and profiles*. While part of this fall could be attributable to changes in classification between 1995 and 1996, most of the fall occurs outside these periods suggesting a broadly based downward trend in energy consumption in this sub-sector.

Table 4.4: Detailed Energy Data

Sub-sectors	Change in energy	% share of energy in 1999	Change in energy share, 1992-99
Rubber tyres and tubes	26	14	5
Re-treading and rebuilding of rubber tyres	-102	0.3	-0.4
Other rubber products	25	12	3
Plastic plates, sheets, tubes and profiles	-76	24	-19
Plastic packing goods	46	19	6
Builders' ware of plastic	10	10	-1
Other plastic products	32	21	6
Total plastics and Rubber	-9	100	-

4.3.2 Fuel Price Induced Structural Change

Method

To undertake an analysis of the effects of fuel price changes on structural change, a MDM-E3 model run was performed whereby a shock to fuel prices was applied. The shock consisted of a tripling of the full CCL rate from 2002 onwards. The effects of the fuel prices shock are measured in terms of differences in sectors' share of gross output with and without the fuel price shocks.

Results

The simulation results are presented in charts in Appendix H. In all cases, the percentage point change is very small; less than 0.1 percentage points. The results appear to present logical trends. The only exemption appears to be the results for Energy Industries' own use. The share of the energy sector's gross output increases after the fuel-prices shock, which at first glance may seem counterintuitive. It should be noted however, that the energy sector's own use includes coal extraction, oil and gas extraction and manufactured fuel (that is, largely petroleum refineries and processing of nuclear fuels) and gross output movements in this sector is largely dominated by petroleum refineries - petrol products are not subject to the CCL. Further, gross output from coal extraction and oil and gas extraction are fixed to the level of proven reserves and so are unaffected by demand fluctuations caused by changes in the price of fuels; these fluctuations are captured by imports of these commodities. Finally, for completeness it should be noted that gross output in electricity supply and gas supply industries do fall as share of economy-wide gross output after the shock.

In conclusion, fuel price changes are not likely to be a driving force behind the structural change. It is more likely that globalisation of production, i.e. increasing imports and changes in consumers' tastes are the main drivers of structural change in the future as they have been in past.

5. Conclusions and Discussion

5.1 Modelling Techniques

A combination of modelling techniques was necessary to perform the analysis. These were the use of ENUSIM, MDM-E3 and off model calculations using data from the models. Data regarding modelled growth rates for the sectors were used from MDM-E3 in ENUSIM to enable historical and future patterns of growth to be more robustly considered.

ENUSIM is currently the most developed bottom-up energy model for the UK. ENUSIM has a number of strengths in the modelling of the CCP policies and measures including:

- Understanding the process of how energy savings are realised and by which sectors;
- A unique data source for energy efficiency technologies by sector, sub-sector and device;
- Wide coverage of industry and current data following the review and update of sectors accounting for 70% of industry energy demand.

As with all models, ENUSIM exhibits some limitations. Examples include:

- Difficult to validate - there are no comparable models against which accurate validation is possible. Efforts have been made to validate certain modelling responses in this work however, the alternative modelling techniques are not directly comparable;
- The interaction of sectors cannot be modelled since sectors are modelled individually. This has particular significance when attempting to understand measures such as the ETS whereby the advantage of sectors adopting energy efficiency measures may vary depending on the relative value of CO_2 ETS credits to sectors;
- Throughput measures are in physical units. To perform a more transparent economic analysis, throughput would need to be measured in standardised economic units (e.g. gross output in constant prices);
- Fuel prices are in current prices but capital, fixed and variable costs are constant through time suggesting that they fall in real terms through time (which may be a reasonable assumption);
- ENUSIM does not capture uncertainty faced by industry. Market penetration of a technology could be tied to an industry's growth profile (i.e. faster growth, faster penetration of energy saving technology);
- ENUSIM does not capture the real option associated with the decision to implement a technology since it uses simple financial payback (although

behavioural aspects are incorporated to a degree). It may be profitable for a firm to wait until the uncertainty is resolved; and

- The absence of boilers and CHP technology from the model's database limits analysis of a number of policies likely to affect the adoption of CHP.

Despite these issues, ENUSIM provides the most extensively developed and robust bottom up model for the analysis of policies and measures affecting energy consumption in the UK. The updating of the model's technology database has improved confidence in data quality and the model's technology coverage. The overall policy analysis however required the use of MDM-E3 to evaluate the contribution of CHP by different policies and measures. Key strengths and weaknesses surrounding MDM-E3 relate to the following which are typical of top-down models:

- Strengths:
    - Provide analysis of economic feedback effects for CO_2 abatement policies on a sectoral level;
    - Provide analysis of the effect on structural change of CO_2 abatement policies in a macro-economic context; and
    - Measure adjustment costs in the economy as a result of CO_2 abatement policies.
- Weaknesses:
    - Only fiscal instruments can be examined;
    - Do not describe energy end uses, technologies and energy efficiency technologies; and
    - Long-term technological and behavioural change in industry is difficult to address.

5.2 Policy Impact

5.2.1 Carbon emission reductions

Table 5.1 summarises the estimated impact of the policies and measures simulated in the modelling conducted for this project. The contributions are relative to a BAU scenario and refer to the year 2010.

The overall effect of the policies and measures modelled to date is anticipated to be a reduction of 4.5 MtC from baseline (no policies) in 2010, with further potential contributions from the ETS discussed below.

Table 5.1 Simulated Policy Contributions to Carbon Reductions from Business as Usual by 2010 (MtC)

Policy Measure	Carbon reduction from policy simulation
Climate Change Levy (CCL) plus Climate Change Agreements (CCA)	>3.4
CCL Package (ECAs)[1]	0.6
Business rate exemption on Combined Heat and Power (CHP)[2]	0.1
Emissions Trading Scheme (ETS)[3]	0.5
Less interaction effects of CHP policies	-0.1
Total contributions	**4.5**

Notes:

All contributions are relative to business as usual (i.e. no policies)

1. CCL Package is the contribution from ECAs and the Carbon Trust. Includes contribution from sectors both with and without CCAs
2. No estimate of the policy impact is provided in the CCP or the 3NC
3. CHP contribution only

For the ETS, although our modelling has only included CHP, our cost curve work has indicated further capacity for savings through emissions trading at reasonable cost - at £5 per tonne of carbon dioxide permit price and 3.5% discount rate, the potential through identified energy efficiency measures (excluding CHP, and relative to baseline) is 4.0 MtC in 2010. Taking into account the 2.7 MtC of non-CHP saving, a further 1.3 MtC, or a total reduction of 5.8 MtC, appears to be feasible under current policies. The cost curves for industry suggest that carbon reductions are limited to about 5 MtC, which corresponds to a total reduction of 7.0 MtC. This figure includes a contribution of approximately 0.8 MtC from a saving in the energy industries' own use of energy.

3NC/CCP projected savings amount to 5.8 – 7.0 MtC. There are difficulties in comparing the estimates due to differences in a number of factors such as modelling principles, CCL rates applied, application of CCL exemptions, number of policies considered in the baseline and industry coverage. Certain differences are noted in Table 5.2 and the reductions relating to the various policy measures are discussed below:-

For the CCL, the total estimated impact by 2010 of the fuel price response, CHP fuel CCL exemption and CHP energy supplied CCL exemption is 3.4 MtC compared with 4.5 MtC in the CCP. The CCP figure does include commercial, public and service sectors; EP68 shows that projected service sector energy use of 24,350 ktoe in 2010 is over 38% of the industry plus service sector total of 65,350 ktoe. The difference may also be attributed to the low response to fuel price change modelled in ENUSIM. However, we have found no evidence that the additional figure of 2.5 MtC for Climate Change Agreements (which offer participants an 80% reduction in the levy) took into account the original CCL estimates, which were based on the full levy.

The extension of the CCL exemption to energy supplied by CHP makes the most significant contribution to the 0.6 MtC. For the CCAs, the estimate of 2.7 MtC is slightly above the 2.5 MtC estimated in the CCP, and we understand this is consistent with recent DTI estimates.

Although the simulation of the ECAs covers CHP only, the change of 0.6 MtC is 0.1 MtC greater than that estimated in the CCP. Further gains may be anticipated from the adoption of other technologies covered by the ECA; this is however, not anticipated to add a significant amount to the 0.6 MtC already achieved through CHP. It is estimated that the Business Rate exemption on CHP contributes a further 0.1 MtC although no formal estimate of the effect of this measure is provided in the CCP.

For the ETS, the CCP estimates 2.0 MtC reduction by 2010. The 3NC estimates a contribution of 0.8 MtC will come from the first tranche of the ETS. ENUSIM does not allow simulation of the ETS, but alternative modelling indicates that 0.5 MtC will result from CHP attributable to the ETS in 2010.

Table 5.2 Summary of Information Available and Assumptions made for EP68, 3NC and the Entec/CE Policy simulation

Issue	EP68	3NC Baseline With Measures	Entec/CE Simulation
Model principle	Top down	Various	Bottom up
CCL rate	Full rate applied to all sectors (+ real term increase)	Assumed that discounted rate applied to sectors where CCA in place	Discounted rate applied to sectors where CCA in place
CCL exemption on CHP	Yes (fuel input only)	Assumed yes (on fuel input only)	Yes (on fuel input and energy output)
CCL exemption on renewables	Yes	Assumed yes	No
CCAs considered	No	No (but estimated effect available)	Yes
ETS	No	No (but estimated effect available)	Yes (CHP contribution only)
Industry coverage	Industry (only minor differences to DUKES)	'Industry' and 'Commerce', assumed to be the same as DUKES	'Industry' comparable with DUKES, also includes 'Energy Industry' own use
Carbon from auto-generation	Not included (transferred to 'Power Station' category	No information	Included
Fuel mix change	Accounted for	Assumes accounted for	Maintained constant unless fuel mix is changed through adoption of a technology

5.2.2 Total emissions of carbon

Table 5.3 presents available carbon emission estimates from EP68, 3NC and the simulations made through this project (termed Entec/CE policy simulation).

EP68/3NC Industry figures refer to end user emissions due to industrial energy use and are obtained from the average of CL and CH projections in Table A1 of EP68 subtracting the industrial process emissions from 3NC Chapter 4. The contribution of CHP to policies is described in section 3.4 of this report.

Table 5.3 Entec/CE Simulation - comparison of industrial emissions with projections (MtC)

Entec/CE policy simulation	1990	1995	2000	2005	2010
Industry (excludes energy industry own use),baseline, no measures	43.18	36.21	35.85	35.31	36.22
Energy industry own use, baseline	13.62	11.35	10.58	10.27	10.19
Industry with CCL, CCA and IPPC **excluding** contribution of CHP	43.18	36.21	35.95	33.41	33.55
Industry with CCL, CCA, IPPC **including** CHP contribution	43.18	36.21	35.95	32.56[1]	31.85
Entec/CE Simulated change on 1990 - Industry	-	-	-	-10.62	**-11.33**
Energy industry own use with policies	13.62	11.35	11.58	10.23	10.13
3NC/EP68 projections					
3NC/EP68 Industry	44.8	38.6	34.95	33.0	33.0
3NC/EP68 change on 1990				-11.8	**-11.8**

Notes:

1. Interpolated

5.2.3 Underlying energy consumption

We have reviewed the energy use in each simulation, and Table 5.4 shows energy projections used in our simulations. Although there are some differences in sub-sectors, notably iron and steel, food and drink, cement and 'other industries', the Entec/CE simulated 2000 figures show consistency with actual data from DUKES. Our simulated 'Industry' total figure of 1320 PJ is 91% of the DUKES (2002) 'Industry' figure for 2000, which includes some 8% of 'unclassified' energy use.

EP68 energy use is significantly higher than both our simulation and DUKES, but includes various transformation uses of energy as well as agriculture. EP68 does not, however, appear to include all the energy industry's own use, which is shown separately.

Table 5.4 Estimated Industry Energy Consumption Trends (PJ)

Industrial energy use	1990	1995	2000	2005	2010	2015	2020
Entec/CE policy simulation							
'Industry' energy use, baseline	1543	1337	1316	1296	1329	1409	1516
'Energy industry' own energy use, baseline	616	587	560	536	518	531	561
'Industry' energy use with CCL/CCA/PPC[1]	1543	1337	1320	1230	1237	-	-
'Energy industry' own energy use with CCL/CCA/PPC	616	587	560	534	516	-	-
EP68 'Industry' Final Energy Demand (average of CL and CH)	-	1641	1662	1687	1717	-	-
DUKES 2002 'Industry' energy use	1619	1519	1444	-	-	-	-

Notes

1. Excludes the impact of CHP policies and Emissions Trading

5.3 Demonstrable Progress

The 3NC presents the expected trend of carbon emissions under current measures of the CCP – the UK total and 'Business' emissions are shown in Table 5.5. Business includes commerce and industrial process emissions. Industrial CO_2 emissions from energy use are inferred from 3NC and EP68, and show an expected reduction of 11.8 MtC from 1990 by 2010, and 10.5 MtC by 2020.

The results of the Entec/CE simulation are also included in Table 5.5, and indicate a reduction from the 1990 level of 11.3 MtC by 2010, similar to the 3NC figure of 11.8 MtC. The simulation for 2020 shows there is a difference of 8.7 MtC between the 3NC projection for 2020 and the BAU case. The contribution from NAs, CHP and other policies such as Emissions Trading will need to expand to reconcile this difference.

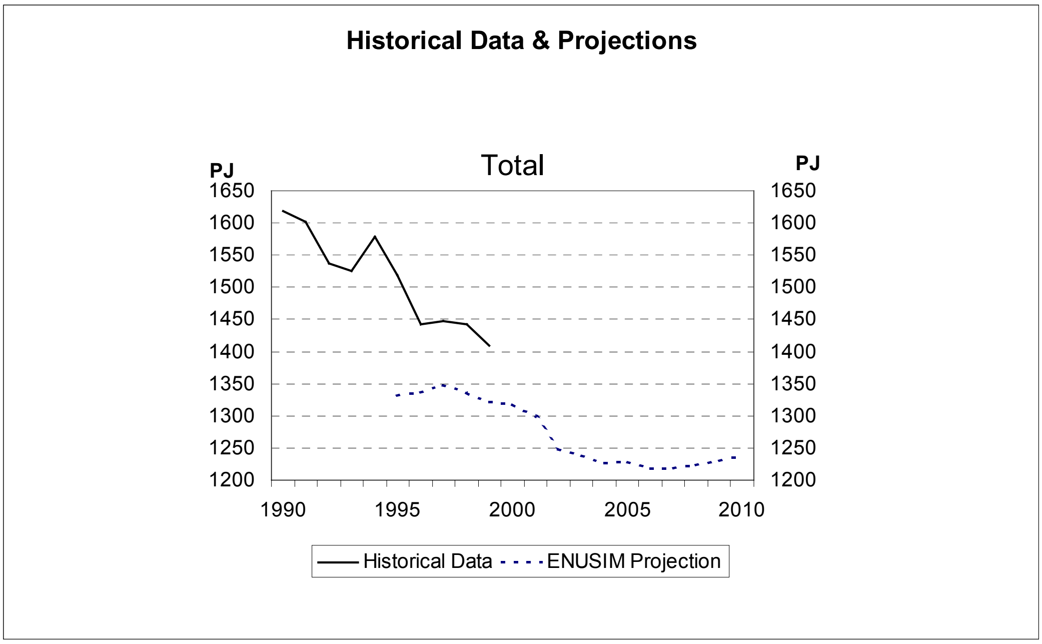
Table 5.5 Industrial Energy Use Contribution to Carbon Emission Reduction (MtC)

Parameter	1990	2010	2020
3NC projections			
UK greenhouse gas emissions	208.4	177.6	184.0
'Business' greenhouse gas emissions	73.3	58.9	60.4
Industrial CO_2 emissions from energy use	44.8	33.0	34.3
Reduction from 1990	0.0	-11.8	-10.5
Entec/CE simulation			
Industrial CO_2 emissions with CCL, CCA, IPPC and contribution of CHP	43.18	31.85[1]	41.39[2]
Contributions to reduction from 1990:			
BAU reduction	0.0	-6.9	-1.8
CCL, CCA, NAs	0.0	-2.7	-
Contribution of CHP to CCP policies	0.0	-1.7	-
TOTAL	-	-11.3	-

Notes:

1. Excludes ETS
2. Excludes ETS, CHP policies and NAs

Figure 5.1 Industrial Energy Use



It is too early to draw substantive conclusions on the impact of policies. Figure 5.1 illustrates progress in terms of energy use against a background of historical data and shows a comparison between ex-post data for industrial energy use and the ENUSIM projections. Historical data is derived from the DTI report Energy Consumption in the UK (2002), and the ENUSIM figures include the CCL, CCA and other policies but exclude the impact of CHP and Emissions Trading. The treatment of energy industry own use is different between the two sets of figures, so in both cases the figures represent industrial energy use excluding the energy industry's own use.

There are a number of competing reasons for the differences, which in 1999 is 87 PJ or 6.2% less than the DTI figure of 1409 PJ. Between 1995 and 1996, there was a reclassification of DTI data for iron and steel, leading to an apparent sharp drop in consumption, most of which is a movement of blast furnace gas used both in the process and for power generation. The ENUSIM figure of 1322 PJ still includes blast furnace energy, but does not include unclassified industry use of at least 120 PJ. The ENUSIM figures are also generally higher for Cement and lower for Food and Drink and 'Other industries'. For comparison, DUKES 2002 presents an industrial energy use of 1455 PJ in 1999.

5.4 Future Opportunity

The projected figures demonstrate some similarity of trend in energy demand with current ex-post data, but there have been difficulties in obtaining consistent, disaggregated ex-post data.

Energy use by SIC is now available to 1999, and as this is updated, comparisons can be made with the ENUSIM model on a sub-sector basis.

It has proved infeasible within this project to develop the ENUSIM model to encompass policies covering CHP and Emissions Trading. The structure of the model is such that major remodelling would be needed to adequately represent these policies. However, there is value in using the model in conjunction with other models and techniques to examine energy use and trends at a sub-sector level.

Examination of the impact of a carbon-based rather than energy-based levy would prove valuable, as would analysis of the outcomes of the joint Confederation of British Industry – Engineering Employers' Federation, and Policy Studies Institute - Green Alliance surveys regarding the impact of the CCL.

The CCA estimate by 2010 of 2.7 MtC compares favourably with the 2.5 MtC estimate in the CCP. This response is a calculated figure using data from ENUSIM and MDM-E3 and assuming that the legal requirements of the CCAs are met. Reporting on progress in meeting CCA obligations is not required until 2003 consequently, an evaluation of planned against actual progress made under the CCAs has not yet been possible. Analysis of CCA reporting data in 2003 will be necessary to evaluate the actual performance resulting from the measure. Following on from this analysis, validation of the behavioural function of ENUSIM (e.g. actual versus predicted market penetration of technologies) using CCA reporting may be performed. Industrial survey work to establish the market penetration of specific energy saving technologies would be valuable to validate the model, which uses expert judgement to estimate the rate of technology up-take and does not appear to have been validated previously.

There is further opportunity for savings resulting from the ECA by 2010 than that currently modelled since the current estimate considers ECA on CHP only. This compares favourably against the estimated effect of the measure in the CCP of 0.5 MtC. Anecdotal evidence from industry suggests however, that the ECAs will primarily be used for major investments such as CHP and that the effect on the investment in other technologies will be driven primarily by other considerations such as investment cycles, sector growth and existing technology conditions rather than the availability of ECAs.

Only CHP has been considered under the ETS to date. The contribution of CHP would appear to be significant in meeting the 3NC/CCP estimates of 0.8 - 2.0 MtC. The ENUSIM cost curves suggest that in 2010, approximately 140 PJ energy, or 4.0 MtC, may be saved at no or negative cost to industry at a 3.5% discount rate. At a cost of £30 per tonne carbon dioxide (£110 per tonne carbon), this potential saving would increase to approximately 4.6 MtC. Beyond this level of carbon reduction, Figure 4.2 shows that the cost curve rises steeply, and approaches a limit of about 5 MtC. Further work is required to evaluate the impact of the ETS as the scheme develops and companies come under pressure to meet stated reduction commitments.

From the review of international policies addressing industrial sector CO_2 emissions[22], areas identified that are not currently covered by UK policy measures are:

- Grants and low interest loans for energy saving equipment;

[22] Industrial Sector Carbon Dioxide. Review of International Policies Addressing Industrial Sector Carbon Dioxide Emissions, Entec UK Ltd, June 2002

- Investment subsidies for large-scale demonstration projects;
- Tax exemption for renewables projects; and
- Regulations on the performance of boilers (small scale).

Future work on the assessment of the potential for such policies and measures is required to complement existing policies and measures of the CCP. This may be particularly important for the impact of grants and low interest loans.

The ENUSIM model only includes foreseeable conventional energy efficiency technologies and techniques. Innovations which may occur through initiatives such as the Carbon Trust resulting in Low Carbon Technologies are not considered; consequently, any step-change that may result through technologies such as hydrogen sourced power and fuel cells are not considered. Investigation of the impact of scenarios surrounding step-changes in energy consumption and generation is worth considering in future work.

6. Glossary of Terms and Abbreviations

ACE	All cost effective
ATP	All technically possible
BAU	Business as usual
BREFs	Best available techniques reference notes
CCA	Climate Change Agreement
CCL	Climate Change Levy
CCP	UK's Climate Change Programme
CHP	Combined heat and power
CO_2	Carbon dioxide
DEFRA	Department of Environment, Food and Rural Affairs
DTI	Department of Trade and Industry
E	Energy
ENUSIM	Industry Energy End-Use Simulation Model
EP68	Energy Paper 68
ETSU	Energy Technology Support Unit
EU	European Union
GQ CHP	Good quality combined heat and power
GWe	Gigawatt electricity
ktoe	Thousands of tonnes of oil equivalent
IPPC	Integrated Pollution Prevention and Control
MDM-E3	Multisectoral Dynamic Model, Energy- Environment-Economy
MtC	Million tonnes carbon
MWe	Megawatt electricity
PJ	Petajoules (= 10^{15} J) 1 PJ is equivalent to 23.88 ktoe
PPC	Pollution Prevention Control
UED	Useful energy demand
UNFCCC	United Nations Framework Convention on Climate Change
SEC	Specific energy demand
3NC	UK's Third National Communication under the United Nations Framework Convention on Climate Change

Appendix A
ENUSIM Modelling Assumptions

Table A1: ENUSIM and Cambridge Econometrics Fuel and Energy Prices

ENUSIM Fuels	(£/GJ) in 2000*	MDM-E3 Energy Types
Coal (Large)	1.2275	Coal and coke (solid fuels)
Coal (Medium)	1.6475	Coal and coke (solid fuels)
Coal (Small)	2.1325	Coal and coke (solid fuels)
Coke	3.6080	Coal and coke (solid fuels)
Electricity (Large)	8.5819	Electricity
Electricity (Medium)	11.1416	Electricity
Electricity (Small)	14.5914	Electricity
Gas (Firm-Large)	1.6123	Gas (Natural gas, coke oven gas and town gas)
Gas (Firm-Medium)	2.1388	Gas (Natural gas, coke oven gas and town gas)
Gas (Firm-Small)	2.7140	Gas (Natural gas, coke oven gas and town gas)
Gas (Interruptible-Large)	1.2092	Gas (Natural gas, coke oven gas and town gas)
Gas (Interruptible-Medium)	1.6041	Gas (Natural gas, coke oven gas and town gas)
Gas (Interruptible-Small)	2.0355	Gas (Natural gas, coke oven gas and town gas)
Oil - Heavy fuel oil	3.3473	Fuel oil
Oil - Light fuel oil	3.8445	Fuel oil
Oil - LPG	7.1660	Fuel oil
Other gases	2.1300	Gas (Natural gas, coke oven gas and town gas)
Steam (Large)	1.1127	Steam (calculated off-model)
Steam (Medium)	1.4814	Steam (calculated off-model)
Steam (Small)	1.8915	Steam (calculated off-model)
Blast furnace gas	1.5873	Gas (Natural gas, coke oven gas and town gas)
Biogas	1.5873	Gas (Natural gas, coke oven gas and town gas)
Coke oven gas	1.5873	Gas (Natural gas, coke oven gas and town gas)
Waste	0.000	Unchanged

Notes:
* Excludes taxes and levies

Table A2: Fuel Price Growth (% pa change)

MDM-E3 Energy Types *	1995-2000	2000-2005	2005-2010	2010-2015	2015-2020
Coal and coke	-2.4	1.8	1.3	0.8	0.8
Gas oil **	10.5	2.1	5	5	5
Fuel oil	9.7	1.7	4.6	4.7	4.7
Gas	-1.9	12.2	3.5	4.4	4.4
Electricity	-6.2	0.4	2.1	2.7	2.7
Steam ***	-2.0	9.6	3.0	3.5	3.5

Notes:
Source: Cambridge Econometrics, *UK Energy and the Environment* report January 2002
* Based on prices for CE's 'energy-intensive industries', unless stated otherwise
** Based on price for CE's 'other industry'
*** A weighted average of gas and coal prices (weights are 0.75 and 0.25 for gas and coal)

Table A3: MDM-E3 Industry Output Growth (% pa average) - Baseline

MDM-E3 Industries	1995-2000	2000-05	2005-10	2010-15	2015-20
Coal	-10.0	-5.0	-2.5	-8.3	-8.3
Oil & Gas etc	1.9	-2.6	-4.2	-4.1	-4.1
Food	0.3	0.9	0.2	0.7	0.7
Textiles	-3.9	-4.4	-3.1	-1.9	-1.9
Wood & Wood Prods.	-1.8	0.3	0.4	1.1	1.1
Paper, Print & Pub.	-0.3	0.8	0.8	1.3	1.3
Manuf. Fuels	-3.8	1.6	2.6	3.2	3.2
Pharmaceuticals	3.6	6.6	5.7	5.9	5.9
Chemicals nes	1.6	0.9	0.9	1.3	1.3
Rubber & Plastics	-0.1	0.4	1.9	2.5	2.5
Non-met. Min. Prods.	-1.0	0.0	-0.3	0.2	0.2
Basic Metals	-2.2	-2.3	0.7	1.3	1.3
Metal Goods	-0.4	-0.4	0.1	0.4	0.4
Mech. Engineering	-2.2	0.7	1.4	1.3	1.3
Electronics	13.9	0.8	7.8	6.2	6.2
Elect. Engineering	0.5	0.1	2.1	1.9	1.9
Motor Vehicles	0.9	0.1	1.1	2.6	2.6
Oth. Transp. Equip.	0.8	2.0	1.9	2.1	2.1
Manuf. nes	0.8	1.3	1.8	2.5	2.5
Water Supply	-2.5	0.5	-0.9	-0.9	-0.9
Construction	1.8	2.3	1.5	2.2	2.2

Table A4: ENUSIM and MDM-E3 Classifications

E	ENUSIM Sector	Sub-sector	MDM-E3 Industry
1	Bricks	Flettons	Non-met. Min. Prods.
2	Bricks	Non Flettons	Non-met. Min. Prods.
3	Cement	Cement - Dry + Precalciner	Non-met. Min. Prods.
4	Cement	Cement - Dry Process	Non-met. Min. Prods.
5	Cement	Cement - S/W + Precalciner	Non-met. Min. Prods.
6	Cement	Cement - Semi-Dry Process	Non-met. Min. Prods.
7	Cement	Cement - Semi-Wet Process	Non-met. Min. Prods.
8	Cement	Cement - Wet Process	Non-met. Min. Prods.
9	Cement	Lime & Plaster	Non-met. Min. Prods.
10	Ceramics	Refractories	Non-met. Min. Prods.
11	Ceramics	Sanitaryware	Non-met. Min. Prods.
12	Ceramics	Tableware	Non-met. Min. Prods.
13	Ceramics	Tiles	Non-met. Min. Prods.
14	Chemical	Ammonia	Chemicals nes
15	Chemical	Chlor-Alkali	Chemicals nes
16	Chemical	Fertiliser	Chemicals nes
17	Chemical	General Organics	Chemicals nes
18	Chemical	Industrial Gases	Chemicals nes
19	Chemical	Misc. Chemicals	Chemicals nes
20	Chemical	Other Inorganics	Chemicals nes
21	Chemical	Pharmaceuticals	Pharmaceuticals
22	Chemical	Resins	Chemicals nes
23	Construction	Construction	Construction
24	Electrical Eng.	Electrical	Elect. Engineering
25	Electrical Eng.	Electronics	Electronics
26	Energy	Coal Extraction	Coal
27	Energy	Coke Manufacture	Manuf. Fuels
28	Energy	Electricity Gen. (Non-Nuclear)	Electricity
29	Energy	Electricity Gen. (Nuclear)	Electricity
30	Energy	Oil And Gas Extraction	Oil & Gas etc
31	Energy	Petroleum Refineries	Manuf. Fuels
32	Food And Drink	Animal Feeds	Food
33	Food And Drink	Beverages	Food
34	Food And Drink	Biscuits	Food
35	Food And Drink	Brewing Incl. Cider	Food
36	Food And Drink	Canned Foods	Food
37	Food And Drink	Cereal Products	Food
38	Food And Drink	Chilled Meals	Food
39	Food And Drink	Confectionery	Food
40	Food And Drink	Craft Bakeries	Food
41	Food And Drink	Crisps, Snacks & Nuts	Food
42	Food And Drink	Dairy Products	Food

E	ENUSIM Sector	Sub-sector	MDM-E3 Industry
43	Food And Drink	Distilling	Food
44	Food And Drink	Dry Mixes	Food
45	Food And Drink	Eggs	Food
46	Food And Drink	Fresh Fish	Food
47	Food And Drink	Fresh Fruit & Veg.	Food
48	Food And Drink	Frozen Fish/Fish Products	Food
49	Food And Drink	Frozen Meals	Food
50	Food And Drink	Frozen Veg. & Products	Food
51	Food And Drink	Glucose	Food
52	Food And Drink	Ice Creams	Food
53	Food And Drink	Industrial Bakeries	Food
54	Food And Drink	Liquid Milk & Cream	Food
55	Food And Drink	Malting	Food
56	Food And Drink	Meal Enhancers	Food
57	Food And Drink	Meat Products	Food
58	Food And Drink	Meats	Food
59	Food And Drink	Milling	Food
60	Food And Drink	Oils And Fats	Food
61	Food And Drink	Pet Food	Food
62	Food And Drink	Poultry Meats	Food
63	Food And Drink	Poultry Products	Food
64	Food And Drink	Preserves & Spreads	Food
65	Food And Drink	Slaughterhouses	Food
66	Food And Drink	Soft Drinks	Food
67	Food And Drink	Starch	Food
68	Food And Drink	Sugar	Food
69	Glass	Container Glass	Non-met. Min. Prods.
70	Glass	Fibre Glass	Non-met. Min. Prods.
71	Glass	Flat Glass	Non-met. Min. Prods.
72	Glass	Other Glass Sectors	Non-met. Min. Prods.
73	Mechanical Eng.	Mach & Equipment	Mech. Engineering
74	Mechanical Eng.	Metal Goods	Metal Goods
75	Non ferrous metal	Aluminium: Finished	Basic Metals
76	Non ferrous metal	Aluminium: Primary	Basic Metals
77	Non ferrous metal	Aluminium: Secondary	Basic Metals
78	Non ferrous metal	Copper: Secondary	Basic Metals
79	Non ferrous metal	Copper: Wrought Products	Basic Metals
80	Non ferrous metal	Lead	Basic Metals
81	Non ferrous metal	Other Non-Ferrous	Basic Metals
82	Non ferrous metal	Zinc	Basic Metals
83	Non Met Minerals	Concrete Products	Non-met. Min. Prods.
84	Non Met Minerals	Stone Etc	Non-met. Min. Prods.
85	Other Industries	Chipboard	Wood & Wood Prods.
86	Other Industries	Furniture	Manuf. nes
87	Other Industries	Miscellaneous	Manuf. nes
88	Other Industries	Sawmilling	Wood & Wood Prods.

E	ENUSIM Sector	Sub-sector	MDM-E3 Industry
89	Paper	Paper & Board	Paper, Print & Pub.
90	Paper	Printing & Publishing	Paper, Print & Pub.
91	Plastics	General Rubber	Rubber & Plastics
92	Plastics	Plastics Extrusion	Rubber & Plastics
93	Plastics	Plastics Injection Moulding	Rubber & Plastics
94	Plastics	Plastics Other	Rubber & Plastics
95	Plastics	Tyres	Rubber & Plastics
96	Steel	Bar And Tubes	Basic Metals
97	Steel	Blast Furnace Route	Basic Metals
98	Steel	Coated Steel And Misc.	Basic Metals
99	Steel	EAF Route	Basic Metals
100	Steel	Strip Plate And Sections	Basic Metals
101	Textiles	Carpets	Textiles
102	Textiles	Cotton Spinning	Textiles
103	Textiles	Finishing	Textiles
104	Textiles	Knitting	Textiles
105	Textiles	Synthetic Fibres	Textiles
106	Textiles	Weaving	Textiles
107	Textiles	Woollens & Worsted	Textiles
108	Vehicle Eng.	Land Transport	Motor Vehicles
109	Vehicle Eng.	Other Transport	Oth. Transp. Equip.
110	Water	Water	Water Supply

Appendix B
ENUSIM Sensitivity and Dynamics

Sensitivity to Change in the Discount Rate

Table B1 shows the impact of the adoption of 6% and 25% discount rates on energy demand and carbon emissions in the chemicals industry. The lower discount rate results in somewhat lower energy demand and carbon emissions by 2020, consistent with a greater take up of energy efficient techniques. Table B2 examines the impact of the adoption of 6% and 25% discount rates on energy demand and carbon emissions in the iron and steel sector. This sector shows very little responsiveness to the lowering of the discount rate over the whole period to 2020.

Table B1: Sensitivity to a Change in the Discount Rate in the Chemicals Industry

Chemicals Industry	1995	2000	2005	2010	2020
Energy Demand					**1995 = 1**
Discount Rate = 6%	1.00	1.08	1.10	1.15	1.24
Discount Rate = 25%	1.00	1.08	1.11	1.16	1.27
Carbon Emissions					**1995 = 1**
Discount Rate = 6%	1.00	1.08	1.10	1.16	1.25
Discount Rate = 25%	1.00	1.08	1.11	1.16	1.28

Fuel prices are the same as in the Base Case
The behavioural assumption is business as usual

Table B2: Sensitivity to a Change in the Discount Rate in the Iron and Steel

Iron and Steel	1995	2000	2005	2010	2020
Energy Demand					**1995 = 1**
Discount Rate = 6%	1.00	0.89	0.76	0.77	0.76
Discount Rate = 25%	1.00	0.89	0.77	0.78	0.75
Carbon Emissions					**1995 = 1**
Discount Rate = 6%	1.00	0.89	0.77	0.77	0.75
Discount Rate = 25%	1.00	0.89	0.77	0.78	0.77

Fuel prices are the same as in the Base Case
The behavioural assumption is business as usual

Sensitivity to Change in Fuel Prices

Two types of fuel price sensitivities were performed:

1. As a level shift in which levels were 20% higher/lower fuel prices than in the base throughout the 1995 to 2020 period (see Figure B1); and
2. As a growth shift in which annual average growth rates were derived to produce levels in 2010 that were 20% higher/lower than the base. (see Figure B2).

The aim was to investigate whether or not ENUSIM produced different results for energy demand and carbon emissions under differing assumptions about the time path of fuel prices.

Figure B1 Price of Coal for Large Users

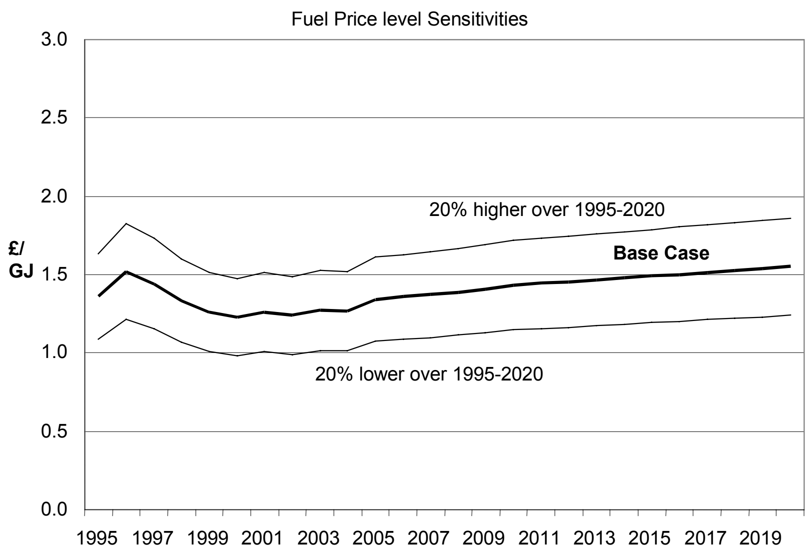
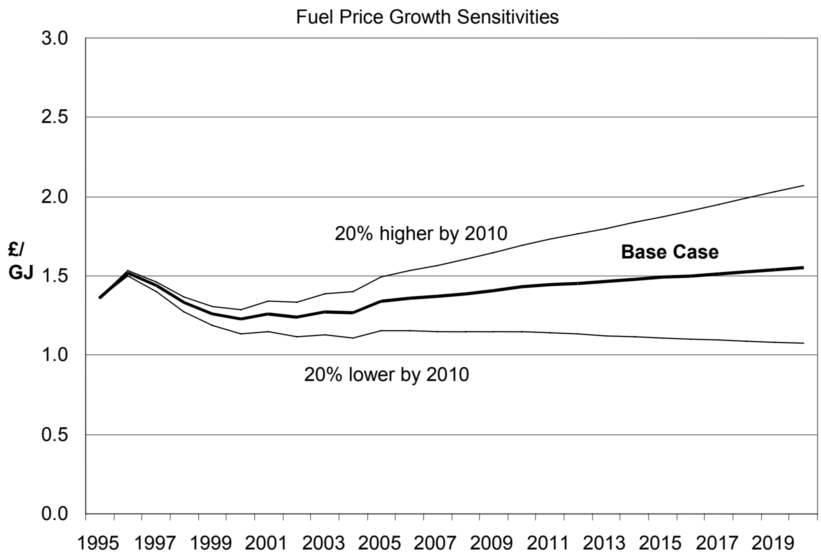


Figure B2 Price of Coal (For Large Users)



Tables B3 and B4 summarise the effects of changes in the various fuel prices, holding the discount rate at its default values of 25%. Tables B5 and B6 present the results assuming the lower discount rate of 6%. In each case, the price of all fuels was changed by the same given percentage. In summary, the results given in Tables B3 to B6 indicate that:

- In chemicals, the growth shift leads to a greater variation about the Base in 2020 for energy demand and emissions than is generated by a level shift of plus/minus 20%; and
- For iron & steel ENUSIM suggests that there is little variation due to differing assumptions about the pattern of fuel prices.

Tables B5 and B6 present the results for the two types of fuel price sensitivities with a lower discount rate of 6 %. They are not materially different from those reported in Tables B3 and B4.

Table B3: Energy Demand Under Various Fuel Price Assumptions (25% discount rate)

Chemicals Industry					**1995 = 1**
	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	1.08	1.11	1.16	1.27
Level Shift					
20% higher	1.00	1.08	1.10	1.15	1.26
20% lower	1.00	1.08	1.12	1.17	1.28
Growth Shift					

1.22% pa average	1.00	1.08	1.10	1.14	1.23
-1.47% pa average	1.00	1.08	1.12	1.17	1.30

Iron and Steel **1995 = 1**

	1995	2000	2005	2010	2020
Base	1.00	0.89	0.77	0.78	0.75
Level Shift					
20% higher	1.00	0.89	0.76	0.78	0.76
20% lower	1.00	0.89	0.77	0.78	0.76
Growth Shift					
1.22% pa average	1.00	0.89	0.76	0.77	0.75
-1.47% pa average	1.00	0.89	0.77	0.78	0.77

Table B4: Carbon Emissions Under Various Fuel Price Assumptions (25% discount rate)

Chemicals Industry **1995 = 1**

	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	1.08	1.11	1.16	1.28
Level Shift					
20% higher	1.00	1.08	1.10	1.16	1.27
20% lower	1.00	1.08	1.12	1.18	1.29
Growth Shift					
1.22% pa average	1.00	1.08	1.10	1.15	1.24
-1.47% pa average	1.00	1.08	1.12	1.18	1.30

Iron and Steel **1995 = 1**

	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	0.89	0.77	0.78	0.77
Level Shift					
20% higher	1.00	0.89	0.77	0.78	0.77
20% lower	1.00	0.89	0.77	0.79	0.77
Growth Shift					
1.22% pa average	1.00	0.89	0.77	0.78	0.76
-1.47% pa average	1.00	0.89	0.78	0.79	0.78

Table B5: Energy Demand Under Various Fuel Price Assumptions (6% discount rate)

Chemicals Industry					**1995 = 1**
	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	1.08	1.10	1.15	1.24
Level Shift					
20% higher	1.00	1.08	1.10	1.15	1.24
20% lower	1.00	1.08	1.11	1.17	1.27
Growth Shift					
1.22% pa average	1.00	1.08	1.09	1.13	1.22
-1.47% pa average	1.00	1.08	1.11	1.17	1.29

Iron and Steel					**1995 = 1**
	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	0.89	0.76	0.77	0.76
Level Shift					
20% higher	1.00	0.89	0.76	0.77	0.75
20% lower	1.00	0.89	0.76	0.78	0.76
Growth Shift					
1.22% pa average	1.00	0.89	0.76	0.76	0.74
-1.47% pa average	1.00	0.89	0.77	0.78	0.77

Table B6: Carbon Emissions Under Various Fuel Price Assumptions (6% discount rate)

Chemicals Industry					**1995 = 1**
	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	1.08	1.10	1.16	1.25
Level Shift					
20% higher	1.00	1.08	1.10	1.15	1.25
20% lower	1.00	1.08	1.10	1.16	1.25
Growth Shift					
1.22% pa average	1.00	1.08	1.09	1.14	1.23
-1.47% pa average	1.00	1.08	1.10	1.16	1.25

Iron and Steel					**1995 = 1**
	1995	**2000**	**2005**	**2010**	**2020**
Base	1.00	0.89	0.77	0.78	0.77
Level Shift					
20% higher	1.00	0.89	0.77	0.78	0.76
20% lower	1.00	0.89	0.77	0.78	0.77
Growth Shift					
1.22% pa average	1.00	0.89	0.77	0.77	0.75
-1.47% pa average	1.00	0.89	0.77	0.78	0.77

Assessment

There are a number of possible reasons for low responsiveness of energy demand and carbon emissions to changes in fuel prices and in the discount rate. These include:

- The choice of behavioural assumption: the BAU assumption does not allow large step movements in the take-up of energy savings technologies;
- Alternative fuel price sensitivities such as relative fuel price sensitivities may lead to larger movements (i.e. if all fuels increase by same percentage, fuel switching is never going to be profitable); and
- The model does not capture important energy-saving technologies such as CHP.

We are not aware of other modelling work that tests the sensitivities of fuel prices (and the discount rate) on the energy demand and carbon emissions in the same manner as outlined above. It is therefore, difficult to assess whether these estimates are reasonable. One possible comparison, however, is with the projections from the DTI's Energy Paper 68 (EP68) 'Energy Projection for the UK' (pp 53).

EP68 provides projection bands for carbon emissions. These projection bands are based on high and low (real) fuel price assumptions (difference between high and low is not uniform across fuel prices). Table B7 presents the impact of these high-low fuel price assumptions on carbon as reported for 'industry' in EP68 against those bands modelled in ENUSIM. The EP68 range is 2%. For the two industry sectors examined in ENUSIM, the range is between 1 and 2 for the level shift and 1 and 3 for the growth shift suggesting, particularly for the growth shift in fuel prices, that ENUSIM's modelled fuel-price response is within a reasonable range when compared with EP68, though much depends on price relativities between fuels

Table B7: EP68 and ENUSIM Sensitivities - Carbon Emissions

Model	Variable	Settings	High-Low Range Relative to Base Year Level (%)
EP68	Carbon 'industry'	Various Real Price Sensitivities	2
ENUSIM	Carbon 'chemicals industry'	20% Nominal Price Levels Sensitivities (25% discount rate)	2
ENUSIM	Carbon 'chemicals industry'	Growth shift to 20% price increase at 2010	3
ENUSIM	Carbon 'iron and steel'	20% Nominal Price Level Sensitivities (25% discount rate)	1
ENUSIM	Carbon 'iron and steel'	Growth shift to 20% price increase at 2010	1

Appendix C
New Industry Sectors

Energy Industry Use

The energy consumption by the energy industry and the resulting emissions is the aspect of interest for modelling rather than the total energy production by the sector. The energy industry use sector, as defined in the Digest of UK Energy Statistics 2001 (DUKES) essentially encompasses the following sub-sectors:

- Electricity generation;
- Oil and gas extraction;
- Petroleum refineries;
- Coal extraction;
- Coke manufacture; and
- Blast furnaces;
- Patent fuel manufacture;
- Pumped storage;
- Other;
- Losses.

All but the blast furnaces (already covered in the iron and steel sector of ENUSIM), patent fuel manufacture, pumped storage, other and losses sub-sectors were investigated and integrated into ENUSIM. The resulting coverage of energy industry use sector by ENUSIM is 95%. Table C1 summarises the sub-sectors, devices and device technologies that the energy sector comprises.

Table C1 Energy Industry Use Description

Sub-sector	Device	Device technology
Coal Extraction	Deep mines	Process improvements
	Opencast mines	Process improvements
Coke manufacture	Coke oven plant	Process improvements
	Coke oven plant	Replacement with non-recovery coke ovens
	Coke oven plant	Larger coke ovens
Electricity generation	Advanced (AGR/PWR[1]) nuclear power station	Process improvements
	CCGT[2]	Process improvements
	Coal fired (conventional steam) fired station	Process improvements
	Magnox (GCR[3]) nuclear power station	Process improvements
Oil & gas extraction	Compressors	New plant
	Compressors	Improved control
	Other	Energy management
	Process heating	New Plant
	Process heating	Improved control
	Process heating	Waste heat recovery
	Pumping	New plant

Sub-sector	Device	Device technology
	Pumping	Improved control
Petroleum refineries	Drives/motors	Variable speed drives
	Drives/motors	High efficiency motors
	Other	Energy management
	Process heating	New Plant
	Process heating	Improved control
	Process heating	Waste heat recovery
	Refrigeration	Improved refrigeration efficiency

1. AGR: advanced gas cooled reactor, PWR: pressurised water cooled reactor
2. CCGT: combined cycle gas turbine
3. GCR: gas cooled reactor

Information for the sector was collected through direct contact with refineries, coke manufacturers, mining companies and electricity generation companies.

Water Industry

The water industry encompasses the collection, purification and distribution of water. The sector does not include waste water treatment works. This definition is in line with the DUKES definition and Standard Industrial Classification (SIC) system.

The original intention was to split the water supply industry into three sub-sectors (collection, purification and distribution) and to choose appropriate devices within each sub-sector. Data were not readily available for each sub-sector however. Following conversations with a number of water companies, the Drinking Water Inspectorate and Office of Water Services (Ofwat), the most readily available data were for a combined sub-sector of ‘collection and purification’ and for ‘distribution’. It was found that the majority of water companies contacted did not separate the cost of purification from the cost of collection and, where studies had been undertaken, energy consumption during purification was found to be small, justifying the combining of these two sub-sectors.

Given the nature of the data available and that pumping costs were identified as the major expense it was decided that, instead of selecting devices in each sub-sector, the sub-sectors themselves would be treated as the actual devices. This was possible due to the main energy user being pumping costs, effectively allowing each device to be treated as a large pumping system.

Following the collection of data from Ofwat relating to the size and number of treatment works and the level of treatment, it was decided to create a third device under the title of ‘other’. This was done to reflect the large number of small water treatment plants that could potentially skew the input data for the average unit throughput. Data from England and Wales showed that of a total of 1,465 treatment plants, 995 (67.92%) have a capacity of less than 9.99 Ml/day and provide only 16.69% of all water distributed. Consequently it was assumed that a small number of large treatment works provide the significant majority of water, and the smaller treatment plants (< 9.99 Ml/day capacity) were divided into a separate device called 'other'. Thus three devices were selected:

1. Collection and purification (for water treatment systems with capacity >9.99 Ml/day);
2. Distribution (for water treatment systems with capacity >9.99 Ml/day); and
3. Other (for water treatment systems with capacity <9.99 Ml/day).

Table C2 summarises the sub-sectors, devices and device technologies that the water sector comprises.

Table C2 Water Sector Description

Sub-sector	Device	Device technology
Water supply	Collection and purification	Variable speed drives
	Collection and purification	High efficiency motors
	Distribution	Variable speed drives
	Distribution	High efficiency motors
	Other	Variable speed drives
	Other	High efficiency motors

Data were obtained from water company energy managers, the DEFRA's 'Digest of Environmental Statistics', Water UK's 'Waterfacts 2000' and the Ofwat.

Construction Sector

The nature of activities in the construction industry are very diverse. Activities range from demolition through to infrastructure and building construction (from the laying of foundations through to final fitting and completion). The approach finally adopted for the construction industry sector revolves around the fuel used to power vehicles and equipment (gas, electricity and petroleum). Table C3 summarises the sub-sectors, devices and device technologies that the construction sector comprises.

Table C3 Construction Sector Description

Sub-sector	Device	Device technology
Construction	Electrically-powered vehicles and equipment	Good practice
	Gas-powered vehicles and equipment	Good practice
	Petroleum-powered vehicles and equipment	Good practice/process improvement

Data used to develop the sector were collected from a range of sources including trade associations, plant hire and supply companies and construction companies

Appendix D
Impact of Non-Climate Change Programme Policies

Non-Climate Change Policies

Introduction

Policies set out in the Climate Change Programme (CCP) aim to reduce greenhouse gas emissions. Outside the CCP policy framework, there are other policies that have the potential to influence energy consumption and hence greenhouse gases, particularly CO_2. The influence of these policies may be either to reduce or increase CO_2 emissions. This section presents a review of key policies to establish which ENUSIM industry sectors and sub-sectors may be affected.

Non-Climate Change Programme Policies

The non-CCP policies and targets reviewed were:

- The Solvents Directive;
- New Energy Trading Agreement;
- Sulphur Content of Liquid Fuels Directive;
- Large Combustion Plant Directive;
- National Emissions Ceiling Directive;
- Clean Coal Technologies Initiatives;
- European Union Energy Efficiency Action Plan;
- European Union CHP target of 18% capacity across Europe by 2010; and
- European Union renewable energy generation capacity of 12% by 2010.

The policies and targets were reviewed to assess, for each ENUSIM sub-sector, whether they would incur additional or reduced energy consumption over and above that that would occur due to the policies of the CCP. If an effect was considered to occur, an assessment was made regarding whether or not the effect would be significant in the context of modelling the influence of the CCP on industrial energy consumption. This effect would require consideration in the modelling.

Significant Non-Climate Change Programme Policies

Table D1 presents results of the assessment. The Table indicates those policies that will have an effect on energy consumption. In the case of the final three policies in the table, the effect is anticipated to be accounted for already through existing UK policies and measures. Only the Sulphur Content of Liquid Fuels Directive (SCLFD) and the Large Combustion Plant Directive (LCPD) are deemed to have a significant effect on energy consumption, this is on the Petroleum refineries and Electricity generation sub-sectors respectively. The SCLFD will increase the energy consumption of refineries due to the additional processing required to reduce sulphur levels. The oil industry expect that emissions from refineries will rise steeply in response to the changes (ENDs Report 322, November 2001, pp 4). The LCPD will increase the consumption of energy by fossil fuel burning energy generation plant due to the increased flue gas abatement required, particularly with regard to meeting more stringent emission limits on oxides of nitrogen.

Table D1: Non-Climate Change Programme Policies with Energy Consumption Effect

Policy	Effect (Sector, Sub-sector)	Significant Effect on Energy Consumption
Solvents Directive	Electrical engineering, Electronics	No
	Mechanical engineering, Mach & equipment	No
	Mechanical engineering, Metal goods	No
New Energy Trading Agreement	Energy industry, Electricity generation	No
	Energy industry, Oil and gas extraction	No
	Energy industry, Petroleum refineries	No
Sulphur Content of Liquid Fuels Directive	Energy industry, Petroleum refineries	Yes – increase
Large Combustion Plant Directive	Energy industry, Electricity generation	Yes – increase
	Energy industry, Petroleum refineries	No
National Emissions Ceiling Directive		
Clean Coal Technologies Initiative	Energy industry, Electricity generation	No
European Union Energy Efficiency Action Plan	Various	No
European Union CHP target of 18% capacity across Europe by 2010	Various	No
European Union renewable energy generation capacity of 12% by 2010	Energy industry use	No

The Large Combustion Plant Directive

LCPD Overview

The LCPD (2001/80/EC) applies to all combustion plants which have a rated thermal input of >50 MW_{th}, irrespective of fuel type (solid, liquid or gaseous). For new and existing plants Emission Limit Values (ELVs) for SO_2, NO_x and particulates are specified depending on the size of the combustion plant. Any new installation which begins operation after November 2003 must comply with the ELVs for new plant, whilst ELVs for existing plants must be complied with by January 2008. The ELVs vary according to the type of fuel used and in some cases are less stringent for existing plant than new plant.

The LCPD is likely to affect the following industrial sectors:

- Electricity generation (i.e. major power plants);
- Petroleum refining;
- Iron & steel;
- Cement manufacture.

There are about 148 large combustion plants currently operating in the UK that will be covered by the Directive (offshore combustion plant is not covered by the LCPD). Energy use is likely to increase in cases where abatement equipment must be installed to meet the ELVs.

SO_2 ELVs

The most significant impact of the ELVs will be on power stations which are coal-fired as shown in the table below.

Table D2: Industrial Sectors/Sub-sectors Affected by LCPD SO_2 ELVs (Entec 2000, 2001a, 2001b)

Sector	Sub-sector	Impact of LCPD SO_2 ELV
Energy	Electricity generation (non nuclear)	Coal fired: Change in energy use due to requirement for SO_2 abatement and closure of some plants/switch to gas to meet the ELVs. Gas fired: No change in energy use since all power stations currently comply with the ELVs. However, some coal-fired plants may switch to gas. Oil fired: No change in energy use since stations are likely to be exempt from the ELVs on the basis of operation hours[2]
	Electricity generation (nuclear)	No change in energy use since nuclear power stations have combustion plant for emergency power supply only. Therefore they are exempt from the ELVs on the basis of operating hours.
	Petroleum refineries	No change in energy use since refineries are likely to switch to lower-sulphur fuels rather than install abatement equipment[3]
	Oil and gas extraction	No change in energy use since offshore operations are not covered by the LCPD
	Coke manufacture	No change in energy use since operators are likely to switch to lower-sulphur fuels rather than install abatement equipment
	Coal extraction	Large combustion plant (>50 MW_{th}) is not normally operated at coal extraction facilities so not covered by LCPD.
Iron and Steel	All sub-sectors	No change in energy use since operators are likely to switch to lower-sulphur fuels[3]
Cement, Lime and Plaster	All sub-sectors	No change in energy use since SO_2 ELVs already met or operators will switch to lower-sulphur fuels.

1. Sector and sub-sector definitions correspond to those used in the ENUSIM model.

2. It is noted that there are 5 oil-fired power stations in the UK. However, in 2000 only 0.3% of total electricity output came from these plants (hence this sub-sector is not present in the ENUSIM model). Due to their low load factors they are unlikely to be covered by the ELVs on the basis of operating hours. The exception is Lerwick power station which already uses SO_2 abatement. Therefore the SO_2 ELV is predicted to have no net effect on energy use at oil-fired power stations. (Entec 2000).

3. Refineries will simply switch to lower sulphur crude oil supplies to ensure that their large combustion plants meet the ELVs (Entec 2000, 2001b). Therefore, the change in energy use would be negligible.

To meet the ELVs for SO_2, coal-fired power stations will normally have to install flue gas desulphurisation (FGD) equipment which can typically remove 90% of the sulphur present in flue gases. Alternative options are to switch to low-sulphur coal or natural gas, or close the plant early where it is uneconomic to install FGD.

FGD normally involves scrubbing the stack gases with a liquid (normally a suspension of finely ground limestone in water) in a packed column. Energy is required for the following (EIPPCB, 2001):

- Grinding of limestone, conveyance and mixing with water to produce liquor;
- Pumping and recirculation of scrubber liquor (N.B. pumps up to 1 MW are used);
- Delivery of air by fans to promote oxidation reactions in the scrubber;
- De-watering of used liquor in centrifuges and filters to produce slurry for disposal;
- Pumps and other electrical equipment in the scrubber wastewater treatment plant.

There are many variations on the FGD design and different reagents, including seawater can be used to remove the SO_2. The energy consumption of a FGD unit varies between 1 and 3% (typically 1.5%) of the electrical output of the power station (EIPPCB 2001). Previous work carried out by Entec (2000, 2001a) to assess the impact of the LCPD has identified that the following changes will be required.

Table D3: Effect of LCPD SO_2 ELVs on Coal-Fired Power Stations (Entec 2001a)

Power Station[1]	Station Capacity (MW_e)	Electricity Generation in 2000 (TWh)[2]	Impact of LCPD SO_2 ELV[3]
Didcot A	2060	6.9	Installation of FGD required
Cottam	1000 (unabated)	3.3 (unabated)	Closure or switch to CCGT likely
Rugeley B	498 (unabated)	1.4 (unabated)	Installation of FGD required
Eggborough	990 (unabated)	2.7 (unabated)	Closure or switch to CCGT likely
Aberthaw	1506	6.1	Installation of FGD required
Longannet	1152 (unabated)	6.0 (unabated)	Installation of FGD required
Totals	FGD required = 5216 MW_e	FGD required = 20.4 TWh	
	Closure/switch to CCGT = 1990 MW_e	Closure/switch to CCGT = 6.0 TWh	
	UK coal capacity = 30500 MW_e	UK output from coal = 105 TWh	

1. The other UK coal-fired large combustion plants either currently met the ELVs, are planned to close before the ELVs come into force, or will opt for a limited life derogation such that the SO_2 ELVs do not apply. (Entec 2001a)
2. This is the electrical power output from the station during the year 2000 based on Entec (2001a) data.
3. There may also be a switch to low-sulphur coal at some of the other UK coal-fired power stations. However, this will have a negligible effect on energy use. (Entec 2000)

In terms of predicting energy use at power stations it is appropriate to use electrical output (TWh), which is a combination of electrical capacity and load factor, rather than electrical capacity (MW_e) alone. Therefore, based on 2000 data a total of around 20 TWh electrical output from coal fired stations will require installation of FGD (which is assumed to increase energy consumption by 1.5% of electrical output). A further 6 TWh of electrical output from coal will be removed by closure or switching to combined cycle gas turbine (CCGT). It is likely that the reduction in coal generation capacity will be balanced by an equal increase in CCGT capacity to ensure that overall output levels are maintained (N.B. in 2000, UK gas based generation was approximately 134 TWh). On this basis, the following calculation is made:

Table D4: Effect of LCPD SO_2 Power Station Energy Use

Sub-Sector	Parameter	Value[1]
Coal-fired stations	Total sub-sector energy use from ENUSIM[2]	4476 TJ/year
	Increase in energy use due to FGD installation	13.0 TJ/year (+0.3 %)
	Decrease in energy use due to closure/switch to CCGT	255.8 TJ/year (-5.7 %)
	Net decrease in sub-sector energy use	242.7 TJ/year (-5.4 %)
CCGT stations	Total sub-sector energy use from ENUSIM[2]	4476 TJ/year
	Increase in energy use to replace coal-fired capacity	81.9 TJ/year (+4.5 %)
Overall Effect	Net decrease in power station energy use (non-nuclear)	161 TJ/year (-2.6%)

1. Projected increases and decreases in energy use are based on 2000 data for power station electrical output. Percentage changes quoted are relative to the current sub-sector or sector energy use.

2. The ENUSIM energy use data quoted is from the 'Update01' model. However, in the model window it is uncertain whether the value displayed corresponds to the base year (1995) or the latest update year.

The results indicate a net decrease in energy use at non-nuclear power stations (gas and coal fired) of around 161 TJ/year due to the SO_2 ELVs. This is because there is a:

- Relatively small increase in energy use due to FGD installation at some coal-fired stations; and
- Relatively large decrease in total energy use at coal-fired stations due to closure of some stations which is counter-balanced by a lesser increase in energy use at gas-fired stations (which are generally more energy efficient than coal-fired stations).

The above changes are expected to occur over the next few years and will be essentially complete by January 2008 when the LCPD ELVs for existing plant come into force. Any new power plant which is built will be designed to comply with the ELVs without a significant change in energy intensity (i.e. a FGD unit can be integrated into the power station at the design stage to avoid a net increase in energy use from the requirement to meet SO_2 ELVs).

However, it is noted that there is significant uncertainty involved in the above assessment since the exact balance between FGD uptake and plant closure/switch to CCGT to meet the ELVs is uncertain. In addition, the UK has the alternative option of implementing a National Plan under the LCPD which will achieve the same reductions in SO_2 emission as enforcing the ELVs. The National Plan would involve switching to low-sulphur coal at some stations and a strategic closure plan for some other stations. Therefore, the above assessment represents an indication of the magnitude of the change in industrial sector energy use due to SO_2 controls under the LCPD.

NO_x ELVs

In the case of NO_x ELVs, some large combustion plants will have to install new combustion controls or abatement systems. The table below indicates which industry sectors will be most affected.

Table D5: Industrial Sectors/Sub-sectors Affected by LCPD NO_x ELVs (Entec 2000, 2001b)

Sector	Sub-sector	Impact of LCPD SO_2 ELV
Energy	Electricity generation (non nuclear)	Coal fired: Possible change in energy use depending on NO_x abatement techniques employed.
		Gas fired: No change in energy use since existing gas turbines (mostly installed in the last 10 years) are generally designed to produce low NO_x emissions which are below the ELVs.
		Oil fired: No change in energy use since stations are likely to be exempt from the ELVs on the basis of operation hours.
	Electricity generation (nuclear)	No change in energy use since nuclear power stations have combustion plant for emergency power supply only. Therefore they are exempt from the ELVs on the basis of operating hours.
	Petroleum refineries	No change in energy use since all UK refineries are currently meeting the ELVs under existing IPC regulations.
	Oil and gas extraction	No change in energy use since offshore operations are not covered by the LCPD
	Coke manufacture	Possible increase in energy use due to NO_X abatement equipment installation.
	Coal extraction	Large combustion plant (>50 MW_{th}) not normally used at coal extraction facilities so not covered by LCPD.
Iron and Steel	All sub-sectors	Possible increase in energy use due to NO_X abatement equipment installation.
Cement, Lime and Plaster	All sub-sectors	Possible increase in energy use due to NO_X abatement equipment installation.

Reductions in NO_x emissions can be achieved either by modifying the combustion process or by installing abatement techniques such as selective catalytic reduction (SCR) or selective non-catalytic reduction (SNCR).

Table D6: Techniques for Reducing NO_x emissions from Large Combustion Plant (EIPPCB 2001a)

Technique	Process Description	Typical NO_x reduction
Low NO_x burners (LNB)	Low NO_x burners modify the means of introducing air and fuel to delay the mixing, reduce the availability of oxygen, and reduce the peak flame temperature, so reducing NO_x formation. They are already widely used and, where not, would be expected to be adopted to meet ELVs.	40%
Advanced low NO_x burners (aLNB)	Advanced low NO_x burners are expected to be given serious consideration for achieving moderate future improvements in NO_x emissions.	20% (from LNB)
Over fire air (OFA) or two-stage combustion	OFA involves introducing air above the primary combustion zone in a boiler to reduce excess air and flame temperature at the burners and prevent NO_x formation. 15 to 25% of the total combustion air can be supplied as OFA. There may be increases in CO and unburnt carbon emissions.	20% (from LNB)
Flue gas recirculation (FGR)	The recirculation of flue gas dilutes the combustion air, hence lowering peak flame temperature and in consequence reduces the thermal NOx produced. It is a useful technique for gas and oil firing, but is less effective for coal firing. With heavy fuel oil particulates may increase.	40% (oil fired, from uncontrolled)
Reburn (RE) or 3 stage combustion	Reburn, which is more suited to larger boilers, involves injecting part of fuel above the main combustion zone. It works be reducing the NO_x that has already been formed. Up to 20% of fuel may be introduced this way and the fuel need not be the same as the primary fuel. Thus gas or oil might be the reburn fuel for a coal fired boiler (N.B. the reburn incorporates OFA hence the NOx reductions are not additive).	50% (from LNB)
Selective catalytic reduction (SCR)	The SCR process is a catalytic process based on the selective reduction of NO_x with ammonia or urea in the presence of a catalyst. The reducing agent is injected into the flue gas upstream of the catalyst.	90 %
Non catalytic selective reduction (NCSR)	The selective non-catalytic reduction (SNCR) process is another secondary measure to reduce NO_x already formed in the flue gas of a combustion unit. It is operated without a catalyst at a temperature between 850 and 1100 °C. This temperature window is strongly dependent on the reagent used (ammonia, urea or caustic ammonia).	50 %
Cement kilns - burning of waste tyres	Burning of waste tyres in cement kilns as a substitute for other duels has been shown to reduce NO_x levels. 25 % substitution of fuel input with tyres can reduce NO_x emissions by 30-50 % (ENDS 2002).	30 %

Of the above NO_X reduction techniques, only three result in a significant change in energy use as follows:

- FGR requires additional energy for recirculation of flue gas via large fans and there may be an associated loss in burner efficiency.
- SCR results in an increase in energy use of around 0.5 % of combustion plant energy output due to extra pressure drop over the catalyst bed and flue gas re-heating requirements.
- NCSR results in an increase in energy us of around 0.2 % of combustion plant energy output due to extra pressure drop over the unit and flue gas re-heating requirements.

It is not expected that FGR will be widely used for existing plants since it requires major equipment modifications (Entec 2000). However, OFA is most likely to be used at large power stations where moderate NO_x reductions are required and this does not entail a significant change in energy use. Where large reductions in NO_x levels are required, SCR and NCSR are likely to be used. The table below summarises the impact of ELVs on various industry sectors.

Table D7: Effect of LCPD NO_x ELVs on Energy Use (Entec 2001a)

Industry Sector/Sub-sector	Impact of LCPD NO_x ELV
Electricity generation (non nuclear)	Didcot A, Rugeley B and Longannet power stations are likely to install OFA for NO_X reduction (Entec 2001a). However, the use of OFA has no significant impact on energy use. Other power stations already meet the ELVs or are installing low-NO_x burners which do not have a significant effect on energy use (Entec 2000).
Coke manufacture	A simple assumption that 50% of all plants require SCR will be used. Based on data from DUKES (2001) data the total UK production of coke in 2000 was equivalent to an energy output of 133 PJ. Assuming that SCR equipment consumes around 0.5 % of the energy output and that this applies to half of all plants, the energy consumption for SCR would be around 332 TJ/year (1.4 % increase for sector).
Iron & Steel sector	Data on the UK iron and steel industry indicates a power output from large combustion plants of around 5.0 TWh in 2000. Assuming that SCR equipment consumes around 0.5 % of the energy output and that this will be required at half of all plants, the energy consumption for SCR would be around 90 TJ/year (1.6 % increase for sector).
Cement	Use of tyres as substitute fuel may be required at some plants to reduce NO_x levels. However, this would not result in a significant change in energy use.
Overall effect	Estimated increase in energy use of 422 TJ/year

Therefore the ELVs for NO_x could lead to a small (but not insignificant) increase in energy use in the coke manufacturing and iron & steel industries. However, the estimated increase of 477 TJ assumes that SCR is required in half of all plants. In reality, many plants will already be able to meet the ELVs (as required under IPC) or will install combustion controls (e.g. low-NO_x burners) which do not lead to a significant change in energy use.

Particulate ELVs

In general, the particulate ELVs are already being met by large combustion plants due to requirements under other regulatory measures (e.g. IPC). Plants using gaseous fuels normally have very low particulate emissions and can normally meet the ELVs without any abatement equipment. However, some coal and oil fired plant will require additional abatement to meet the ELVs. The types of abatement equipment commonly used are shown below.

Table D8 Particulate Abatement Techniques (EIPPCB 2001a)

Technique	Description	Particulate Emissions
Electrostatic precipitators (ESPs)	ESPs are widely adopted for controlling particulate emissions for all scales of operation. Upgrades to existing ESPs (piggy back ESPs) are possible where space allows. In the electricity generation industry many ESPs will already have been or are being upgraded. The ability to install additional upgrades will depend on available space. Where this is not possible the complete replacement of existing plant will be required. ESPs are generally preferred to fabric filters (FFs) for larger plant due to lower operating costs (with comparable capital costs).	Can achieve 25 mg/m^3
Fabric filters (FF)	FFs can be used for controlling particulate emissions from all large combustion plant. For oil fired plant a pre-coat of lime may be required. Their use at small scales of operation is established and they are now being used on very large plants world-wide.	Can achieve 10 mg/m^3
Flue Gas Desulphurisation (FGD)	In addition to removing SO_2, the FGD unit (a type of wet scrubber) leads to a reduction in particulate emissions to around 25 mg/m^3 which is below the ELV for solid and liquid fuelled plants.	Can achieve 25 mg/m^3

Of the above techniques, FGD is likely to be used at power stations to primarily reduce SO_2 emissions but also reduce particulate emissions to below the ELVs. The impact of this change on energy use was estimated in Section 3.2. At other plants (e.g. coke manufacturing units), ESP and fabric filters may be used and this would increase energy use as follows:

- ESP units require electrical energy (high voltage) to generate the electrostatic charge and there may be additional pressure drop over the unit. Energy use is increased by about 0.3 % of combustion plant energy output (EIPPCB 2001a).
- Fabric filters cause increased pressure drop and require fans for back-flush cleaning. Energy use is increased by about 0.2 % of combustion plant energy output (EIPPCB 2001a).

The UK power stations which currently exceed the particulate ELVs but which will not be exempt from the ELVs (through closure/limited life derogation) and are not installing FGD to reduce particulates are the coal-fired stations Tilbury, High Marnham, Ironbridge and West Burton (Entec 2000). Their total power output in 2000 was approximately 12.0 TWh. Assuming that they install ESPs, this will increase their energy use by around 0.3% of their power output. In the case of other industry sub-sectors, it is expected that, with the exception of a few plants with oil-fired boilers, the ELVs are currently being met (Entec 2000). Therefore, the net effect of the ELVs is shown below.

Table D9: Effect of Particulate ELVs on Energy Use

Sub-Sector	Parameter	Value
Electricity generation (non-nuclear)	Total sub-sector energy use from ENUSIM[2]	6305 TJ/year
	Increase in energy use due to ESP installation	129.6 TJ/year (+2.0 %)
Other sub-sectors	Change in energy use due to enforcement of ELVs	No significant change expected
Overall Effect	Net increase in energy use	130 TJ/year

Summary of LCPD Impact

There is some uncertainty associated with predicting the impact on energy use of the LCPD. It is noted that the UK may implement a National Plan to reduce emissions under the LCPD rules, rather than take the ELV route and therefore, the above analysis is only a first-pass estimate of the magnitude of the impact of the LCPD. In some industry sectors it is clear that additional abatement equipment will be required to meet the ELVs and this will increase energy use. However, the main impact will be on coal, gas and oil fired (non-nuclear) power stations and the analysis above has focused on this sub-sector. In general, operators of large combustion plant in other industry sub-sectors already meet the ELVs as required under existing regulations (e.g. IPC) and in this case no significant change in energy use is expected from introducing the LCPD. The results are summarised below.

Table D10: Overall Effect of LCPD

Pollutant	Sub-sectors Most Affected	Change in Energy use
SO_2	Electricity generation (non-nuclear) - installation of FGD at some power stations and closure/switch to gas in others (leads to net reduction in energy use)	-161 TJ/year
NO_x	Electricity generation (non-nuclear), coke manufacture, iron & steel and cement sub-sectors - installation of NO_x abatement measures in some plants	+422 TJ/year
Particulates	Electricity generation (non-nuclear) - installation of ESP at some power stations	+130 TJ/year
Overall Effect	Net change in energy use	+ 391 TJ/year

Therefore, a net increase in UK energy use of around 400 TJ/year (equivalent to a power plant rate at ~13 MW running continuously) might be expected from introduction of the LCPD. The total UK industrial sector energy use in 2000 was around 1877 PJ (Entec 2001c) and so the increase due to the LCPD is ~0.02 % of total UK energy use which is small but not insignificant. These changes are expected to occur over the next few years and will be essentially complete by January 2008 when the LCPD ELVs for existing plant come into force. For new large combustion plant (beginning operation after November 2003) it is expected that these will be designed with integrated measures to meet the relevant ELVs, thereby preventing any further net increase in energy use.

The Sulphur Content of Certain Liquid Fuels Directive

SCLFD Overview

The SCLFD (1999/32/EC) will limit the sulphur content of heavy fuel oil and gas oils which are used in combustion equipment as shown below.

Table D11: SCLFD Conditions

Fuel	Maximum sulphur content of fuel burnt	Notes
Heavy fuel oil	1.00 %w/w from January 2003	Does not apply to new plants or oil refineries[1]
Gas oil	0.20 %w/w from July 2000 and 0.1 %w/w from January 2008	Does not apply to marine gas oil used by ships travelling outside the EU

1. New large combustion plants which are covered by the LCPD and meet the relevant ELVs are not covered by the SCLFD conditions. Oil refineries must instead meet a bubble SO_2 emission limit of 1700 mg/m^3 when burning heavy fuel oil and gas oil.

Impact of the SCLFD

Heavy fuel oils and gas oils are derived from crude oil and are produced by the petroleum refining industry. The amount of sulphur in these fuels depends on the sulphur content of the crude oil and the degree of desulphurisation that is carried out at the refinery. The SCLFD raises two issues for UK refineries:

1. They will not be able to market (in Europe) heavy fuel oil and gas oil which contain more sulphur than the SCLFD allows.
2. They will have to limit sulphur emissions from burning of heavy fuel oil and gas oil for their own energy requirements.

On this first issue, data from CONCAWE (2001) and previous Entec reports (2000, 2001b) indicates that most refineries are already using low-sulphur crude or are likely to switch to lower-sulphur crude in future to allow them to produce low-sulphur heavy fuel oil and gas oil. This switch would not significantly alter energy use at the refineries. Alternatively, refineries may export heavy fuel oils and gas oils that do not comply with the SCLFD to countries outside the EU. Additionally, desulphurisation to remove sulphur from fuels is a routine refinery operation and additional units have been installed in recent years to comply with the European Fuels Directives. It is therefore unlikely that significant further changes in UK refinery operations will occur due to the need to produce low-sulphur fuels under the SCLFD.

On the second issue, the majority of refinery SO_2 emissions come from burning of residual fuel oil (RFO) which is a type of heavy fuel oil that contains between 1 and 5 %w/w sulphur. In order to meet the refinery bubble SO_2 limit of 1700 mg/m^3 under the SCLFD, the sulphur content of the RFO would have to be limited to around 1 % w/w (CONCAWE 2001). A previous report by Entec concluded that it would be uneconomical to remove the sulphur from RFO and therefore UK refineries were most likely to switch to gas to replace the energy supplied by RFO and then sell the RFO outside the EU. RFO accounts for around 30 % of a refinery's energy supply (CONCAWE 2001). However, the switch to gas is unlikely to have a significant effect on refinery energy use but it will affect the fuel split. Currently in the ENUSIM 'petroleum refineries' sub-sector, the fuel split for the 'process heating' device (i.e. the largest energy user) is modelled as 5% natural gas and 95% oil (N.B. fuel oil and refinery fuel gas are modelled as oil for emission calculation purposes). In future, the balance is likely to change to around 35% natural gas and 65 % oil. This change is likely to occur over the next few years as some refineries will use low-sulphur crude rather than immediately switch to gas which requires significant capital investment (for new gas mains etc.).

In all other industry sub-sectors, the impact of the SCLFD on energy use is likely to be negligible since the fuel purchased will simply contain a lower sulphur levels but will have an almost identical calorific value and burning efficiency.

Conclusions

The two non-climate change policies which will have the greatest effect on industrial sector energy use are the LCPD and the SCLFD. The impact of these polices on the relevant sectors has been investigated and the conclusions are summarised in the table below.

Table D12: Summary of Non-Climate Change Policy Impact

Policy Measure	Industrial Sectors/Sub-sectors Affected	Change in Energy Use	Effect on Energy/Fuel Use
Large Combustion Plant Directive	Electricity generation, petroleum refining, coke manufacture, iron & steel, cement	Estimated net increase of ~400 TJ/year (0.02 % of UK total) by January 2008	Some operators will have to install additional abatement equipment. The main impact is on coal-fired power stations.
Sulphur Content of Liquid Fuels Directive	Petroleum refining	No significant change	Most refineries will switch to low-sulphur crude or are already producing low-sulphur fuels. Some refineries will switch to natural gas for internal energy use.

On the basis of this first-pass assessment it is concluded that non-climate change policies will lead to a small but not insignificant increase in industrial sector energy use of around 0.02 % of the UK industrial sector total. Considering that total UK primary energy demand for all sectors (i.e. industrial, domestic, transport, etc.) in 2000 was around 102220 PJ (DUKES 2001), the impact of non-climate change policies is to increase total UK energy use by around 0.004 %.

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Appendix E
Combined Heat and Power Modelling Options

Combined Heat and Power Modelling Options

Introduction

One of the action points that arose out of the April 2002 meeting was to assess whether any results from CE's study on *Modelling Good Quality Combined Heat and Power Capacity in the UK to 2010* for the DTI/DEFRA could be incorporated into or adapted for use as part of the Industrial Sector CO_2 project. Two possible options were flagged in the April meeting. They were:

1. Data and analysis from the DTI/DEFRA work are directly incorporated into the ENUSIM model (ENUSIM contains no data regarding boilers or CHP); or

2. Data and analysis from the DTI/DEFRA work supplement the ENUSIM results.

The points that arose out of a review of these options are summarised below.

Option 1 - Incorporating CHP data into ENUSIM

Incorporating CHP data directly into ENUSIM would offer the most consistent way forward. There are however, difficulties with incorporating CHP into the ENUSIM:

- ENUSIM models energy consumption at (what could be called) an ‘end process’ level. Consequently, boilers are not explicitly represented in the model. (They are implicitly represented, as energy generated from a boiler appears to be assigned to relevant device's energy consumption in the form of steam). Boilers represent the main alternative to CHP. Without boiler as an alternative, the economics of CHP can not be assessed.

- Incorporation of boilers into ENUSIM would require considerable model restructuring and reallocation of fuel source data to boilers from the current devices and require considerable resources to complete and validate prior to use for modelling.

- Another key factor of the economics of CHP is the sales of excess electricity to grid. This factor has become more important with the announcement in the 2002 Budget of an exemption of certain CHP electricity exports from the Climate Change Levy. ENUSIM's cost-benefit calculation, which determines whether a technology is sufficiently financially attractive to implement, does not easily allow for the benefit of sales of electricity to be included. Further development work would be required to extend ENUSIM in this way.

- The main source of published data on CHP is DUKES, which publishes data on CHP installations and use. The data however, are not sufficiently disaggregated in DUKES to be incorporated into the model (ideally, the data needs to be cross-referenced by economic sector and technology). In the DTI/DEFRA CHP modelling study, CE was provided with disaggregated data. These data may be sufficiently disaggregated for this study but are confidential due to business sensitivity and hence can not be used.

Option 2 - Modelling CHP in MDM

This option avoids extensive restructuring of ENUSIM. There are however, also difficulties with supplementing ENUSIM results with the results from modelling CHP in MDM:

- The economic sector classifications used in CE's CHP report do not match those used in ENUSIM. ENUSIM has 19 sectors. These sectors are largely contained in five MDM classifications: Iron and Steel, Minerals, Energy Sectors' Own Use, Chemicals, Other Industry. The ‘Other Industry’ classification contains most of the 19 ENUSIM sectors. Due to reasons of confidentiality with CHP data, the 'Other Industry' grouping had to be merged with ‘Power Generation’, another MDM sector grouping, which is not covered by ENUSIM.
- Relating the results from the CHP modelling to those in ENUSIM may be problematic. ENUSIM does not indicate whether steam used is sourced from a boiler or CHP installation (indeed no boiler or CHP devices are included in ENUSIM). Similarly, there is no indication in ENUSIM between electricity generated by conventional power stations and that generated on-site. This information is important in calculating carbon savings. The modelling of CHP potential and the impact on carbon savings would be required to be undertaken outside ENUSIM, i.e. off model.

Assessment

Option 1 would have involved considerable development of ENUSIM as neither boilers or CHP are represented. Of the difficulties presented by the two options, those associated with Option 2 were anticipated to be the easiest to resolve and therefore, Option 2 was considered the most feasible. Further modelling was carried out in MDM-E3 to carry out the work.

Below is a list of variables modelled to 2010 (‘qualifying’ being that recognised as ‘good quality’ CHP as specified by the CCP).

Qualifying Power Capacity

Qualifying Power Output

Qualifying Heat Output

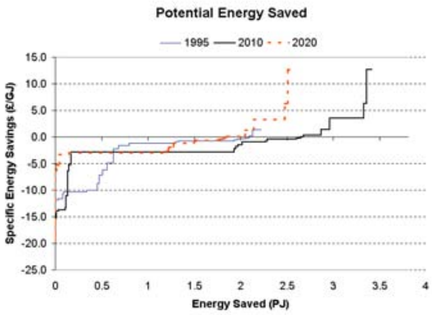
Qualifying Fuel Input

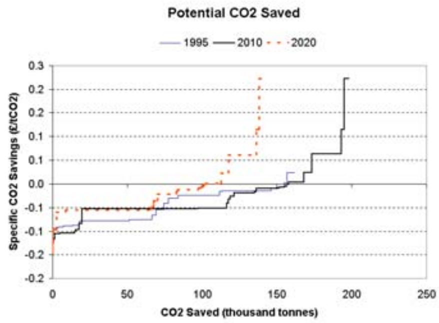
CO_2

These variables were estimated for the five MDM-E3 fuel users (mentioned above). ‘Other Industry’ was separated from ‘Power Generation’. The level of industry sector disaggregation of the results was not as great as that possible in ENUSIM. The variables were estimated for two scenarios to calculate the contribution of the CCP to carbon savings; a baseline and a baseline plus CCP measures.

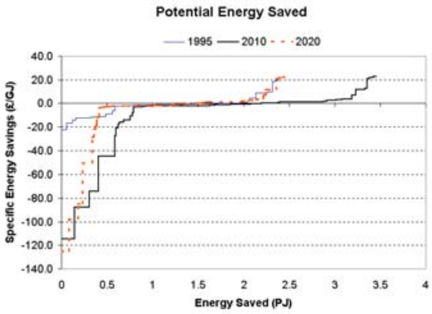
Appendix F
ENUSIM Cost Curves

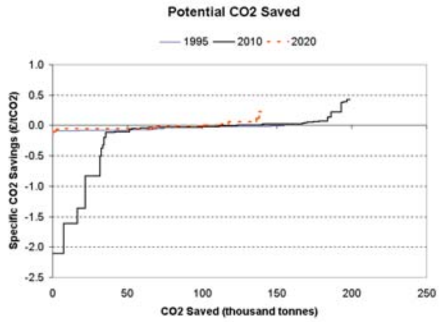
Bricks





Ceramics





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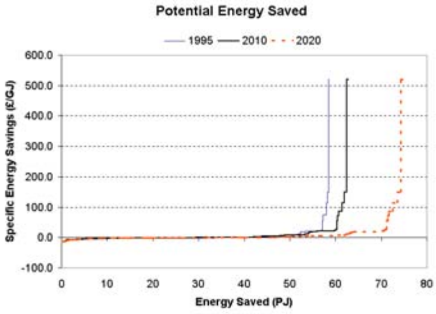
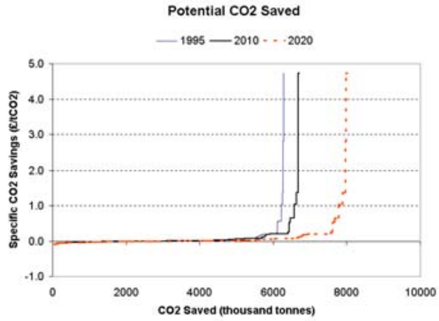
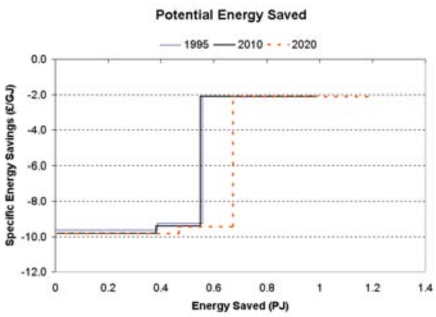
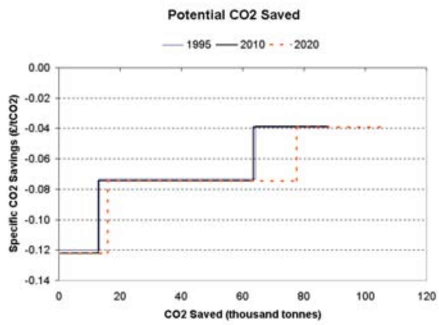


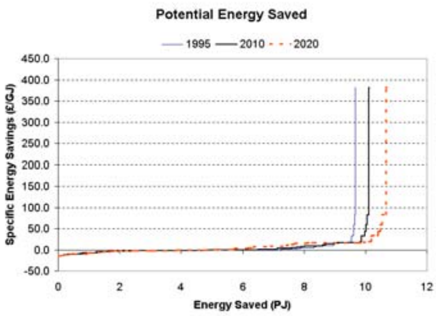


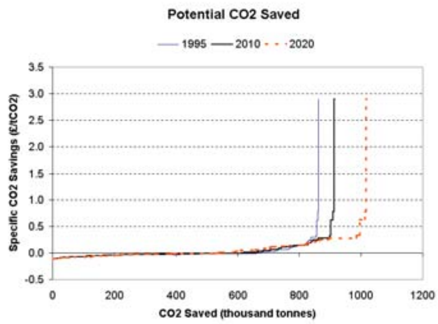
Construction



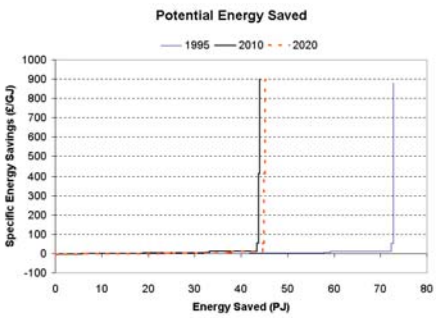


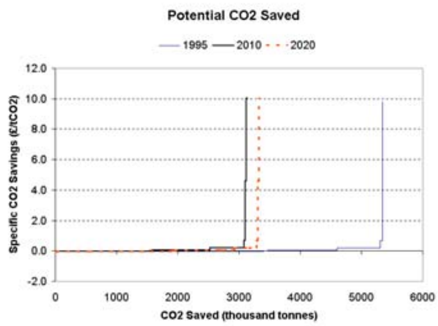
Electrical Engineering



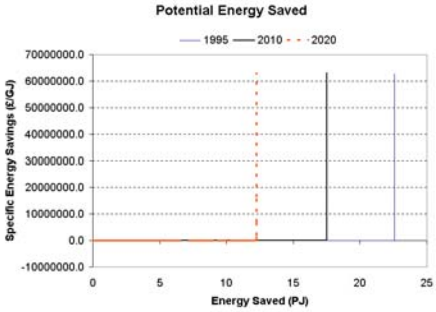


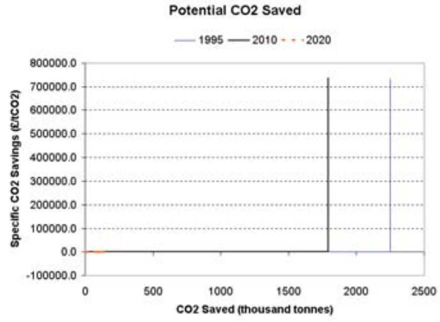
Energy Sectors



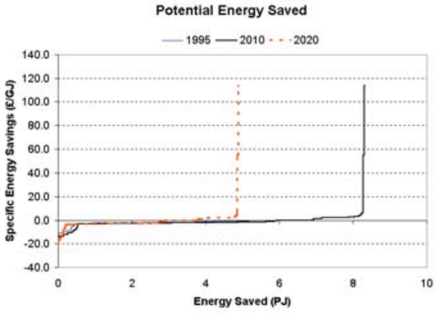


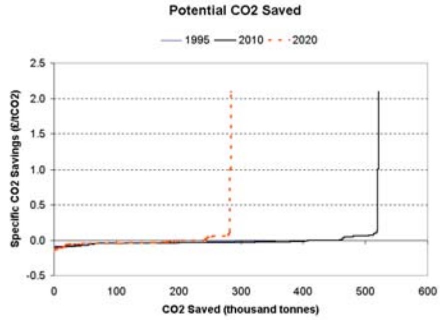
Food and Drink



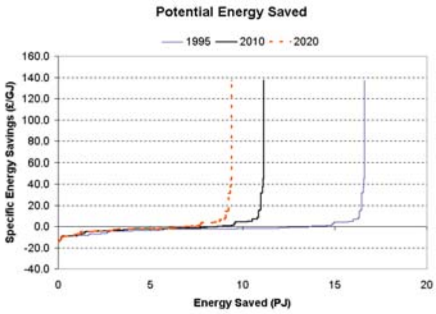


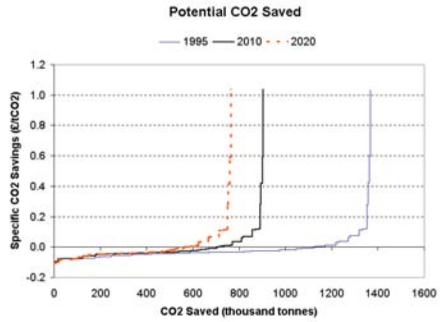
Glass



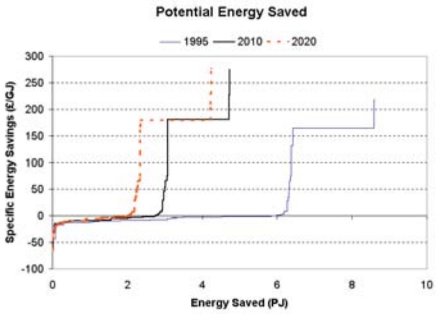


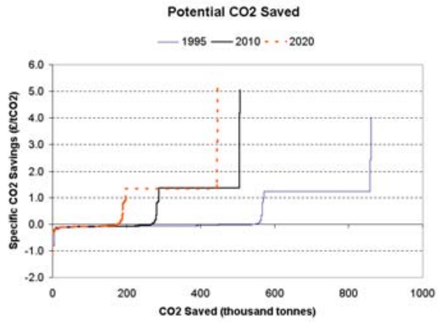
Mechanical Engineering



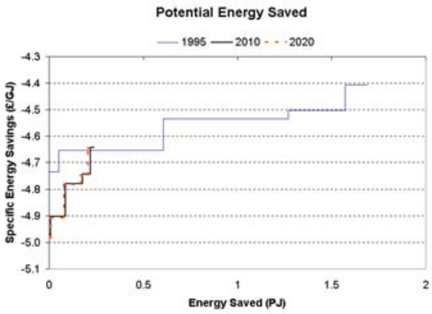


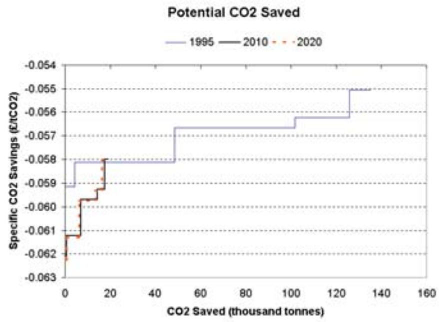
Non Ferrous Metals



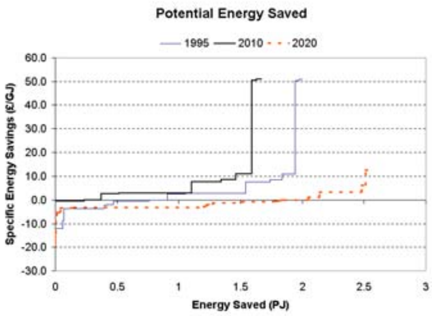


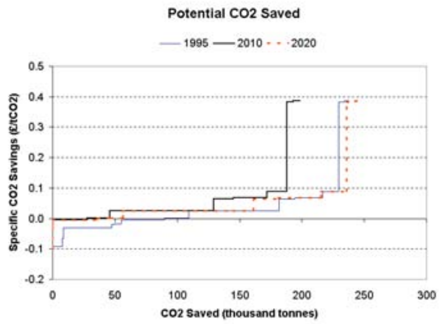
Non Metallic Minerals



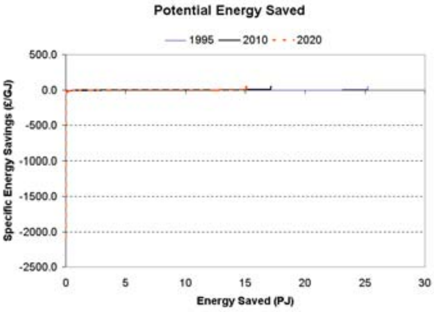


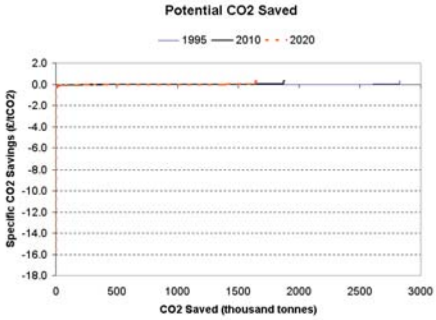
Other Industries



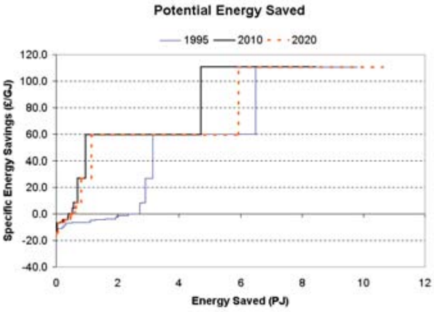


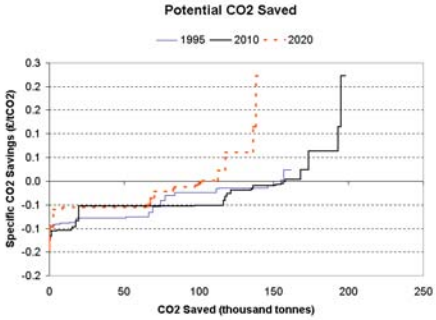
Paper



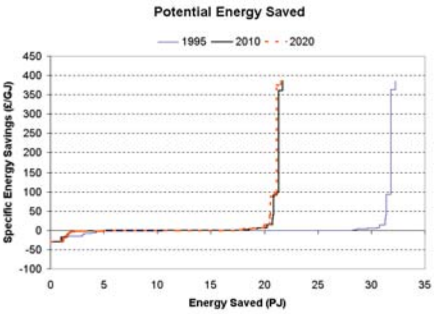


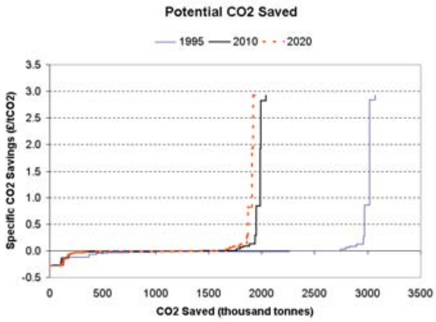
Plastics

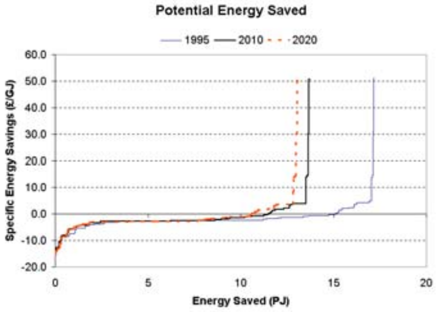
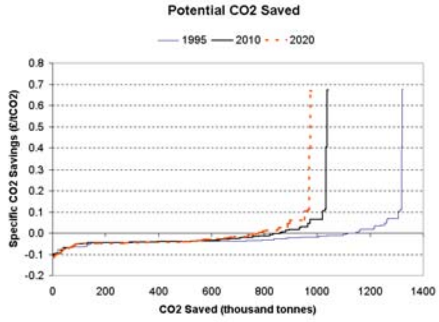
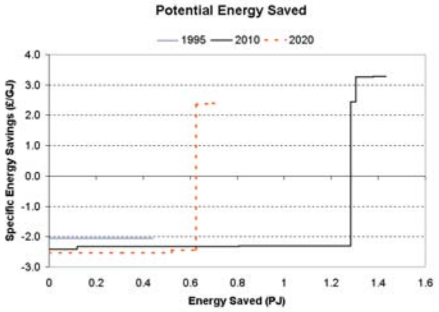
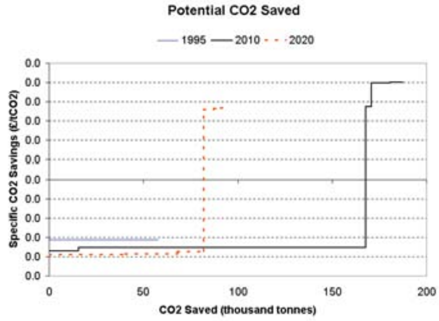




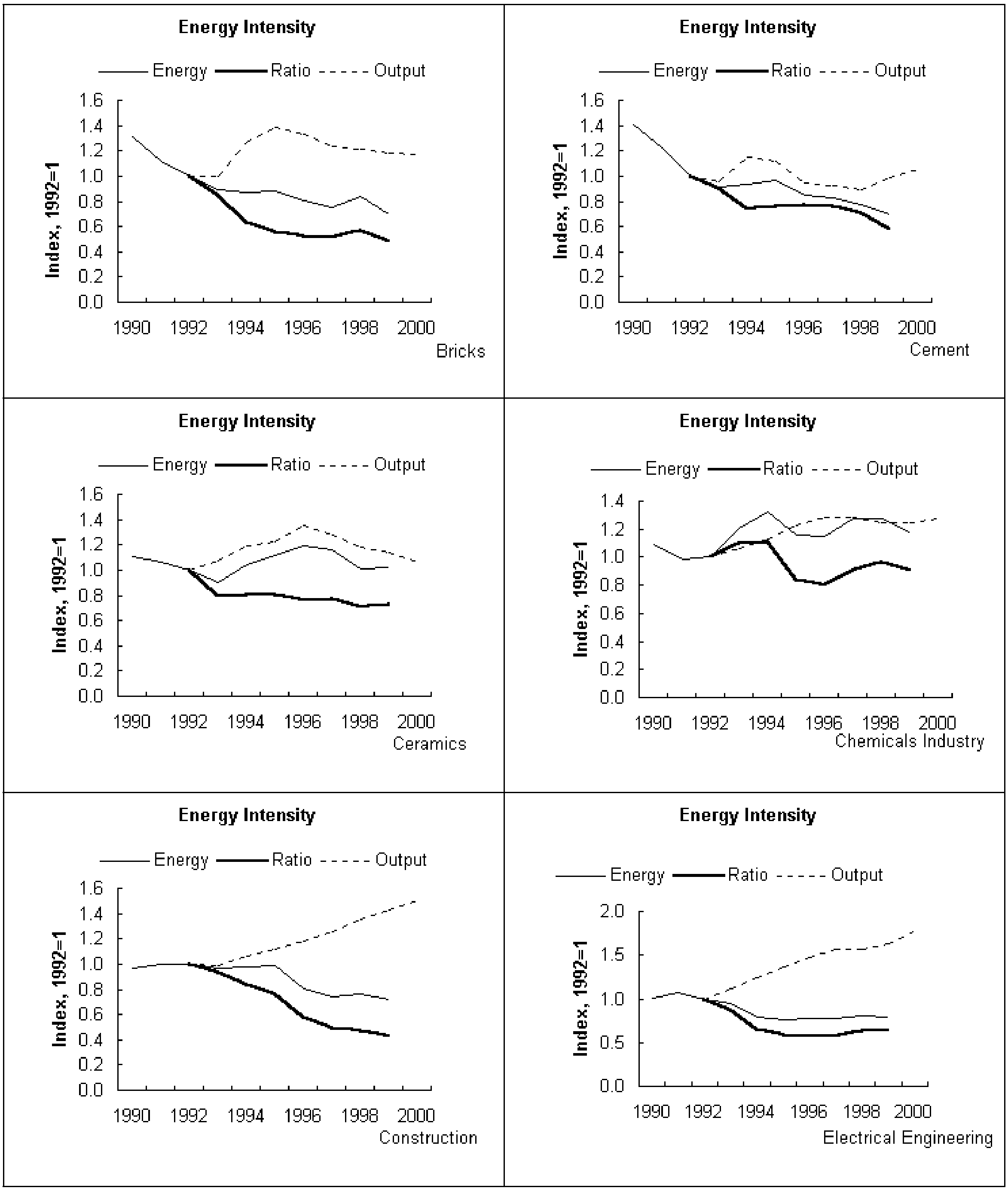
Steel

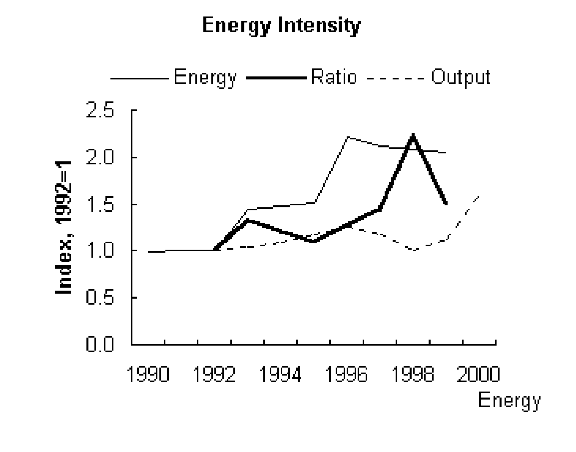


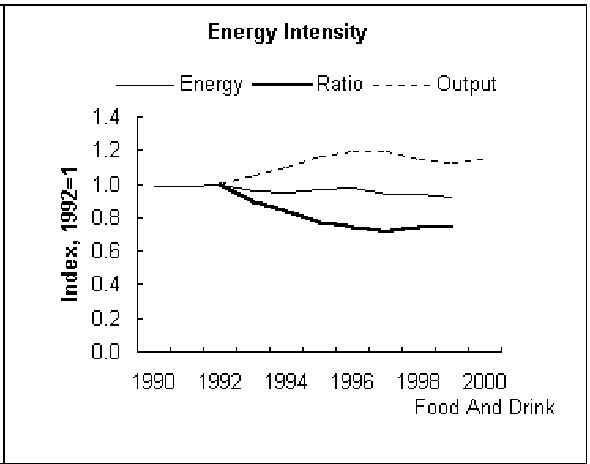


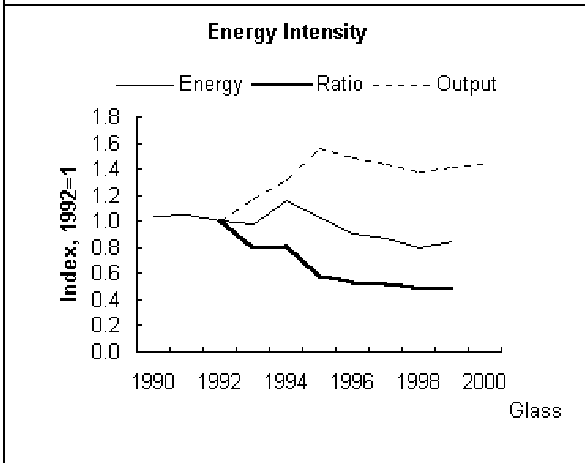
Vehicles	
	
Water	
	

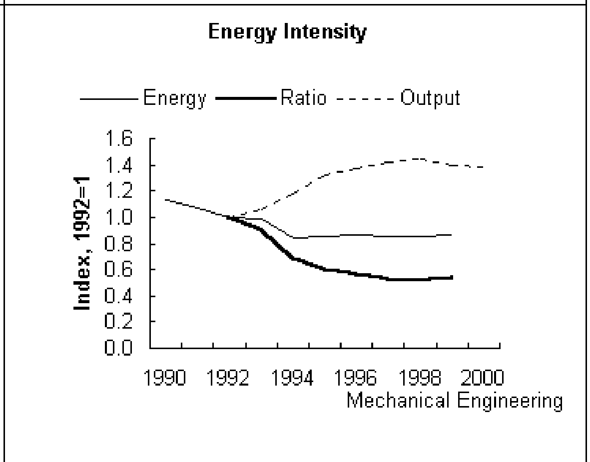
Appendix G
Historical Structural Change

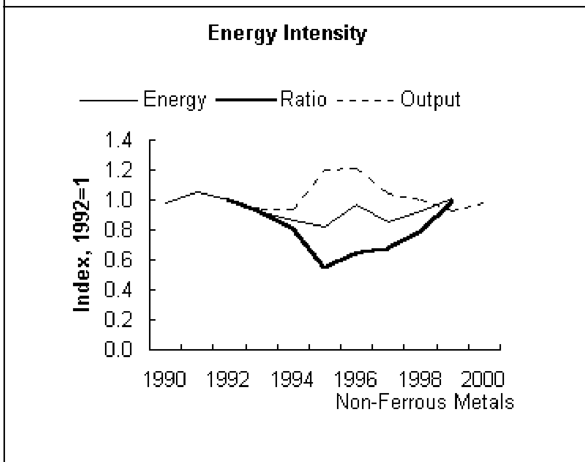

Energy Intensity
Energy Ratio Output
Index, 1992=1
1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
1990 1992 1994 1996 1998 2000
Bricks
Energy Intensity
Energy Ratio Output
Index, 1992=1
1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
1990 1992 1994 1996 1998 2000
Cement
Energy Intensity
Energy Ratio Output
Index, 1992=1
1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
1990 1992 1994 1996 1998 2000
Ceramics
Energy Intensity
Energy Ratio Output
Index, 1992=1
1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
1990 1992 1994 1996 1998 2000
Chemicals Industry
Energy Intensity
Energy Ratio Output
Index, 1992=1
1.6 1.4 1.2 1.0 0.8 0.6 0.4 0.2 0.0
1990 1992 1994 1996 1998 2000
Construction
Energy Intensity
Energy Ratio Output
Index, 1992=1
2.0 1.5 1.0 0.5 0.0
1990 1992 1994 1996 1998 2000
Electrical Engineering

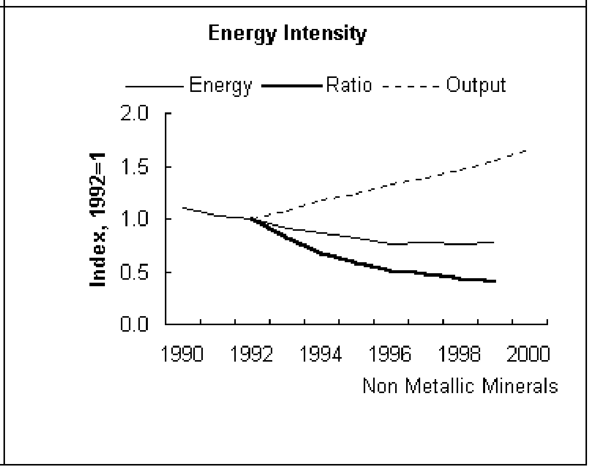

Energy Intensity
Energy
Ratio
Output
Index, 1992=1
2.5
2.0
1.5
1.0
0.5
0.0
1990
1992
1994
1996
1998
2000
Energy

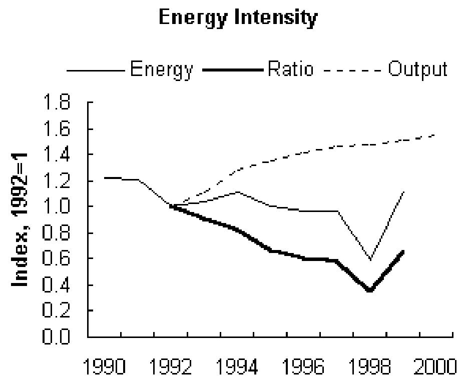

Energy Intensity
Energy
Ratio
Output
Index, 1992=1
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1990
1992
1994
1996
1998
2000
Food And Drink


Energy Intensity
Energy
Ratio
Output
Index, 1992=1
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1990
1992
1994
1996
1998
2000
Glass

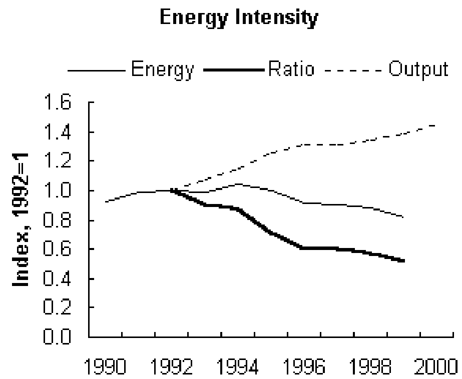

Energy Intensity
Energy
Ratio
Output
Index, 1992=1
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1990
1992
1994
1996
1998
2000
Mechanical Engineering


Energy Intensity
Energy
Ratio
Output
Index, 1992=1
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1990
1992
1994
1996
1998
2000
Non-Ferrous Metals

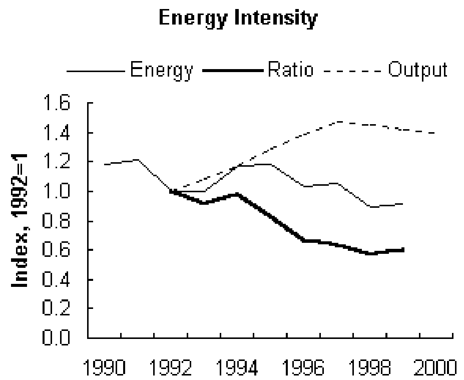

Energy Intensity
Energy
Ratio
Output
Index, 1992=1
2.0
1.5
1.0
0.5
0.0
1990
1992
1994
1996
1998
2000
Non Metallic Minerals



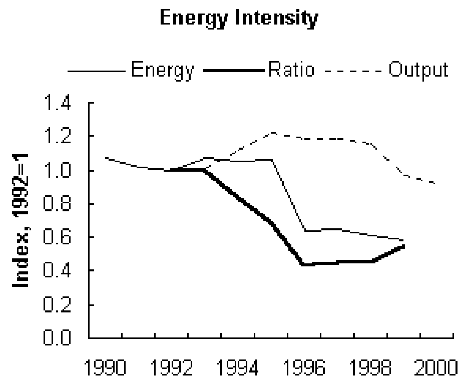
Other Industries



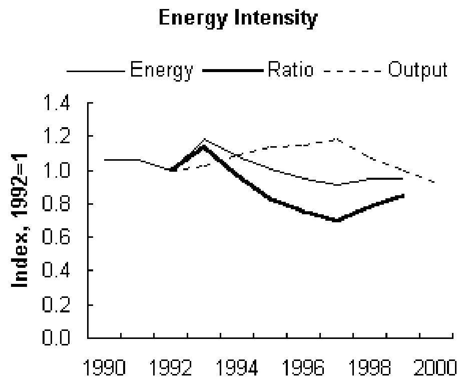
Paper



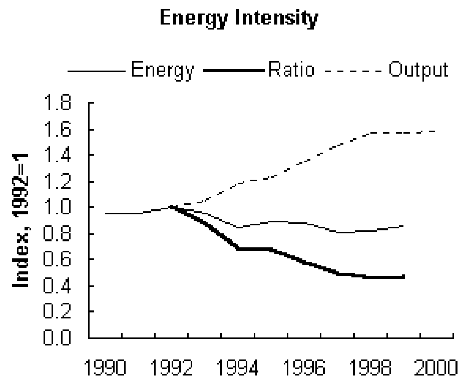
Plastics



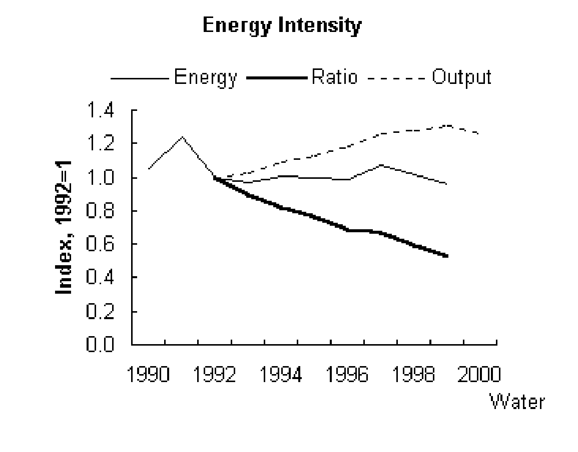
Steel

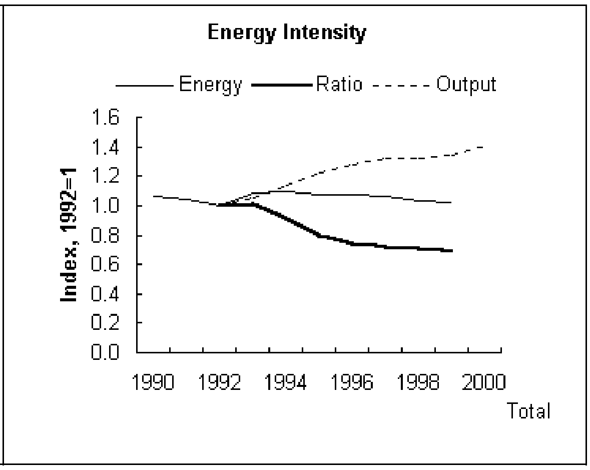


Textiles

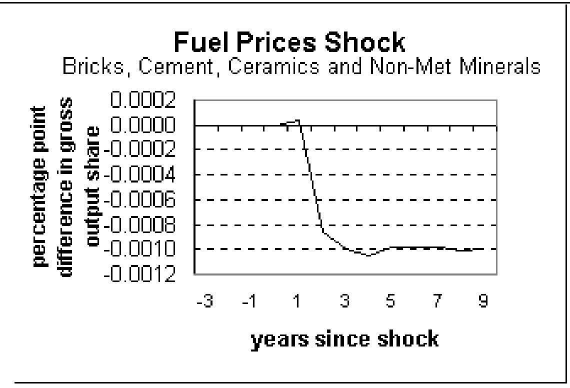


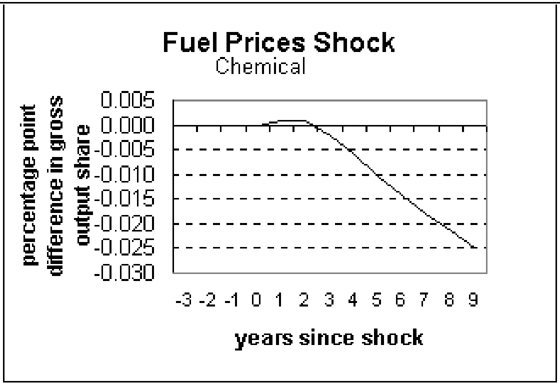
Vehicle Engineering

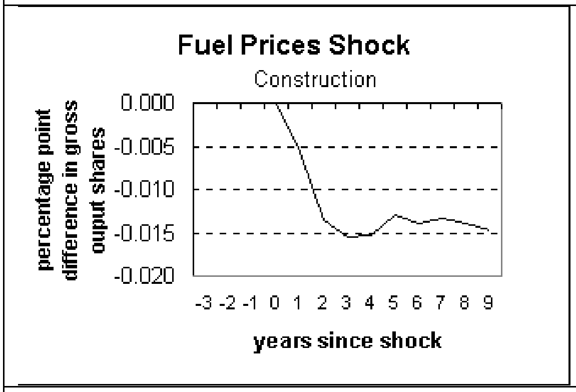

Energy Intensity
Energy
Ratio
Output
Index, 1992=1
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1990
1992
1994
1996
1998
2000
Water

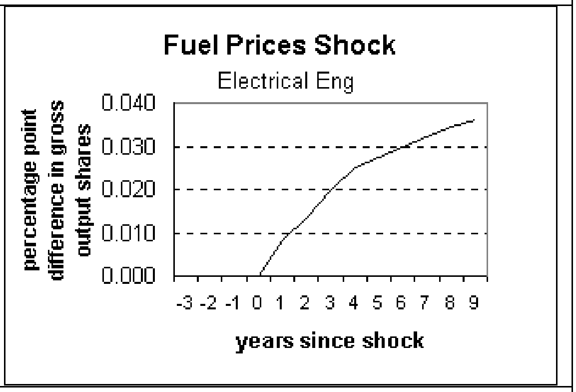

Energy Intensity
Energy
Ratio
Output
Index, 1992=1
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1990
1992
1994
1996
1998
2000
Total

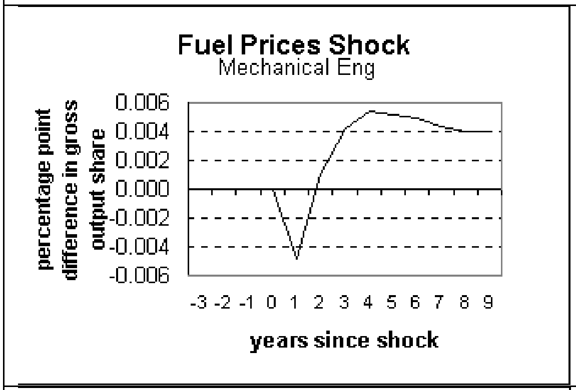
Appendix H
Fuel Price Shocks

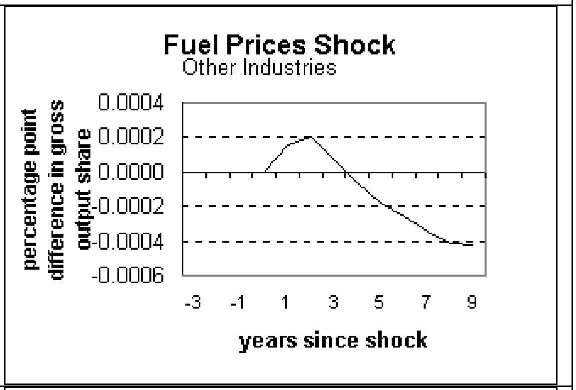

Fuel Prices Shock
Bricks, Cement, Ceramics and Non-Met Minerals
percentage point difference in gross output share
0.0002
0.0000
-0.0002
-0.0004
-0.0006
-0.0008
-0.0010
-0.0012
-3 -1 1 3 5 7 9
years since shock

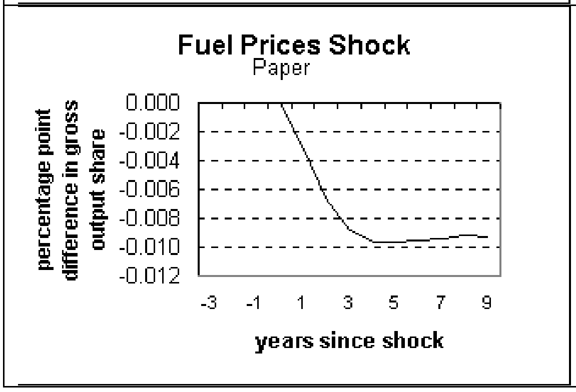

Fuel Prices Shock
Chemical
percentage point difference in gross output share
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

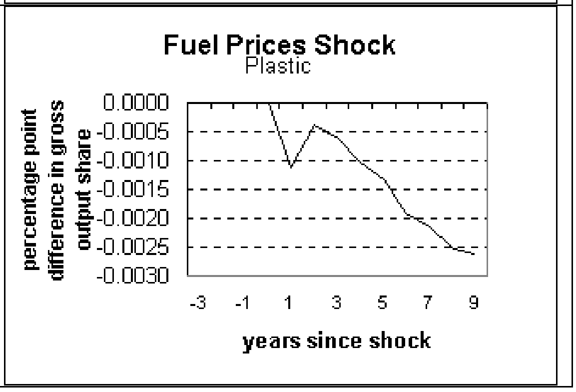

Fuel Prices Shock
Construction
percentage point difference in gross ouput shares
0.000
-0.005
-0.010
-0.015
-0.020
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

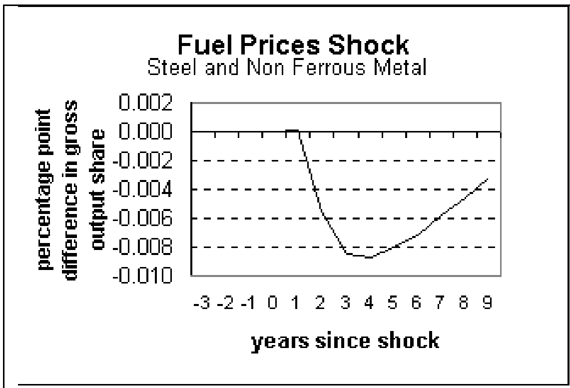

Fuel Prices Shock
Electrical Eng
percentage point difference in gross output shares
0.040
0.030
0.020
0.010
0.000
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

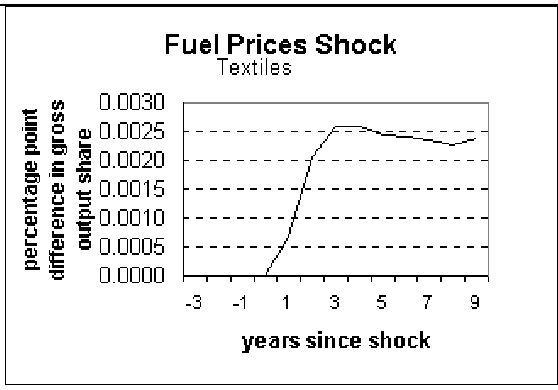

Fuel Prices Shock
Mechanical Eng
percentage point difference in gross output share
0.006
0.004
0.002
0.000
-0.002
-0.004
-0.006
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

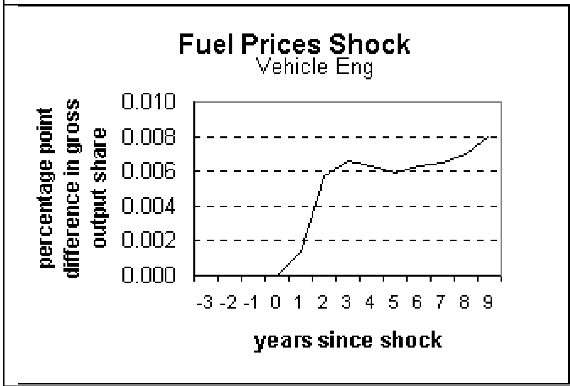

Fuel Prices Shock
Other Industries
percentage point difference in gross output share
0.0004
0.0002
0.0000
-0.0002
-0.0004
-0.0006
-3 -1 1 3 5 7 9
years since shock

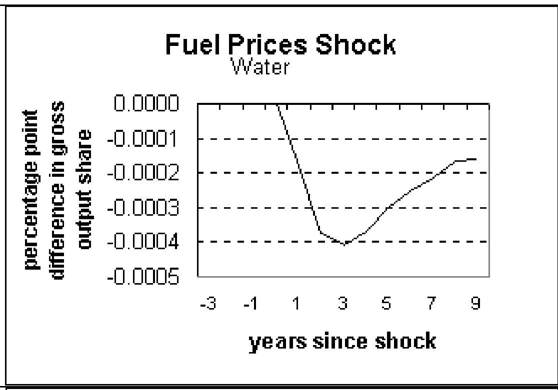

Fuel Prices Shock
Paper
percentage point difference in gross output share
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-0.012
-3 -1 1 3 5 7 9
years since shock

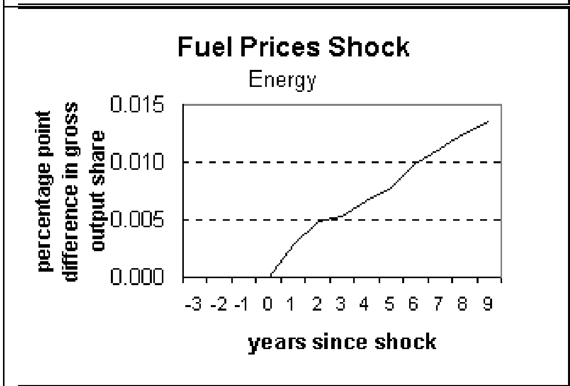

Fuel Prices Shock
Plastic
percentage point difference in gross output share
0.0000
-0.0005
-0.0010
-0.0015
-0.0020
-0.0025
-0.0030
-3 -1 1 3 5 7 9
years since shock

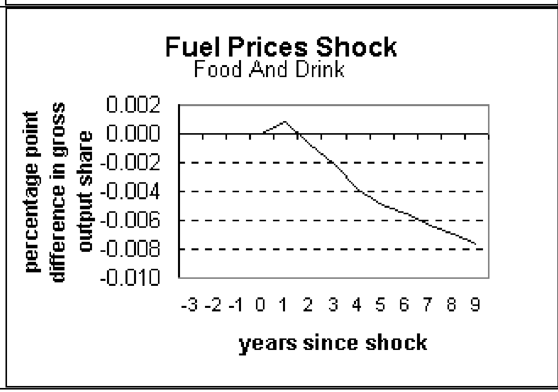

Fuel Prices Shock
Steel and Non Ferrous Metal
percentage point difference in gross output share
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

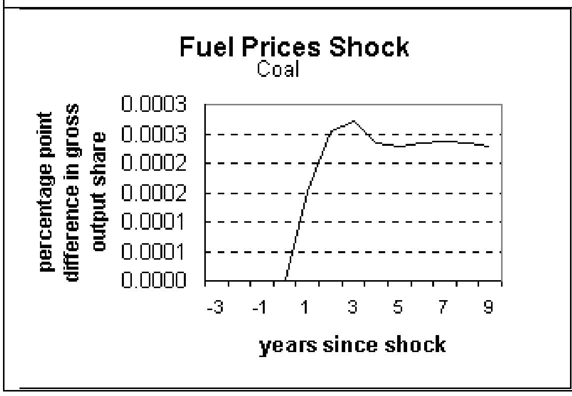

Fuel Prices Shock
Textiles
percentage point difference in gross output share
0.0030
0.0025
0.0020
0.0015
0.0010
0.0005
0.0000
-3 -1 1 3 5 7 9
years since shock

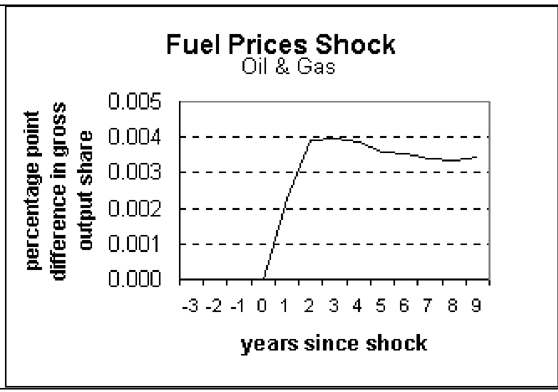

Fuel Prices Shock
Vehicle Eng
percentage point difference in gross output share
0.010
0.008
0.006
0.004
0.002
0.000
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

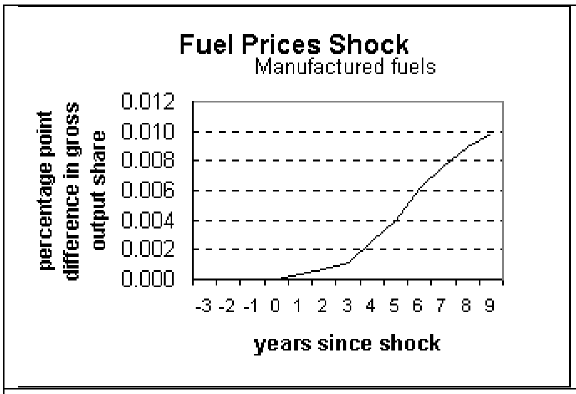

Fuel Prices Shock
Water
percentage point difference in gross output share
0.0000
-0.0001
-0.0002
-0.0003
-0.0004
-0.0005
-3 -1 1 3 5 7 9
years since shock

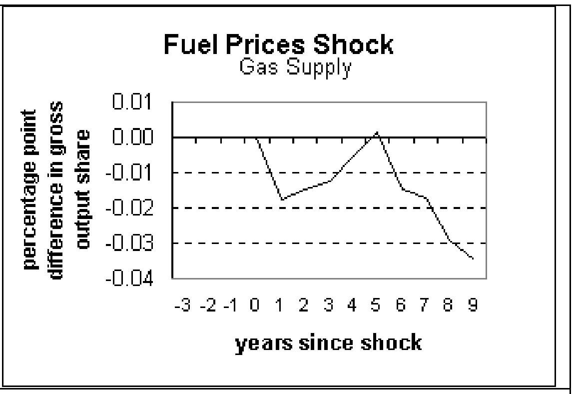

Fuel Prices Shock
Energy
percentage point difference in gross output share
0.015
0.010
0.005
0.000
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock

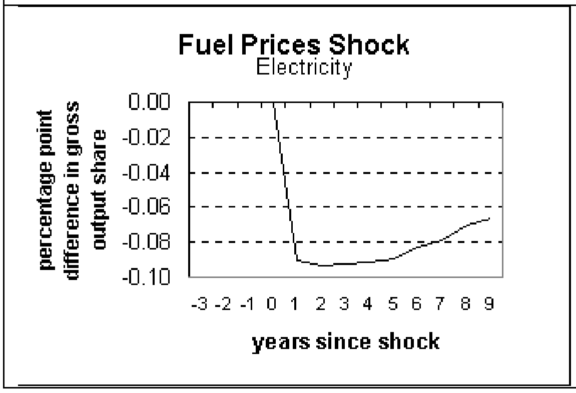

Fuel Prices Shock
Food And Drink
percentage point difference in gross output share
0.002
0.000
-0.002
-0.004
-0.006
-0.008
-0.010
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock


Fuel Prices Shock
Coal
percentage point difference in gross output share
0.0003
0.0003
0.0002
0.0002
0.0001
0.0001
0.0000
-3 -1 1 3 5 7 9
years since shock


Fuel Prices Shock
Oil & Gas
percentage point difference in gross output share
0.005
0.004
0.003
0.002
0.001
0.000
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock


Fuel Prices Shock
Manufactured fuels
percentage point difference in gross output share
0.012
0.010
0.008
0.006
0.004
0.002
0.000
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock


Fuel Prices Shock
Gas Supply
percentage point difference in gross output share
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock


Fuel Prices Shock
Electricity
percentage point difference in gross output share
0.00
-0.02
-0.04
-0.06
-0.08
-0.10
-3 -2 -1 0 1 2 3 4 5 6 7 8 9
years since shock