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The impact on the Scottish economy of reducing greenhouse gas emissions in Scotland:

Illustrative findings from an experimental computable general equilibrium model for Scotland

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PREFACE

This report has been produced by the Energy Modelling Team at the Fraser of Allander Institute and Department of Economics, University of Strathclyde. The objectives of the research were:

(i) To review the literature on the macroeconomic impacts of mitigation against climate change.
(ii) To model the impact of climate change mitigation policies on the Scottish economy.

The main method adopted in this project involved the use of the existing and experimental energy-economy-environment computable general equilibrium (CGE) model of the Scottish economy (AMOSENVI) to simulate the impacts of a set of policy options and/or scenarios regarding economic conditions that were agreed with the Scottish Government project management team.

The main results of the scenarios modelled are summarised in a Main Report, supported by six in-depth Technical Appendices, as follows:

A1. Review of literature on applying the CGE modelling approach to the problem of climate change mitigation and other environmental issues.
A2. Simulation results: Energy Efficiency
A3. Simulation results: Population Scenarios
A4. Simulation results: Costly Requirements on Households to Reduce Energy Use
A5. Simulation results: Renewable Energy Supply 1 – Input-Output Analysis
A6. Simulation results: Renewable Energy Supply 2 – CGE Analysis

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Executive Summary

Introduction

This project uses an experimental energy-economy-environment computable general equilibrium (CGE) model of the Scottish economy (AMOSENVI) to conduct illustrative simulations of the economic and environmental impacts of various options to reduce the generation of CO2 emissions (as the main greenhouse gas) in Scotland. These simulations are illustrative in nature because the process of appropriate database development and model specification for a comprehensive and accurate analysis of climate change policy issues for Scotland, while advanced relative to many regional (and even national) economies, is still in its very early stages. One of the key objectives of this project is to illustrate the potential value-added to Scotland's analytical capacity if further investment is made (by both the policy community, particularly in terms of data provision, and the research community, with public support, for example by seeking support from the research councils) in developing an appropriate CGE modelling framework

Objectives of the research

The objectives of this project were:

1. To review the literature on the macroeconomic impacts of mitigation against climate change.

2. To model the impact of climate change mitigation policies on the Scottish economy.

The literature review is reported in Technical Appendix 1; it has informed development of the existing (experimental) energy-economy-environment computable general equilibrium (CGE) model of the Scottish economy (AMOSENVI) used under Objective 2, and will continue to inform future developments of the modelling framework. The CGE simulations carried out under Objective 2 were agreed with the Scottish Government project management team in the context of the current Government Economic Strategy and National Performance Framework in order to inform the forthcoming Scottish Climate Change Bill. However, given the early stage of development, and consequent experimental nature of the current AMOSENVI model, the simulations carried out are illustrative in nature. In this context, a more fundamental objective of this project was to explore how far this model can be used to answer questions regarding the economic impact of reducing greenhouse gas emissions in Scotland, and to identify further steps in the development of the AMOSENI framework.

Simulation results

Five sets of illustrative simulations using the AMOSENVI CGE modelling framework have been carried out and report the impacts of: increased energy efficiency; population and demographic change; the imposition of costly requirements on households to reduce energy use; and the impacts of increasing renewable energy supply. In the case of the latter, we also offer a detailed input-output analysis of the impacts of changing the structure of the electricity supply sector in favour of renewables. The motivation for carrying out and reporting this additional analysis is that we are able to examine a more detailed disaggregation of the electricity supply sector using input-output than CGE, as the current AMOSENVI framework only distinguishes between renewable and non-renewable generation at a very aggregate level.

Findings of energy efficiency simulations

We simulate a very simple increase in energy efficiency in the production sectors of the Scottish economy. This allows us to identify the key drivers of what are known as 'rebound' effects. We do not attempt to consider *how* the efficiency improvements may be achieved (this will be the focus of future research). The results of the energy efficiency simulations highlight the issue that, because of the system-wide response to falling actual and effective energy prices, particularly in an economy like Scotland (a producer and exporter of energy), reductions in energy consumption due to increased efficiency are likely to be partially or even wholly offset by increased demand for energy (i.e. rebound effects will occur). The more extreme variant of rebound effects, backfire, where energy consumption actually increases in response to increased energy efficiency, with consequent increases in the level of CO2 emissions and the CO2 intensity of GDP/production, is more likely when the Scottish energy supply sectors, particularly the electricity sectors, are targeted directly. This is due to the fact that these are heavily traded and the responsiveness of demand to falling prices is therefore relatively high. Our long run analysis suggests that a 5% increase in energy efficiency directed at the Non-Renewable Electricity sector will increase GDP by 0.5%, but total CO2 emissions in Scotland by more, 1.18%, with the implication that the CO2 intensity of Scottish GDP will rise by 1.29%. If a 5% increase in energy efficiency is directed at the Renewable sector instead, our analysis suggests a smaller increase in CO2 emission (0.07% in the long-run, but only a 0.05% increase in GDP, so, again the long-run impact on the CO2 intensity of GDP would be an increase of 0.02%. However, if the same proportionate increase is directed at any other of the 25 sectors modelled, (smaller) increases in GDP would be accompanied by reductions in CO2, even though rebound effects are present in all cases, leading to a reduction in the CO2 intensity of Scottish production.

Our analysis actually suggests that, in terms of reducing the CO2 intensity of Scottish production (if not the level of CO2 emissions), improving *labour* productivity may actually be a more effective form of technological progress to focus attention on. However, we qualify our results not just with respect to the quality of currently available data, but by the fact that we do not attempt to consider the precise form of efficiency improvements, the costs involved in introducing them or the use of any resulting revenues. These factors may have a significant impact on results. However, at present the specification of the AMOSENVI framework is not sufficiently sophisticated to effectively account for them (though some broad brush analysis has previously been attempted in carrying out comparable analysis for the UK in a project commissioned by DEFRA). Here, in our initial work for Scotland, we instead focus on isolating and examining the basic system-wide response to improved energy efficiency (i.e. the basic drivers of rebound and backfire effects) on the basis that it is necessary to understand these before introducing more complex, albeit very policy relevant issues.

Findings of population/demographic simulations

The results of the population/demographic change simulations suggest that population decline and ageing has a significant impact on the Scottish labour market, on economic activity, as well as on energy use and CO2 generation. Our central case of a 1.7% decline in total population and 15% decline in working age population between 2000 and 2050 produces a decline in GDP of 9.30% and a fall in CO_2 generation or 8.76%. The CO_2 intensity of production thus increases. Energy (both electrical and non-electrical) demands fall in this scenario. The functioning of the labour market and possibilities for in-migration of labour are the key factors influencing environmental impacts. This is because, as working population falls, the labour market will tighten, pushing wages up. The greatest impact will be felt in labour intensive sectors, where output prices will increase and competitiveness reduce to the greatest extent. Our analysis suggests that, because of the precise structure of the Scottish economy, and particularly the export intensity of more directly and indirectly labour intensive sectors, the export price index is particularly badly hit leading to falling competitiveness. With higher values for net migration to Scotland, the economic impact of ageing can become positive, and, although this will tend to increase CO_2 emissions, the faster rate of GDP growth means that the CO_2 intensity of Scottish production falls.

Findings of simulating income effects of costly requirements on households to reduce their energy use

The next scenario we attempted to simulate focussed on the labour market effects of costly requirements on households to reduce their energy use. At present the AMOSENVI model cannot be used to simulate policies aimed at changing household energy consumption behaviour. However, it can be used to examine the likely knock-on effects of reductions in household income that are likely to occur as a result. Therefore we simulate the economy-wide impacts of a reduction in household income (that may accompany/result from policy actions requiring households to reduce their energy use). We find that this will lead to a reduction in the level of CO2 emissions in the Scottish economy (up to 1.81% in the long-run for a 1% decrease in real household income), and also to the CO2 intensity of Scottish Production (-0.19% where real income falls by 1%), but this is at the cost of a contraction in GDP (-1.63% in the 1% scenario). The key driver of these results is out-migration from Scotland, due Scottish real (take-home) wages declining relative to those in the rest of the UK.

Findings of simulations increasing the share of electricity generated from renewable sources

In the final two sets of simulations, we attempted to model the impacts of increasing the share of electricity generated from renewable sources. Ideally, this should be done using a CGE framework, where more theory consistent supply and demand side behaviour can be modelled, and the economy's path of adjustment can be tracked. We do attempt a CGE analysis in our final set of simulations; however, the electricity sector is quite highly aggregated in the current AMOSENVI model. Therefore, we also carry out analyses of the impact of shifting the generation technology mix towards the target of 50% of generation from renewable sources by 2020, using an IO model that identifies eight different types of generation technology. We examine four illustrative scenarios where different types of generation technologies make up the 50% from renewable and non-renewable sources respectively, with complete removal of nuclear generation. While all the scenarios examined lead to between 3% and 9% reductions in Scottish CO2 emissions (taking income effects into account) in the long-run, our results suggest that the biggest gains in terms of CO2 reduction, 8.9%, are made when coal generation is phased out all together (although the introduction of carbon capture and storage may overturn this conclusion). However, again, while all scenarios generate long-run increases in GDP (between 0.27% and 0.63% above the baseline), the largest GDP gains and reductions in the CO2 intensity of production (-6.28%) are found where non-renewable electricity production is split between coal and gas generation, but with a relatively high share of production (10%) from marine technology. This is primarily because of the strong backward linkages that the marine generation sector has with sectors such as Construction and Communications, Finance and Business, all of which have relatively high GDP multipliers. However, it is important to bear in mind that these results will be sensitive to what is currently only an illustrative/experimental disaggregation of the electricity sector and input-output assumptions of fixed input relationships. As technologies mature (e.g. marine generation), we may expect these to change over time, a factor that is not reflected in the results reported here.

In our final set of simulations, we move back to the AMOSENVI model to conduct a more sophisticated analysis of the impact of increasing reliance on renewable electricity generation technologies, but where we are only able to distinguish between aggregate renewables and non-renewables, and where the composition of these is fixed to that given by the 1999 input-output database. However, here we are able to consider *how* the growth in renewables may be induced (using subsidies). On the other hand, in the current CGE framework, we are not able to simulate the full 50% target for electricity from renewable sources by 2050 stated under the National Performance Framework. The maximum share of Scottish electricity generated from renewables that we are able to simulate is just over 20%. Our main finding in this scenario is that the proportion of electricity generated from renewable electricity technologies in Scotland from 10.40% to 20.06% reduces CO2 emissions by 4.15% in the long-run, but lowers Scottish GDP by 1.25% in the same time frame. When we allow total electricity generated in Scotland to be lower than in the base year, we can find scenarios in which electricity generated from renewable energy sources, and consequently, the falls in CO2 generation are greater. However, this comes at the cost of larger declines in GDP

Discussion of limitations of current CGE analysis

We present summary results of each of the scenarios modelled, along with a basic introduction to the CGE modelling approach, and offer our conclusions and recommendations in the main body of the report. This is followed by six in-depth technical appendices, providing more detail on the results of each of the simulation scenarios and a comprehensive review of wider developments in the energy-economy-environment CGE literature. It is important to bear in mind the illustrative/experimental nature of the current AMOSENVI model and the assumptions involved in each simulation reported (outlined in the main body of the report with more detail in the technical appendices).

Conclusions and recommendations

We emphasise that the analysis presented here is experimental and constrained by two broad factors:

- The need to further develop the Scottish input-output tables for the purposes of examining energy-economy-environment issues.
- The need to further develop the AMOSENVI CGE modelling framework to look at a wider range of issues.

Both of these points are discussed in Section 7 of the report. We also offer some recommendations for strengthening Scotland's analytical capacity in this area. Development of the AMOSENVI framework is currently ongoing through various EPSRC and ESRC funded research projects being carried out by the regional and energy modelling teams at the Fraser of Allander Institute, University of Strathclyde. In terms of the development of the data infrastructure, this is an area where Scottish Government can play a direct role and it is important to note that the benefits of doing so would not be limited to better informing CGE models, as environmentally augmented input-output tables can be applied for a wide variety of analyses, including carbon accounting and footprint analyses.

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1. Introduction to the CGE modelling approach

Policy actions to reduce the generation of greenhouse gas (GHG) emissions may have impact that permeate throughout an economy, leading to a series of adjustments in the production and consumption of different goods and services. These adjustments cannot be adequately captured within a partial equilibrium framework but may be explored through the use of Computable General Equilibrium (CGE) models of the macro-economy. CGE models are widely used in the investigation of energy and climate policy, partly as a consequence of the increasing availability of modelling frameworks and associated benchmark data. In the case of Scotland, an energy-economy-environment CGE modelling framework has been in development at the Fraser of Allander Institute (FAI), Department of Economics, University of Strathclyde over the last decade. CGE model development for Scotland at the FAI, in the form of the AMOS suite of models[1], has been greatly enhanced by the availability of comprehensive region-specific economic accounts in input-output (IO) format for Scotland, the required core database for CGE modelling. However, policy applications of the environmental variant, AMOSENVI, have been limited, due to the absence of an appropriate environmental augmentation to the Scottish IO accounts to provide a region-specific linked environmental component to the model database. The purpose of the current project is to provide illustrative findings from AMOSENVI as an experimental energy-economy-environment CGE model for Scotland. This serves to demonstrate the type of analytical capability that is potentially available given the appropriate commitment to developing the data and modelling infrastructure by the policy and research communities.

This section of the report begins by clarifying the strengths and weaknesses of multi-sector CGE models for investigating the economy-wide impacts of policies to reduce GHG emissions, summarising the theoretical underpinnings and basic methodology of the CGE modelling approach, before outlining the specific AMOSENVI model employed here.

1.1 Basic characteristics, including strengths and weaknesses, of the CGE approach

Computable General Equilibrium (CGE) modelling involves numerically simulating the general equilibrium structure of an economy, where a general equilibrium is characterised by a set of price and output levels across all sectors of the economy such that market demand equals supply in all markets simultaneously. The technique is an important tool in evaluating the economy-wide impact of exogenous shocks, and has proved to be appropriate for economic policy appraisal. CGE modelling has been employed to examine a whole range of policy and other non-policy disturbances in a variety of research areas, including questions relating to regional trade agreements (see Lloyd and Maclaren (2004) for a review), public finance (Shoven and Whalley, 1984), tax reform (Jorgenson, 1997) and the distributive impacts on different household groups of policy change (e.g. Bourguignon et al, 1991). Furthermore, it has become the most widely use approach for system-wide analysis of energy-economy-environment issues at both national (Beausejour et al, (1995), Bergman (1990), Bohringer and Loschel (2006), Conrad and Schroder (1991), Goulder (1998), and Lee and Roland-Holst (1997), and Conrad (1999) provides a review) and regional levels (e.g. Despotakis and Fisher (1988) and Li and Rose (1995)). The key characteristics motivating the use of CGE models to analyse economy-environment problems are their multi-sector nature (sharing the desirable characteristics of input-output models, where sectors with differing resource use and/or pollution generation characteristics can be distinguished) and the simultaneous modelling of prices and quantities, supply and demand (characteristics not shared by input-output). A fuller literature review and overview of the application of CGE modelling techniques to environmental issues/problems is given in Technical Appendix 1 below.

CGE analysis is grounded in economic theory, but can deal with circumstances that are too complex for analytical solutions. As such, CGE analysis can be considered a numerical aid to analytical thought. For example, in the first set of simulations in this project, CGE analysis can simulate the various substitution, income, output and composition effects that may follow from energy efficiency improvements and give rise to what are referred to as 'rebound effects'.

[1] AMOS is an acronym for A Model of Scotland, so called because the modelling framework was initially calibrated on Scottish data (see Harrigan et al, 1991).

CGE models are generally parameterised to reflect the structural and behavioural characteristics of a particular economy. As a result, they can estimate not only the direction, but also the order of magnitude of effects that may result from a particular exogenous disturbance, such as any one of the scenarios simulated in the present project. A feature of CGE models is that they tend to have a very well developed supply side, allowing investigation of supply-side policies, such as energy efficiency improvements, where other models (e.g. input-output) are inappropriate. CGE models also make it easier to evaluate the net impacts of a given policy or other disturbance, where the counter-factual is simply the model run without any changes. Since all changes in output, employment and energy use are measured relative to this baseline, the marginal effects of the disturbance simulated are clear. Evaluating the same policy using time series or cross-sectional statistical data would require the counter-factual to be identified by appropriate statistical control, which may be harder, and risks confusing the drivers of changes in activity.

However, CGE models do have a number of well-established weaknesses. For example, most represent production behaviour through the use of ‘well-behaved’ but relatively restrictive functional forms, with limited facility for testing their appropriateness. Parameter values for these functions may be assigned through calibration to a base year, but this may not be representative an equilibrium in the economy. Alternatively, they may be taken from empirical studies, but these may relate to different countries and/or time periods from that to which the CGE model is applied. While sensitivity tests are feasible, they are not always conducted in practice.

CGE models generally also assume that firms minimise costs, that consumers maximise utility and often that the source and direction of technical change is exogenous. Each is partly inconsistent with empirical evidence. Markets may also be assumed to be competitive and factor inputs may be assumed to be mobile, although neither is a necessary feature of CGE models. While the results of CGE models may sometimes be driven by assumptions that are not readily apparent, a CGE model should not be regarded as a ‘black box’. Transparency may be considerably improved by providing information on key features and assumptions, and by the modeller explaining the results with reference to economic theory.

1.2 The AMOSENVI model

Over the last decade the regional modelling team based at the Fraser of Allander Institute (FAI), Department of Economics, University of Strathclyde, has developed an energy-economy-environment computable general equilibrium modelling framework of the Scottish economy (AMOSENVI). This framework has mainly been (and continues to be) developed with the support of the ESRC and EPSRC.

AMOSENVI is a 25-sector CGE model of the Scottish economy. The current database is a social accounting matrix (SAM) that incorporates a 25-sector aggregation of the 1999 Scottish IO tables. The motivation for continuing to use the 1999 IO tables is that these include a limited experimental (not publicly available) disaggregation of the Scottish electricity sector (carried out by the Scottish Government IO team, with input/development by the FAI regional modelling team), which is clearly important for environmental analyses. The 25 sector aggregation of the 1999 IO tables is also augmented with sectoral physical energy use and pollution data, constructed by the FAI modelling team as part of a project carried out in consultation with the Scottish Environmental Accounts Working Group in 2003 (see Turner, 2003).

However, as noted in Section 7 (Conclusions and Recommendations), the current database is limited and would benefit from more environmentally-focussed development of the Scottish Government’s Input-Output economic accounting framework. For example, the current (experimental) disaggregation of the Scottish electricity supply sector is limited to generation type and could be improved particularly by separately identifying the different stages of the electricity supply process (i.e. generation, distribution and supply to consumers). In terms of physical energy-use pollution generation, the current environmental input-output component of the model database is heavily reliant on adapting UK national energy and pollution intensities to the Scottish case, and would benefit from the development of more region-specific environmental input-output data for Scotland.

Details of the AMOSENVI modelling framework can be found in Hanley et al (2008). Key details are that it has three transactor groups, namely households, firms and government; 25 commodities and activities (five of which are energy commodities/supply – coal, gas, oil and electricity from renewable and non-renewable sources); and two exogenous transactors, the rest of the UK (RUK) and the rest of the world (ROW). We regard AMOSENVI as a modelling *framework* as there is a high degree of flexibility in terms of choice of key parameter values and functional forms, assumptions about how the labour market functions and the nature of macroeconomic constraints (government budget constraints etc). Greenhouse gas emissions are modelled as linked to energy-use in the case of CO2 emissions generated through fuel combustion in each production sector and final consumption sector, and otherwise to sectoral outputs/final demand expenditures (see below).

The model can be run for three conceptual time periods, namely the short, medium and long- run, which allows examination of the sectoral and macroeconomic impacts of any disturbance under alternative assumptions about factor supply.

- In the short run, the population and capital stock is fixed.
- In the medium run, population can adjust through migration.
- In the long run, capital stocks can vary through net investment

The model can also be run in period-by-period (year-by-year) mode in order to examine the path of adjustment over time as the labour supply adjusts in response to changes in real wages and investment responds to changes in profitability. This allows us to examine the extent of adjustment, and impacts on key economic and environmental indicators over different timeframes and towards a long-run equilibrium. Simulation results are reported so that the impacts of any disturbance can be examined in isolation and relative to a 'no change' baseline. That is, we do not attempt to forecast the future performance of the Scottish economy; rather we focus on examining the impacts of a given policy scenario in isolation under different assumptions about supply and demand conditions in the economy at the time the shock is introduced. Disturbances/policy scenarios may be introduced as transitory or permanent shocks and they can be introduced gradually or as step-changes.

Modelling pollution generation in AMOSENVI

The simplest way to model pollution as a result of economic activity is through fixed coefficients linking pollution outputs to each sector's output level. This approach was one of the earliest steps in general equilibrium economy-environment modelling, developed in Leontief's (1970) environmental IO framework. Nonetheless, it remains common in both IO and more general CGE modelling e.g. Ferguson et al (2005). However, as explained in more detail in Section 4 of Technical Appendix 1, below, the major limitation of relating emissions to sectoral outputs only is that there is no scope for changes in emissions due to technical substitution within sectors. That is to say, if pollution coefficients are output-based and/or only pure Leontief technology is modelled, then the only way to reduce emissions within any sector is to reduce that sector's output. In discussing this issue, Beghin et al (1995) identify three underlying components of changes in emissions levels over time. The first component is composition: the change in pollution induced by a change in the commodity composition of aggregate production (more or less dirty/clean goods). Secondly, technology relates to evolving cleaner technologies (which usually result in a change in the input mix or input substitution). Finally, scale: the increase/decrease in pollution attributable to an increase in aggregate economic activity

The present AMOSENVI model captures input substitution by relating emissions of CO2 to different types of energy use through input-pollution coefficients. In the absence of appropriate economic-environmental input-output accounts for Scotland, these coefficients are determined using data on the CO2 emissions intensity of different types of fuel use in the UK economy (see Turner, 2003 and Hanley et al, 2008). The application of fuel-use emissions factor data is fairly straightforward in the case of CO2 emissions, as these are primarily dependent on fuel properties rather than combustion conditions and/or technology. Modelling input-pollution relationships becomes more complex when it comes to non-CO2 emissions. This is because non-CO2 emissions tend to be dependent not only on fuel type, but also combustion conditions and technology, meaning that appropriate emissions factors are likely to be more difficult to identify and numerous for models with a high level of sectoral detail. Thus, at this time we do not attempt to extend the input-pollution approach to any other pollutants. In the environmental CGE literature, models that adopt an input-pollution approach have indeed tended to focus solely or primarily on CO2 emissions (see Turner, 2002, for a review).

We also include an output-pollution component for the generation of CO_2 emissions (see Hanley et al, 2008). This is following the argument put by Beauséjour et al (1994, 1995) that there is a role for modelling both input-pollution relationships, and output-pollution relationships where emissions not only result from input use but also from processes that are inherently polluting. Beauséjour et al (1994, 1995) identify processes such as non-ferrous smelting, which generates SO_X, and pulp and paper production, which generates CO2. Here, in the case of CO2 emissions, we identify industrial process emissions relating to the production of mineral products and metal in the 'Mfr metal and non-metal goods' sector. We also apply output-pollution coefficients to capture CO2 emissions that occur during extraction activities in the 'Oil and gas extraction' sector and flaring in the 'Refining and distribution of oil' sector. While these are obviously related to energy supply, they are not easily related to energy input use through the application of emissions factors.

Due to a lack of Scottish-specific data on sectoral pollution data (i.e. Scottish environmental input-output accounts), the input- and output-pollution coefficients in AMOSENVI are currently mainly based on UK direct emissions intensities for each SIC-classified production sector and for household final consumption (see Ferguson et al, 2005 and Hanley et al, 2008), adjusted to reflect the composition of Scottish output at the aggregate and sectoral levels. A more detailed account is given in Turner (2003), but basically we have taken the following steps to derive the input- and import-pollution coefficients. First we used UK data on physical fuel intensities for the broad (directly polluting) fuel types – oil, gas and coal – to estimate total Scottish fuel uses. These are then distributed across the production and final consumption sectors identified in the model according to the distribution of local and imported purchases of these fuels implied by the Scottish IO tables and the experimental data on commodity imports to estimate sectoral fuel uses. UK data on the level of emissions (tonnes) per unit of each fuel type (tonnes of oil equivalent) are then used to derive estimates of direct CO2 emissions resulting from each production and final consumption sector's use of local and imported coal, gas and oil. Finally, we divide each sector's estimated emissions from each type of fuel use by the IO and (experimental) import-by-commodity data on fuel *purchases* to derive the input- and import-pollution coefficients for the model (tonnes of CO2 per £1million expenditure on each local and imported fuel respectively).

However, it is important to introduce Scottish-specific data on sectoral emissions where it is possible to do so (Turner, 2006). As explained in Turner (2003), even though region-specific estimates of CO2 and other GHG emissions have been made for 1999 by Salway et al (2001), there are problems in mapping emissions reported for IPCC classified activities to the SIC classification used in economic IO accounting. However, it is possible to map for some activities, most notably electricity production and supply. Moreover, we were able generate the output-pollution coefficients for non-fuel-combustion emissions of CO2 in the 'Mfr metal and non-metal goods', 'Oil and gas extraction' and 'Refining and distribution of oil' sectors, using the estimates of CO2 emissions in 1999 from the relevant sources reported by Salway et al (2001). These are simply divided by the base year outputs for each of these sectors.

In general though, given the limitations of appropriate energy-economy-environment data currently available for Scotland, and the many uncertainties involved in modelling the types of policy that are of interest here, it is important to note that results should be regarded as indicative of the scale and direction of impacts on the Scottish economy of a given policy scenario.

Reporting results from the AMOSENVI model

All simulation results are reported in terms of the percentage change relative to the (no change) base case scenario represented by the 1999 model database. For each simulation we report a range of key economic variables – including GDP, employment, unemployment, exports and imports, wages, household consumption and CPI. We also report results for energy consumption, separately identifying electricity and non-electricity energy types, and for CO2 emissions, and three composite indicator variables: GDP per unit of energy consumed (GDP divided by total, economy-wide, electricity and non-electricity consumption, respectively, in physical units) and CO2 intensity of production (total CO2 emissions generated from production and consumption divided by GDP). For improved environmental productivity (sustainability), the value of the first two (energy) indicators should rise, while the value of the third should decrease.

Table 1.1 Sectoral breakdown of the 1999 AMOSENVI model

		IOC
1	AGRICULTURE	1
2	FORESTRY PLANTING AND LOGGING	2.1, 2.2
3	FISHING	3.1
4	FISH FARMING	3.2
5	Other mining and quarrying	6,7
6	Oil and gas extraction	5
7	Mfr food, drink and tobacco	8 to 20
8	Mfr textiles and clothing	21 to 30
9	Mfr chemicals etc	36 to 45
10	Mfr metal and non-metal goods	46 to 61
11	Mfr transport and other machinery, electrical and inst eng	62 to 80
12	Other manufacturing	31 to 34, 81 to 84
13	Water	87
14	Construction	88
15	Distribution	89 to 92
16	Transport	93 to 97
17	Communications, finance and business	98 to 107, 109 to 114
18	R&D	108
19	Education	116
20	Public and other services	115, 117 to 123
	ENERGY	
21	COAL (EXTRACTION)	4
22	OIL (REFINING & DISTR OIL AND NUCLEAR)	35
23	GAS	86
	ELECTRICITY	85
24	Renewable (hydro and wind)	
25	Non-renewable (coal, nuke and gas)	

We also report results for the individual sectors identified in the model (see Table 1.1), giving particular attention both to the main sectors particularly affected by different shocks, and to particular sectors of interest, i.e. the Key Sector identified in the current Government Economic Strategy. These are: Creative Industries (which we have we mapped to our Sectors 17 and 18, 'Communications, Finance and Business' and 'R&D' respectively, through the input-output classifications used in the model database); the energy supply sectors (Sectors 21-25); Financial and Business Services (also mapping to our Sector 17); Food and Drink (covering our Sector 1, ‘Agriculture’ and the two fishing sectors, Sectors 1 and 3, as well as Sector 7, ‘Mfr Food, Drink and Tobacco’). We also focus on ‘Distribution’ (Sector 15), as the one with the highest share of output serving tourist expenditure (largely because of the inclusion of hotels etc), and ‘Education’ and ‘Public and Other Services’ (Sectors 19 and 20) sectors, where more than 50% of output goes to meet public sector demand. In the case of the energy efficiency simulations, we also identify some groups of sectors that are likely to be of particular interest, which we label ‘Agriculture and Primary’ (Sectors 1-6), ‘Manufacturing’ (Sectors 7-12), ‘Energy Use’ (Sectors 1-20), ‘Energy Supply’ (Sectors 21-25).

2. Simulation results: impacts of increased energy efficiency

In the recent AEA report to the Scottish Government (Mitigating Against Climate Change in Scotland: Identification and Initial Assessment of Policy Options), one policy option suggested to reduce GHG emissions is to reduce demand for energy through efficiency improvements. However, as some of our own recent work (Allan et al, 2006, 2007a; Hanley et al, 2008; Turner, 2008a) and recent developments in the policy and academic literature relating to the possibility of 'rebound' effects demonstrates, the relationship between efficiency in energy use and demand for energy may not be so straightforward.

There are five distinct types of effects that occur throughout the economy in response to an energy efficiency improvement. These comprise (i) a need to use less physical energy inputs to produce any given level of output (the pure engineering or efficiency effect); (ii) an incentive to use more energy inputs since their effective price – the cost of energy to produce one unit of output - has fallen (the substitution effect); (iii) a compositional effect in output choice, since relatively energy-intensive products benefit more from this fall in the effective price; (iv) an output effect, since supply prices fall and competitiveness increases; and (v) an income effect as real household incomes rise. While (i) will reduce energy demand, (ii)-(v) will increase it. However, in an economy, such as Scotland, where energy is produced locally, the *actual* price of energy will also fall as production becomes more efficient (if the energy supply sectors themselves are targeted with the efficiency improvement) and as demand contracts (due to the efficiency effect, (i) above). Falling actual energy prices will give further impetus to effects (ii)-(v) above, which are the drivers of rebound effect. However, falling prices will also lead to reduced revenue and profitability in the energy supply sectors, which, if not countered by increased demand as competitiveness improves, will cause a drop in the return to all factors of production, particularly capital in what are relatively capital intensive sectors. The fall in the return in capital will trigger a contraction in the capital stock in the energy supply sectors (what we refer to as (vi), a 'disinvestment' effect) and prices will begin rising again, dampening rebound effects over time.

In the simulations reported in this section, we introduce a 5% increase in energy-augmenting technological progress to each of the 25 sectors identified in the AMOSEVNI model in turn (i.e. 25 separate simulations are carried out, with the efficiency shock directed at one sector at a time). We abstract from how the efficiency improvement is actually made, or any associated costs, in order to identify the main drivers of any rebound effects that occur. In each case, we find evidence of the six effects identified above to varying degrees, depending on the demand and supply characteristics of the sector targeted with the improvement in energy efficiency. However, as the results reported in Tables 1 and 2 show, some degree of rebound effect occurs in all cases.

If we have a rebound effect, this means that there is a fall in energy consumption in response to an increase in energy efficiency, but this is less than proportionate. For example, where energy efficiency increases by 5%, we would expect the direct (engineering) efficiency effect – effect (i) above - to be a 5% decrease in energy consumption. However, if the change in the effective and/or actual price of energy triggers substitution, output/competitiveness, composition and/or income effects (effects (ii)-(v) above, which all act to increase energy consumption) we would expect to see a decrease in energy consumption that is less than 5%. If, for example, energy consumption only falls by 2.5%, we have 50% rebound. However, if there is sufficient price responsiveness in the system (through direct and indirect, or derived, internal and external – or local and export - demands for energy) coupled with features such as the direct and/or indirect energy intensity of the sector targeted with shock, the increase in energy consumption may act to more than fully offset any pure efficiency gains. This would give us backfire effects (rebound effects of more than 100%), with a consequent increase in energy-related emissions generation at the economy-wide level. As noted above, the strength of rebound effects is governed by the direct and indirect/derived elasticities of demand for energy throughout the economic system, as well as features such as direct and indirect energy intensities, openness to trade, elasticity of supply of factors of production etc.

Tables 2.1 below shows the short and long run (equating, respectively, to the first year after the shock is introduced and the point at which the economy is full adjusted) impacts on GDP, economy-wide CO2 and, the CO2 intensity of Scottish production. Table 2.2 indicates the presence of rebound and disinvestment effects.

Table 2.1- Short and Long Run Impacts on GDP and CO_2 from a 5% Increase in Energy Efficiency in Each Sector of the Scottish Economy

Production Sector	Short Run GDP	Long Run GDP	Short Run CO2	Long Run CO2	Short Run CO2/Y	Long Run CO2/Y
Agriculture	0.00	0.01	-0.03	-0.03	-0.03	-0.03
Forestry Planting and Logging	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Sea Fishing	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Fish Farming	0.00	0.00	0.00	0.00	0.00	0.00
Other Mining and Quarring	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Oil and Gas Extraction	0.00	0.00	0.00	0.00	0.00	0.00
Mfr Food Drink and Tobacco	0.00	0.02	-0.04	-0.04	-0.04	-0.05
Mfr Textiles and Clothing	0.00	0.00	0.00	-0.01	0.00	-0.01
Mfr Chemicals	0.00	0.02	-0.03	-0.02	-0.03	-0.04
Mfr Metal and Non-metal goods	0.00	0.01	-0.02	-0.02	-0.02	-0.04
Mfr Transport and other machinery	0.00	0.02	-0.02	-0.03	-0.02	-0.04
Other Manufacturing	0.00	0.01	-0.03	-0.03	-0.03	-0.04
Water	0.00	0.00	0.00	0.00	0.00	0.00
Construction	0.00	0.03	-0.04	-0.02	-0.04	-0.05
Distribution	0.01	0.10	-0.09	-0.06	-0.10	-0.16
Transport	0.00	0.02	-0.11	-0.11	-0.12	-0.13
Communications, business and finance	0.00	0.03	-0.10	-0.10	-0.10	-0.13
R&D	0.00	0.00	0.00	0.00	0.00	0.00
Education	0.00	0.01	-0.02	-0.02	-0.02	-0.03
Public and Other Services	0.01	0.02	-0.25	-0.31	-0.26	-0.33
Coal (Extraciton)	0.01	0.10	-0.09	-0.06	-0.10	-0.16
Oil (Refining and distr oil and nuclear)	0.00	0.01	-0.02	-0.02	-0.02	-0.02
Gas	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Electricitity-Renewable	0.00	0.05	-0.01	0.07	-0.01	0.02
Electricity- Non-renewable	0.02	0.52	-0.17	1.18	-0.19	1.29

Table 2.2 – Short and Long Run Rebound Effects from a 5% Energy Efficiency Improvement Targeted at Each Sector of the Economy

Production Sector	Electricity Rebound (%)		Non- Electricity Rebound (%)		Disinvestment in	
	Short Run %	Long Run %	Short Run %	Long run %	Electricity Sectors	Non- Electricity Energy Sectors
Agriculture	36.4	37.6	34.5	36.0	✓	✓
Forestry Planting and Logging	31.7	47.8	34.0	37.6	✓	✓
Sea Fishing	7.3	323.8	37.1	47.3	X	✓
Fish Farming	33.0	43.5	33.5	46.9	✓	✓
Other Mining and Quarring	35.0	30.3	34.3	31.1	✓	✓
Oil and Gas Extraction	31.7	27.2	16.5	13.1	✓	✓
Mfr Food Drink and Tobacco	35.6	39.3	33.5	40.8	✓	✓
Mfr Textiles and Clothing	43.2	41.5	42.1	39.4	✓	✓
Mfr Chemicals	49.7	54.6	48.0	55.3	✓	✓
Mfr Metal and Non-metal goods	46.9	46.3	43.5	42.2	✓	✓
Mfr Transport and other machinery	36.4	31.6	28.9	13.2	✓	✓
Other Manufacturing	41.4	38.9	36.8	34.3	✓	✓
Water	53.7	53.8	60.6	64.0	✓	✓
Construction	31.9	93.2	30.6	78.8	X	✓
Distribution	46.7	55.6	31.6	59.7	✓	✓
Transport	34.9	44.4	34.9	44.4	✓	✓
Communications, business and finance	34.5	35.0	32.2	32.9	✓	✓
R&D	37.6	27.6	28.3	7.3	✓	✓
Education	39.2	35.9	23.6	18.1	✓	✓
Public and Other Services	36.6	25.9	30.6	18.7	✓	✓
Coal (Extraction)	35.8	36.5	35.3	35.7	✓	X
Oil (Refining and distr oil and nuclear)	45.3	65.8	46.6	65.8	✓	✓
Gas	52.2	89.6	46.3	53.8	✓	X
Electricity-Renewable	81.0	194.3	29.1	807.3	X	X
Electricity- Non-renewable	96.5	263.5	80.9	253.3	X	X
All Sectors 1-25	92.4	93.6	96.0	97.7	✓	✓

An increase in any type of efficiency generally manifests as a positive supply shock, which will lower the unemployment rate, increase wages and have a positive impact on Scottish economic activity (represented at the aggregate level by GDP) that is greater in the long run (with boosted activity in all sectors of the economy). However, as reflected in Table 2.1, the extent of the positive economics effect, and the nature, magnitude and direction of effects on environmental indicator variables depends on the type of activity targeted with the efficiency improvement. Generally, the more energy-intensive the sector, the greater the more important the improvement in energy efficiency will be. However, the extent to which even a very energy-intensive sector will be boosted, and the strength of the consequent ripple (multiplier) effects throughout the economy, will be determined by the responsiveness of the system (including external, or export demands) to the improvement in its productivity and competitiveness.

If any one of the 23 non-electricity sectors (i.e. Sectors 1-23 identified in Table 1.1 in Section 1 above) is the recipient of the 5% improvement in energy efficiency, the long run result is an increase in GDP over and above the baseline, with an accompanying reduction in CO2 emissions as energy consumption contracts to some extent (the universal presence of rebound effects in Table 2.2 shows that the pure efficiency effect is offset to some degree in all cases). Therefore the CO2 intensity of Scottish production falls if any one of these 23 sectors is targeted with the shock. However, it is important to examine the component changes in GDP and CO2 in determining where efficiency improvements would best be targeted. It is also important to note that in all 23 cases, the positive impacts on GDP and CO2 generation are accompanied by disinvestment effects leading to a contraction in capacity in some or all of the Scottish energy supply sectors.

Net increases in energy consumption and backfire effects are observed in three cases: where the increase in energy efficiency is directed at Sea Fishing (only in the case of electricity consumption), Renewable Electricity or Non-Renewable Electricity. These cases are likely to be of particular interest because the increased energy consumption in response to increased energy efficiency will lead to increases in the level of Scottish CO2 emissions (though, in the case of Sea Fishing, this is offset by reductions in CO2 generation from non-electricity energy consumption). It is useful to look more closely at the cases where backfire is observed as the nature of this effect is quite different in each of the three cases.

Backfire in the Non-renewable Electricity sector follows the patterns expected in the existing literature. This is the most directly energy-intensive production sector and, in our 1999 database, accounts for around 25% of total electricity use and around 20% of total non-electricity energy use in the Scottish economy. It is also a relatively heavily traded sector and we assume here that export demand is highly responsive to the drop in price for what is a relatively homogenous commodity. That is, there are strong competitiveness effects when energy efficiency improves in this sector. Table 2.1 above and Figures 2.1 and 2.2 below show that, while there is a significant positive impact on GDP (0.5% over the long run – the largest of all of the 25 sectoral cases), the proportionate increases in all types of energy consumption at the economy-wide level are much bigger (2.1% for electricity and 1.6% for non-electricity energy consumption), with a resulting negative impact on all the key ‘sustainability’ indicators reported.

Figure 2.1 Impact of a 5% increase in energy efficiency in the Non- Renewable Electricity Sector on Environmental Indicators

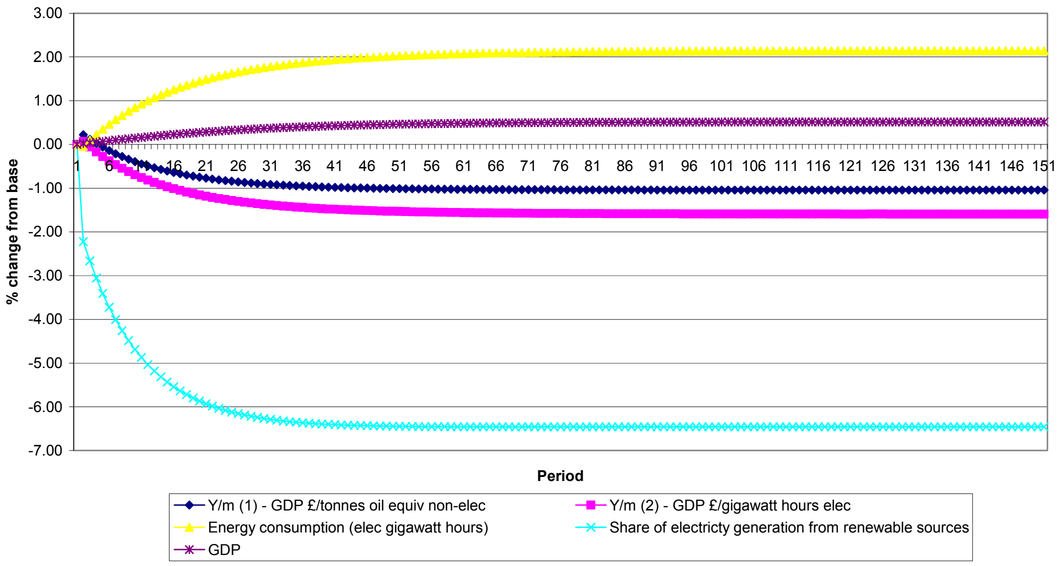
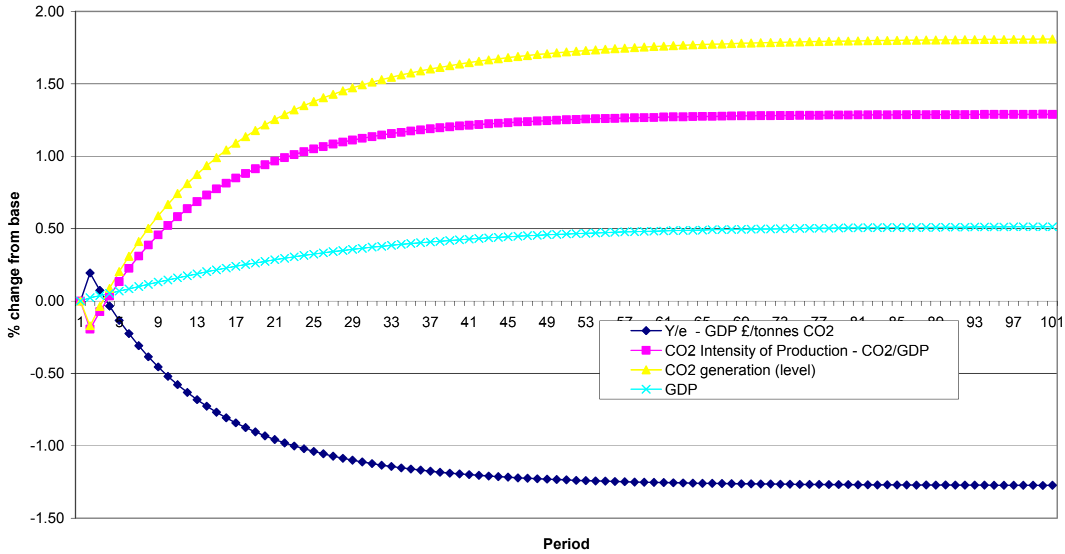


Figure 2.2 Impact of a 5% increase in energy efficiency in the Non-Renewable Electricity Sector on Environmental Indicators



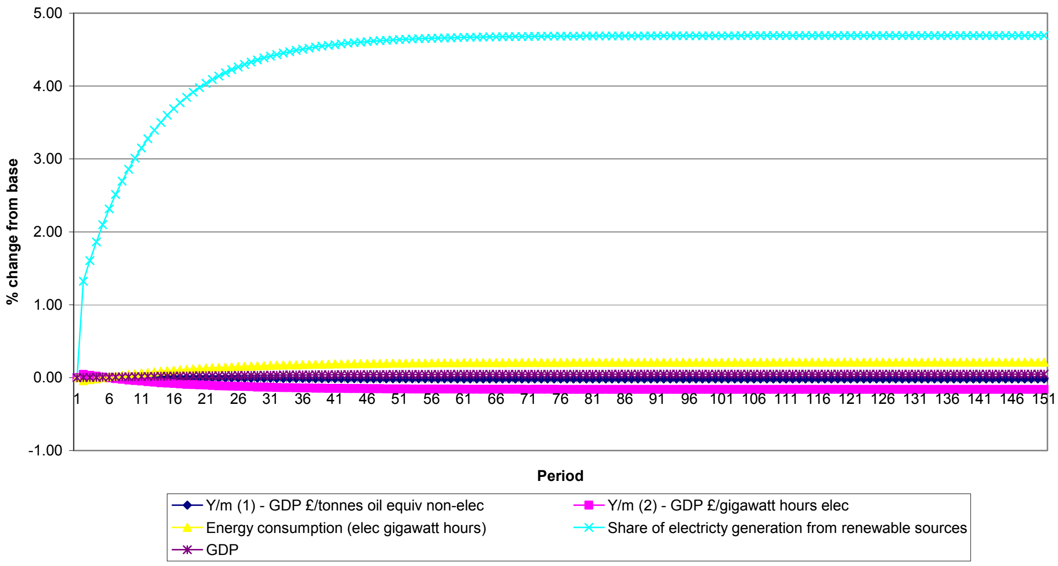
In the case of Renewable Electricity, on the other hand, while the backfire results in Table 2.1 are also very large, while this sector is as open to trade as the Non-renewable sector, it is much less energy intensive, with the implication that the impact on its output price and the consequent positive competitiveness effects will be smaller. Figures 2.3 and 2.4 show that, while both types of energy consumption rise over the long run - by 0.2% for electricity and 0.07% for non-electricity – these increases are much smaller than in the case of Non-Renewable Electricity, with the large backfire effect driven by the fact that such a small share of energy use is directly affected by the shock.[2] However, Table 2.1 shows that the impacts on GDP, CO2 and the CO2 intensity of Scottish production are much smaller when the shock is targeted at the Renewable sector. Thus, there is a trade-off to be considered - both positive economic and negative environmental effects

[2] the rebound effect should be calculated as: $R = \left[1 + \frac{\dot{E}_T}{\alpha\rho}\right] \times 100$,

where E_T is total energy use and α is the share of total energy use affected by the efficiency improvement.

are smaller. However, there are a wide range of variables to be taken into account; for example when the Renewable Electricity sector is targeted, there is a fairly rapid and significant increase in the share of electricity generated from renewable sources (see Figure 2.3), but this is assuming no constraints on the growth of this sector in response to the positive supply stimulus.

Figure 2.3-Impact of a 5% increase in energy efficiency in the Renewbale Electricity Sector on Key Indicators



The Sea Fishing sector is an interesting case. This is the least electricity-intensive sector in the Scottish economy. Table 2.2 shows that here we observe the smallest electricity rebound effect in the short-run, but the biggest long-run backfire effect (bigger even than in the electricity sectors). Again, the changes in energy consumption underlying this dramatic result are very small in the case examined here. Electricity consumption in the Sea Fishing sector itself falls in response to the increase in efficiency, but there is a small increase in aggregate electricity consumption of 0.0008% (over the long-run). This is mainly driven by increases in imported and domestic electricity used by the 'Transport' and 'Textiles and Clothing' sectors, both of which are direct intermediate suppliers of inputs to the 'Sea Fishing' sector. The increase in aggregate energy consumption is small but the efficiency shock is applied to a very small share of total energy use. This means that there is in fact a sizeable backfire effect in terms of electricity consumption (323.8% over the long run) even though the shock is limited to the least (directly) electricity intensive production sector in the economy. This demonstrates why a general equilibrium framework is essential in assessing the nature and scope of rebound effects, even when improvements in energy efficiency are focussed in a single sector/activity.

In summary, the results of the simulations in this section suggest that improvements in energy efficiency will always give rise to some extent of rebound effects (this will be the case if there is any degree of direct and/or indirect price responsiveness in the system to falling energy prices) but that in most cases there will be a reduction in the level of CO2 emissions at the economy-wide level and a reduction in the CO2 intensity of GDP. However, the more directly or indirectly energy-intensive the sector targeted with efficiency improvements is, the more its competitiveness will increase, and greater the degree of price responsiveness to this, the more likely we are to observe backfire effects and increases in CO2 emissions. A crucial point, though, is to be aware of the assumptions underlying the analysis reported here. In the absence of econometric evidence to inform specification of key parameters in our model, we have adopted a common assumption from the CGE literature that elasticities of substitution in production (i.e. the ease with which producers can switch between different types of inputs in response to a change in relative prices) are relatively inelastic (i.e. for an X% change in relative prices, intermediate demand will change by less than X%). These are set at 0/3 in most, but not all, cases (see Hanley et al, 2008 and Turner, 2008a, for details). However, as Turner (2008a) shows, as price responsiveness increases in any part of the system, rebound and other economic and environmental effects will also increase.

It is out with the scope of the current project to carry out a systematic sensitivity analysis of the results reported in Tables 2.1 and 2.2 to the specification of key parameter values. However, initial (as yet unpublished) results for another project have involved extending the simulation work for the commercial Transport sector (the base simulation for which is reported in Tables 2.1 and 2.2).[3] This analysis focuses on rebound effects for the key energy input of oil, and suggests that if only one parameter, representing the substitutability of energy and non-energy intermediate inputs to production in the Transport sector is raised from the current value of 0.3 to 1 (i.e. unitary elasticity of demand – the relative price of energy falls by X%, intermediate demand rises by X%), we get rebound effects of around 100% (and all disinvestment effects disappear). If we raise it any further we get backfire (energy consumption and emissions rise). Similar changes would be expected if we were to increase the responsiveness of different elements of direct and derived energy demands to changes in prices in any one of the sectors for which results are reported here. This conclusion emphasises the need to improve the modelling infrastructure for Scotland, with attention to, and availability of appropriate data for the econometric estimation of key energy demand relationships.

Labour productivity

Another stream of ongoing work by the energy modelling team (under the ESRC First Grants Initiative project) involves examining the impacts of increasing labour rather than energy efficiency. We are currently at a very early stage in running and analysing simulation results. Nonetheless, the initial results may be of some interest. As with the energy efficiency simulations, we introduce a 5% increase in productivity, but this time the technological progress is labour augmenting. Table 2.3 shows results for the short and long run changes in GDP, CO2 and the CO2 intensity of production at the economy-wide level when the labour efficiency improvement is introduced to each sector. These results are comparable with those in Table 2.2

[3] This work was carried out with Sam Anson, an Economic Adviser with the Scottish Government, and student on our MSc in Economic Management and Policy, for his dissertation in the summer of 2008. We hope to extend this analysis in a co-authored paper in the near future.

Table 2.3 Short and Long Run Impacts on GDP and CO2 from a 5% Increase in Labour Efficiency in Each Sector of the Scottish Economy

Production Sector	**Short Run GDP**	**Long Run GDP**	**Short Run CO2**	**Long Run CO2**	**Short Run CO2/Y**	**Long Run CO2/Y**
Agriculture	0.018%	0.035%	0.01%	0.03%	-0.01%	0.00%
Forestry Planting and Logging	0.005%	0.015%	0.00%	0.01%	0.00%	0.00%
Sea Fishing	0.007%	-0.035%	-0.14%	-0.09%	-0.14%	-0.06%
Fish Farming	0.005%	0.028%	0.00%	0.02%	0.00%	-0.01%
Other Mining and Quarring	0.005%	0.014%	0.00%	0.01%	0.00%	0.00%
Oil and Gas Extraction	0.031%	0.179%	0.02%	0.13%	-0.02%	-0.05%
Mfr Food Drink and Tobacco	0.062%	0.247%	0.04%	0.21%	-0.03%	-0.04%
Mfr Textiles and Clothing	0.029%	0.050%	0.01%	0.03%	-0.02%	-0.02%
Mfr Chemicals	0.025%	0.075%	0.02%	0.08%	-0.01%	0.00%
Mfr Metal and Non-metal goods	0.078%	0.147%	0.05%	0.14%	-0.02%	-0.01%
Mfr Transport and other machinery	0.142%	0.313%	0.02%	0.14%	-0.12%	-0.17%
Other Manufacturing	0.060%	0.120%	0.03%	0.10%	-0.03%	-0.02%
Water	0.006%	0.017%	0.01%	0.02%	0.00%	0.00%
Construction	0.147%	1.542%	0.04%	1.61%	-0.11%	0.07%
Distribution	0.446%	1.392%	0.31%	1.39%	-0.14%	-0.01%
Transport	0.164%	0.481%	0.08%	0.35%	-0.08%	-0.03%
Communications, business and finance	0.390%	1.123%	0.15%	0.88%	-0.24%	-0.24%
R&D	0.006%	0.006%	0.00%	0.00%	0.00%	0.00%
Education	0.158%	0.354%	0.03%	0.27%	-0.12%	-0.09%
Public and Other Services	0.464%	0.638%	0.13%	-0.33%	0.39%	-0.24%
Coal (Extraciton)	0.002%	0.002%	0.00%	0.00%	0.00%	0.00%
Oil (Refining and distr oil and nuclear)	0.003%	0.011%	0.01%	0.02%	0.01%	0.01%
Gas	0.004%	0.012%	0.00%	0.01%	0.00%	0.00%
Electricitity-Renewable	0.002%	0.016%	0.00%	0.03%	0.00%	0.02%
Electricity- Non-renewable	0.018%	0.166%	0.22%	0.85%	0.20%	0.68%

The first point to note is that the GDP effects are significantly bigger in Table 2.3, with the exception of the cases where efficiency improvements are introduced to the Electricity sectors. This is largely explained by the fact that labour is a more important input to production than energy in most sectors. In most cases, the absolute level of CO2 emissions increases. However, in a number of cases the greater growth in GDP in the labour efficiency shocks brings with it a bigger long run decrease, or smaller increase, in the CO2 intensity of Scottish production. For example, if the efficiency improvement is directed at the Communications, Business and Finance sector (which contains a number of the key sectors identified in the Scottish Government Economic Strategy), the long run decline in the CO2 intensity of Scottish production is 0.24% with the labour efficiency improvement, compared with 0.13% in Table 2.1 (energy efficiency). When efficiency improvements are directed at the Non Renewable Electricity sector, the increase in the CO2 intensity of Scottish production is 0.68% when this takes the form of an increase in labour productivity compared with 1.29% for energy efficiency.

However, it is important to bear in mind that improved labour productivity does increase CO2 emissions in most cases. The exceptions are where the efficiency improvement is aimed at Sea Fishing and Public and Other Services sectors (at least over the long run). Generally, over the long run, if all sectors experience a 5% improvement in either labour or energy efficiency, our initial results suggest that improved labour productivity gives better aggregate results in terms of GDP and the CO2 intensity of Scottish production, but not levels of CO2 production. However, if we focus the shock only on energy use sectors (i.e. omit the five energy supply sectors), the results are mixed in terms of the CO2 intensity of production and the larger increases in GDP from improving labour productivity need to be set against larger increases in Scottish CO2 production. However, again some initial sensitivity analyses suggest that if we make it easer to substitute between different types of input in production (including labour and energy), the results in terms of the CO2 intensity of production become more favourable for labour productivity and less so for energy efficiency. Therefore, further research is required. Nonetheless, the initial results presented here will hopefully stimulate discussion and consideration of potential positive and negative spillover effects of existing labour productivity policies and objectives to addressing the problem of climate change.

3. Simulation results: impacts of demographic change

In this section, we extend previous work done at the Fraser of Allander Institute on the impact of demographic change on the Scottish economy. In recent work for the Scottish Executive, colleagues at the University of Strathclyde examined the economic impact of demographic change on the Scottish economy, through linking a demographic model with the AMOS CGE model for Scotland. Their findings and results are discussed in Lisenkova *et al*. (2008).

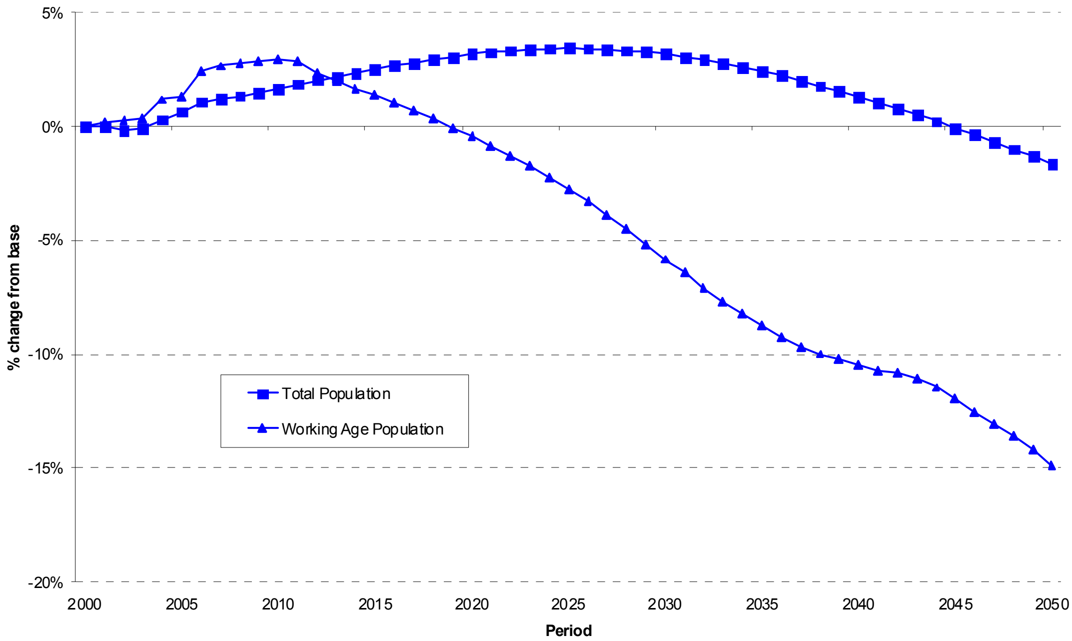
We extend this analysis by using the AMOSENVI model, rather than the AMOS model, for a set of anticipated changes to the Scottish total and working age population consistent to those modelled in this previous work. The AMOSENVI model has a more sophisticated treatment of energy inputs and a set of linked environmental accounts for Scotland. This provides considerably more detail on the relationship between economic activity in Scotland and energy and environmental impacts, and allows us to construct and report environmental and sustainability indicators. An earlier variant of the AMOSENVI model was used to examine the economic and environmental impacts of population change in the Jersey economy (see Learmonth et al, 2007).

The earlier work for Scotland (Lisenkova *et al*., 2008) found that forecasted changes to the level and age structure of the population of Scotland will produce significant impacts upon the Scottish labour market, and the competitiveness of Scottish industries, which will include energy industries. Changes in the size of total Scottish output, the composition of that output across industries and the structure of production within industries will have impacts on energy demand and environmental impacts, including on emissions. In this note, we explore these impacts of anticipated population change using the AMOSENVI CGE model.

The AMOSENVI model is currently calibrated for a base year of 1999. Colleagues in the Fraser of Allander Institute have estimated a number of alternative projections for the Scottish population from 2000 to 2050. These use the same assumptions for key demographic parameters as are used by the Government Actuaries Department (GAD) in their projections, but allow us to make annual projections, and create alternative projections, annually to 2050. For the simulations reported in this chapter, we therefore assume that our models base year of 1999 also represents the Scottish economy in the year 2000.

The demographic changes estimated by our colleagues are used as the exogenous disturbances in the model simulations which follow. The population scenarios used therefore differ slightly from those produced by the General Registers Office for Scotland (GROS). We use a scenario of net migration to Scotland of 5000 per year as our "Central" projection.[4] This is similar, although not identical, to the assumed rate of net migration in the "Principal Projection" for the Scottish population used by GROS. Assumed changes in the total and working age population for Scotland from 2000 to 2050 under our "Central" scenario are shown in Figure 3.1.

Figure 3.1: Percentage changes from base year for working age and total population under "Central" projection



In 2050, under our "Central" scenario, total Scottish population is 1.7% lower than in 2000, however this is a significantly older population than in 2000, with the working age population down 14.9%.

We follow the method employed in Lisenkova *et al*. (2008) in estimating the impact on Scotland of population decline and ageing. The fall in working age population will cause the labour supply to contract at any given real wage rate. As the model is currently configured, we enter the changes in the labour force by means of a linear trend between 2000 and 2050, so that the change in the working age population over the 50 years is modelled as a linear reduction.

On the demand side, we assume that real per capita government expenditure remains constant, so that the level of government spending changes with the size of the Scottish total population. We would argue that this assumption is realistic since Government expenditure in Scotland is mainly financed through the Westminster Parliament and the experience of the Barnett formula over recent years is that per capita Government expenditure figures for Scotland have remained fixed relative to the level in England. Any changes in the composition of government and household consumption demand which occur because of demographic changes described above are not considered in this analysis. The results presented here will be driven by general demand side

[4] The most recent GROS figures for their "Principle" scenario assumed a net migration of 8500 p.a. Details of the differences between the scenarios presented here and the GROS projections can be found in Lisenkova et al. (2008) and Lisenkova et al. (forthcoming).

factors, such as movements between public and private consumption as population structure changes, as well as supply-side factors operating through the tightening of the Scottish labour market and the impact of this on the competitiveness of individual sectors.

Our central scenario takes the demographic data presented in Figure 3.1 and converts these to shocks introduced to the model in the form of disturbances to labour demand and supply. We assume regional wage bargaining in this scenario (as in the energy efficiency simulations in Section 2). As in all the other simulations reported here, we examine the impacts of the demographic and population changes (with constant per capita government spending) in isolation. That is, our results are changes relative to a base where nothing else changes (our simulations are not forecasts – i.e. the economy may be expected to grow due to other drivers, such as increased productivity, during our simulation period). The aggregate results are shown in Table 3.1

Table 3.1: Percentage change of aggregate economic and demographic variables under the central projection, bargaining labour market closure

	2000	2005	2010	2020	2030	2040	2050
GDP	0.00	-0.41	-0.99	-2.60	-4.59	-6.88	-9.30
Real Wage	0.00	0.95	1.90	3.69	5.30	6.65	7.89
Consumption	0.00	-0.21	-0.49	-1.37	-2.63	-4.25	-6.08
Working Age Population	0.00	1.29	2.91	-0.45	-5.85	-10.48	-14.91
Total Population	0.00	0.63	1.66	3.16	3.16	1.28	-1.68
Total Employment	0.00	-0.54	-1.20	-2.87	-4.94	-7.32	-9.89
Competitiveness Index	0.00	0.23	0.62	1.52	2.44	3.25	4.00
Consumer Price Index	0.00	0.18	0.48	1.16	1.83	2.40	2.93
CO_2 generation	0.00	-0.31	-0.83	-2.33	-4.26	-6.45	-8.76
CO_2 intensity of output	0.00	0.09	0.17	0.27	0.35	0.45	0.60
Electrical energy demand	0.00	-0.47	-1.21	-3.26	-5.72	-8.38	-11.10
Non-electrical energy demand	0.00	-0.31	-0.82	-2.28	-4.18	-6.34	-8.63
GDP/electrical energy demand	0.00	0.06	0.22	0.68	1.19	1.64	2.02
GDP/non-electrical energy demand	0.00	-0.10	-0.18	-0.32	-0.44	-0.57	-0.73

The results in Table 3.1 should be interpreted as variations away from what would have occurred but for the changes in total and working age population. Our key results are as follows. We find that population decline and ageing has a significant impact on the Scottish labour market, and on economic activity, as well as on energy use and environmental damage. Our central case of a 1.7% decline in total population, and 15% decline in working age population, between 2000 and 2050 produces a decline in GDP of 9.30% and a fall in CO2 generation or 8.76%. The CO2 intensity of Scottish production thus increases. Energy (both electrical and non-electrical) demands fall.

Two important points can be noted from the results in Table 3.1 Firstly, the fall in employment (9.89%) is less than the fall in working age population (14.91%). This suggests that there is an increase in the labour market participation rate, and a fall in the unemployment rate. The tightening of the Scottish labour market is clear from the 7.89% rise in real wages by 2050. Secondly, the decline in GDP closely follows the observed reduction in employment. The reduction in GDP is driven by the reduction in the labour force, and increase in real wages, causing a reduction in Scottish exports generated by the reduced competitiveness of Scottish output.

In 2050 the consumer price index is 2.93% higher, but the increase in the export price index (Competitiveness Index) is higher at 4.00%. As a consequence the demand for exported goods falls in the central projection by 7.55%. The capital stock will adjust to changes in output demand but this will occur more slowly than the change in employment in particular sectors so that the change in GDP will slightly lag the change in employment. There will also be a tendency for production to be more capital intensive given the increase in the nominal wage rate, so that there is some substitution of capital for labour.

Public consumption, e.g. by Government in Scotland, is exogenously shocked in line with total population, but private consumption, e.g. by households, is endogenous within the AMOSENVI model, and can give a useful indication of the welfare of Scottish households. By 2050, the fall in private consumption is 6.08% - less than the fall in GDP and employment. This reflects the increase in the real wage for those in employment. As in Lisenkova et al (2008), private consumption falls by more than the reduction in total population, meaning a decline in *per capita* private consumption.

Figure 3.2: Impact on sectoral output and employment, % changes from base year values by 2050

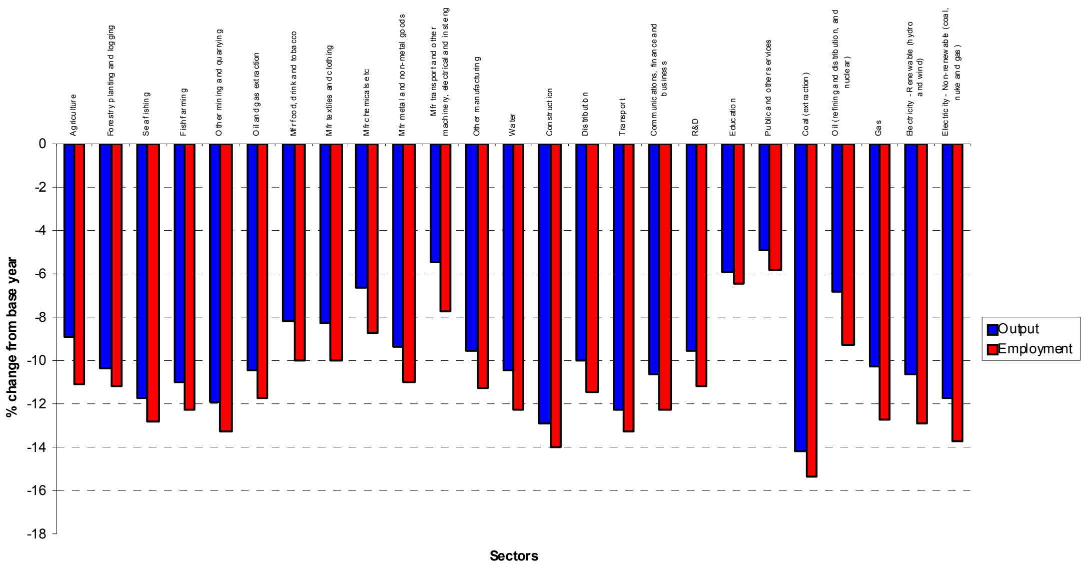
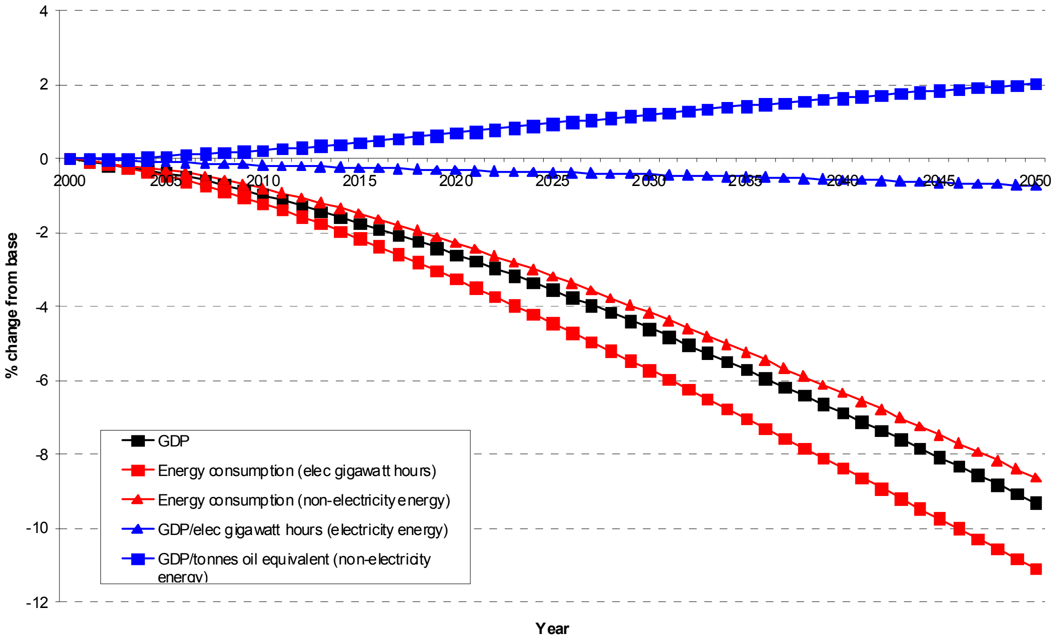


Figure 3.2 shows the impacts on sectoral outputs and employment. By 2050 the output of, and employment in, all sectors in the Scottish economy are negative affected. There is, however, wide variation in the impacts across sectors, with the output of ‘Education’ and ‘Public and Other Services’ sectors falling by 5.9% and 4.9%, while ‘Coal Extraction’ and ‘Construction’ see a decline in output by 2050 of 14.2% and 12.9% respectively. The sectors in which government demand is concentrated in the base year IO – ‘Education’ and ‘Public and Other Services’ – are least affected since government expenditure *per capita* remains constant over the period simulated, and in total falls by 1.68% by 2050 (in line with the fall in total population). The other main sector of (in the Scottish Government Economic Strategy) that suffers a relatively large decline in output is the Communications, Finance and Business (CFB) sector, which incorporates that the finance and business and ‘creative industries’ sectors. The CFB sector suffers a decline in output of just over 12% by 2050, and a slightly smaller drop in employment.

The extent of the negative impact upon other sectors is determined by two factors. Firstly, labour intensive sectors are worst affected because of the now increased cost of labour. Second, the sectors which are more exposed to international trade feel the negative effects on competitiveness more strongly. For example, sectors such as ‘Sea Fishing’, ‘Fish Farming’, ‘Oil and Gas Extraction’, ‘Chemicals’ and ‘Transport and Other Machinery’ suffer these negative export competitiveness effects, with each of these sectors having exports constituting more than 80 per cent of sectoral output in the base year data set. ‘Sea Fishing’, which is the most export intensive sector, sees the biggest decline in output of these sectors because is it also the most labour intensive.

Changes in the energy and environmental indicators can be seen in Figure 3.3. Looking firstly at GDP, we can see that under the central simulation for the change in total and working age population, GDP reduces by 9.30% per cent by 2050. As observed above, the output of each sector contracts by 2050 as competitiveness suffers, particularly for export- and labour-intensive sectors. The level of energy demands also fall as output declines. Electrical energy consumption (measured in GWh) and non-electrical energy consumption (measured in tonnes oil equivalent) fall by 11.09% and 8.63% respectively.

Figure 3.3: Energy indicators, % changes from base year under the central population projection, bargaining labour market closure



The other indicators of sustainability, in figure 3.3, show mixed results. These two measures relate the amount of energy consumption divided by GDP, and use electrical energy and non-electrical energy as the respective numerator. Note in these measures that GDP is the numerator, rather than the denominator as in the 'CO2 intensity of Scottish production' measure. A positive change in these indicators therefore indicates a positive movement in sustainability of economic activity, while a negative change indicates the opposite. As mentioned above the fall in electrical energy consumption is greater than the fall in GDP, and so the GDP/electrical energy consumption indicator moves in a positive direction, indicating greater sustainability. On the second measure, the fall in non-electrical energy consumption is less than the falls in GDP, and so on this indicator, there is a negative movement showing a fall in sustainability.

Figure 3.4: CO_2 emissions and CO_2 intensity of production indicator, % changes from base year under the central population projection, bargaining labour market closure

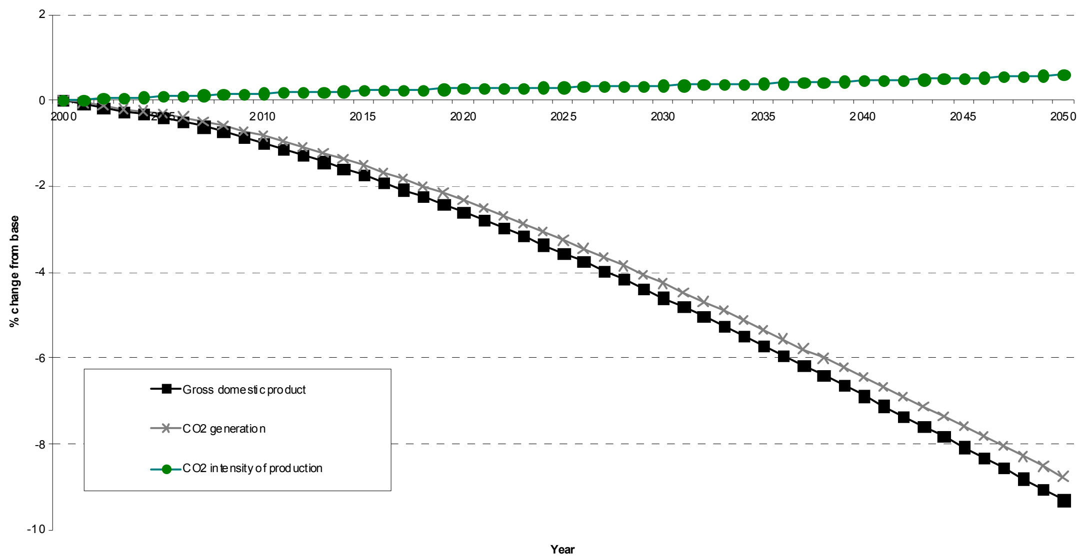
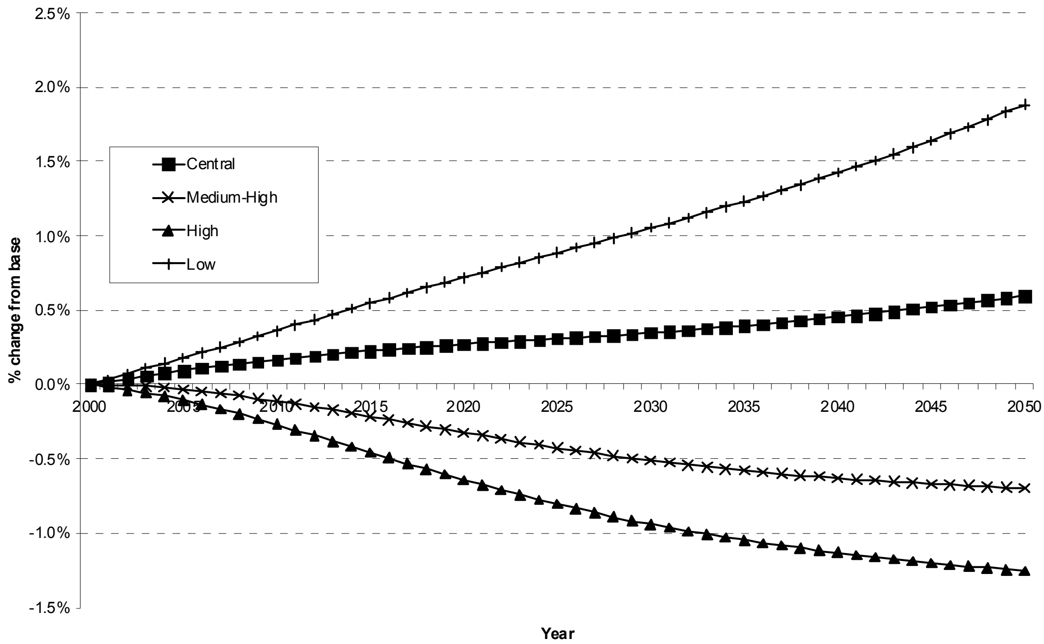


Figure 3.4 shows the changes in GDP and CO_2 emissions as well as the CO2 intensity of Scottish production. Emissions of CO2 are 8.76% lower by 2050, a smaller fall than the decline in GDP. This means that the CO2 intensity of production – defined as CO2 emissions divided by GDP output (£million) – shows a small increase, i.e. consistent with decreasing sustainability of output. The carbon intensity of Scottish output is rising; however this is due to the greater relative decline in output than decline in CO2 emissions by 2050.

Detailed sensitivity analysis of these results to alternative population scenarios, labour market structure and key parameter values are reported in Technical Appendix 3. The key result arising from these sensitivity analyses is that if we assume higher values for net migration to Scotland the economic impact of ageing can become positive. While this will tend to increase CO2 emissions, a faster rate of GDP growth (as labour market conditions ease) means that the CO2 intensity of Scottish production falls. Figure 3.5 shows the impacts on the CO2 intensity of Scottish production under 3 alternative population scenarios: the "High" scenario revised the rate of net migration up from 5000 per year (central case) to 30000; "Medium-High" to 20000; and "Low" retains the assumption of 5000 in-migration per year but lowers the birth rate from 1.65 to 1.45 births per woman. Figure 3.5 shows that under the Medium-High and High scenarios (increased migration) the qualitative impact of population change on the CO2 intensity of Scottish production becomes positive (i.e. the value of this indicator falls over the period modelled).

Figure 3.5: Trends in CO_2 intensity of production indicator under "Central", "Medium-High", "High" and "Low" population scenarios



However, it is important to bear in mind that under these two scenarios both GDP and the level of total CO2 emissions generated in Scotland rise – see Figures 3.6 and 3.7 below.

Figure 3.6: Trends of Gross Domestic Product for "Central", "Medium-High", "High" and "Low" population scenarios

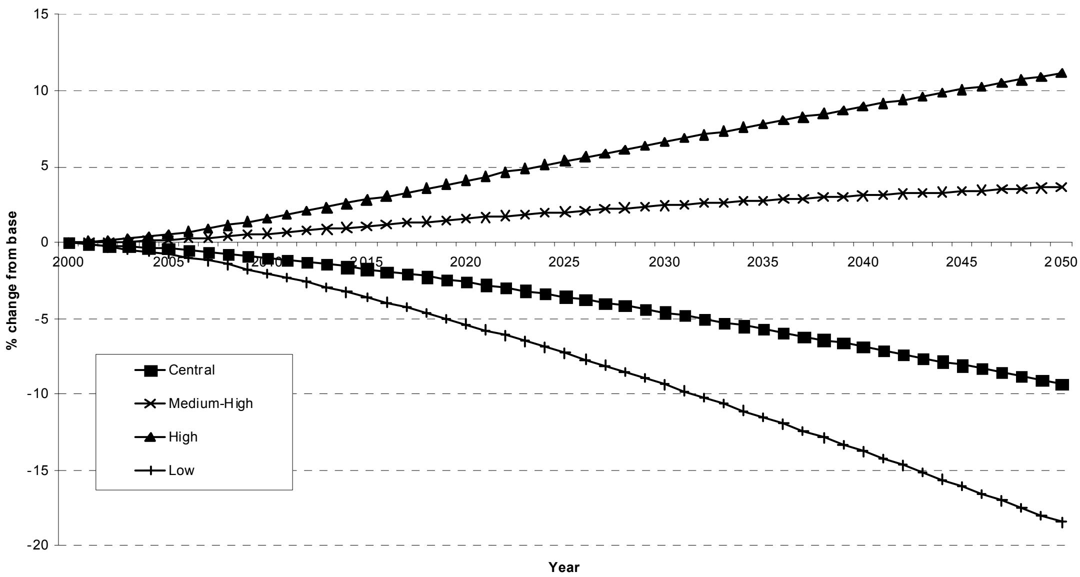
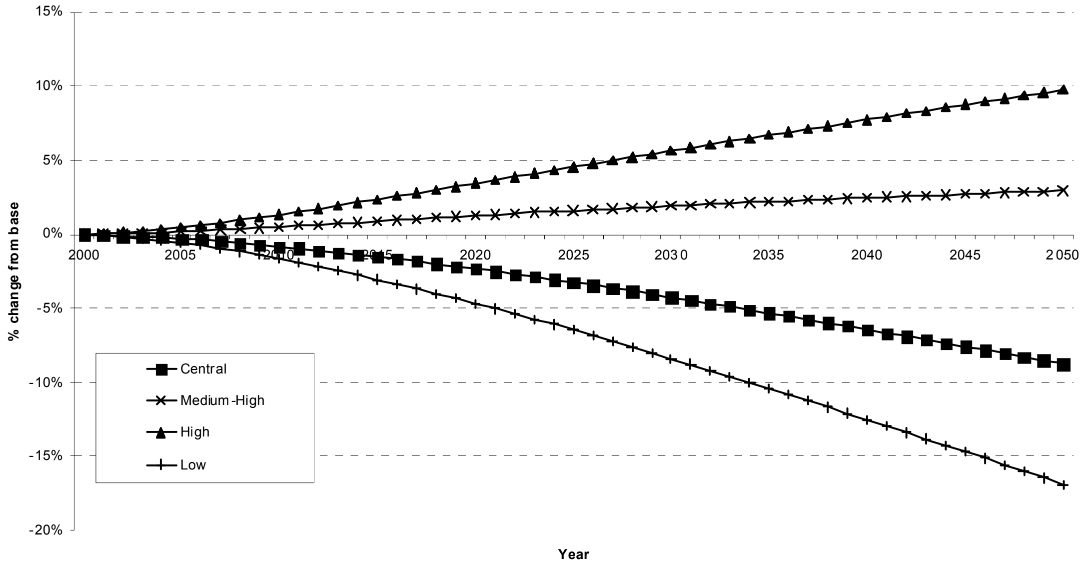


Figure 3.7: Trends in CO_2 generation under "Central", "Medium-High", "High" and "Low" population scenarios



The only other case where we find a reversal of the impact of population change on the CO2 intensity of production is where we increase the substitutability between labour and capital. Increasing the value of this parameter means that we ease the pressure on the labour market, leading to smaller impacts on GDP. We find that as we raise the value of this parameter from 0.3 in the central case to 1 and over, the decline in CO2 generation overtakes the decline in GDP and, therefore, the CO2 intensity of Scottish production falls (see Technical Appendix 3 for more details).

4. Simulation results: costly requirements on households to reduce energy use

The next scenario we attempt to simulate focuses on the labour market effects of costly requirements on households to reduce their energy use. At present the AMOSENVI model cannot be used to simulate policies aimed at changing household energy consumption behaviour. However, it can be used to examine the likely knock-on effects of reductions in household income that are likely to occur as a result. Our simulation strategy in explained in Technical Appendix 4. In short, we simulate the economy-wide impacts of a reduction in household income (on the assumption that this may accompany/result from policy actions requiring households to reduce their energy use).

Such an approach is consistent with a mandatory requirement for households to purchase costly technologies that may reduce their energy use. There will be system-wide labour market consequences of the implied reduction in household income. The reduction in household income will lead to workers bargaining for an increased nominal wage, which will in turn reduce the competitiveness of Scottish economic activity. We would also expect there to be migration effects as, in AMOSENVI, net migration is driven by real wage and unemployment rate differentials between Scotland and the rest of the UK. A lower real (take-home) wage may induce out-migration from Scotland.

Our main result (which is qualitatively robust to sensitivity analysis) is that a reduction in real household income will lead to a reduction in the level of CO2 emissions in the Scottish economy (up to 1.81% in the long-run for a 1% decrease in real household income), and also to the CO2 intensity of Scottish Production (-0.19% where real income falls by 1%), but this is at the cost of a contraction in GDP (-1.63% in the 1% scenario). This result is qualitatively only sensitive to how we specify the labour market. However, halting the decline in GDP requires a very restrictive (and most likely quite unrealistic), specification of the Scottish labour market.

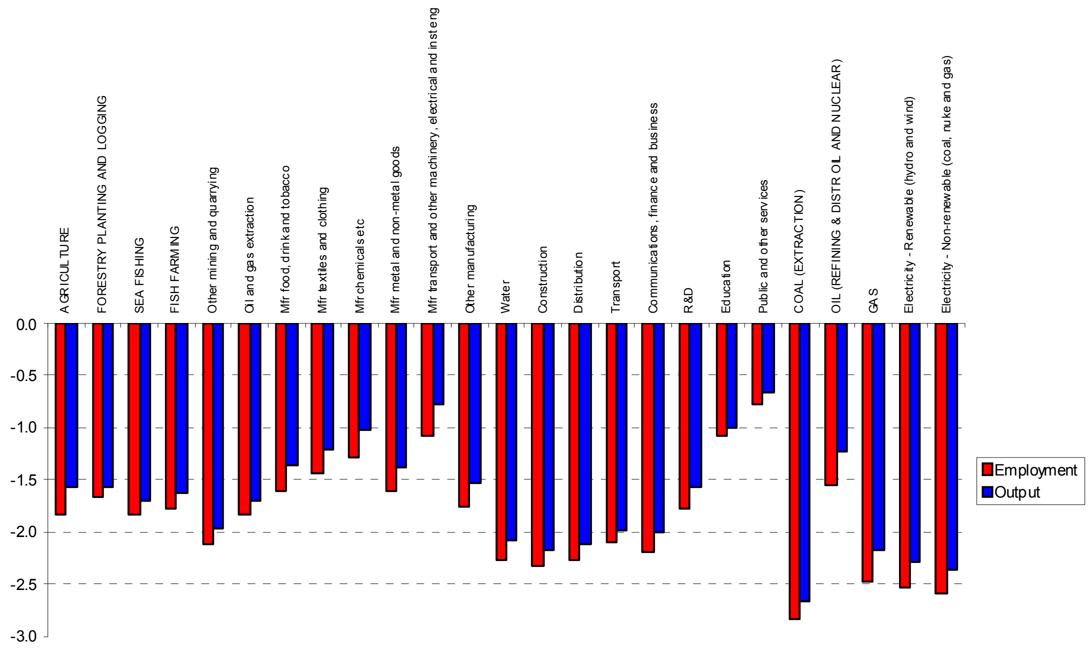
Let us examine our central case scenario more carefully. As with previous simulations, results should be interpreted as being variations away from what would have happened to economic activity and environmental impacts but for the policy that reduced household income. Table 4.1 shows the aggregate results for economic, energy and environmental from such a policy in the long-run. The long-run here is a conceptual time period over which labour and capital stocks have fully adjusted to new equilibrium levels. In AMOSENVI with migration possible, this is consistent with a time period over which the real wage and unemployment rate have been restored to their initial equilibrium values, and the capital rental rate is equalised across all sectors in the economy.

Table 4.1: Short- and long-run impacts on aggregate economic, energy and environmental indicators under a 1% decrease in household income, bargaining labour market, % changes from base year

	Short-run	**Long run**
Gross Domestic Product (GDP)	-0.23	-1.63
Consumption	-0.80	-1.80
Investment	-0.53	-1.67
Exports	-0.03	-1.14
Imports	-0.48	-0.73
Nominal (before tax) wages	0.43	1.33
Real (take home) wages	-0.35	0.00
Total Population	0.00	-1.66
Total Employment	-0.37	-1.66
Unemployment Rate	3.15	0.00
Consumer Price Index (CPI)	-0.10	0.44
CO_2 generation	-0.33	-1.81
CO_2 intensity of output	-0.11	-0.19
Electrical energy demand	-0.29	-2.20
Non-electrical energy demand	-0.35	-1.80
GDP/Electrical energy demand	0.06	0.58
GDP/Non-electrical energy demand	0.12	0.18

Table 4.1 shows that the initial decrease in household income leads to a 0.35% fall in the real wage in the short run (i.e. while capital and labour stocks are fixed). (Private) consumption is down by 0.80%, and overall GDP is lower by 0.23%. Under a bargaining labour market specification with migration from and to Scotland possible, as is used here, we would expect that this would lead to outmigration. While population is fixed in the short-run, over the long run outmigration should act to restore the real wage differential between Scotland and the rest of the UK.

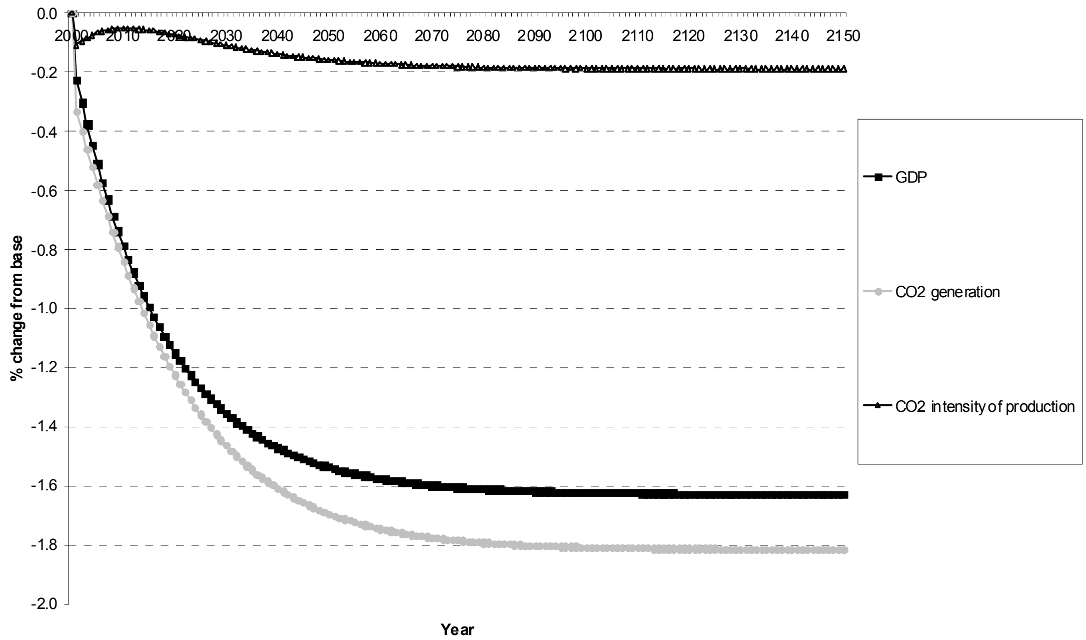
Figure 4.1: Long-run impact on sectoral output and employment, % changes from base year



By the long-run, GDP is 1.63% lower, and while real wages have risen back to their pre-shock levels, nominal wages are 1.33% higher and the CPI is higher. This has a damaging impact on employment and exports. The sectoral pattern of changes in output and employment is shown in Figure 4.1. Sectors that are labour intensive and export intensive suffer particularly badly, as (before tax) wages are higher and higher prices damage the competitiveness of output. Due to their export intensity, the energy sectors (with the exception of Oil) suffer the greatest long-run declines in output and employment. Sectors such as Communications, Finance and Business (which incorporates a number of the key sectors identified in the Government Economic Strategy), Transport and Distribution also suffer declines in output of more than 2% in the long run, along with Water and Construction.

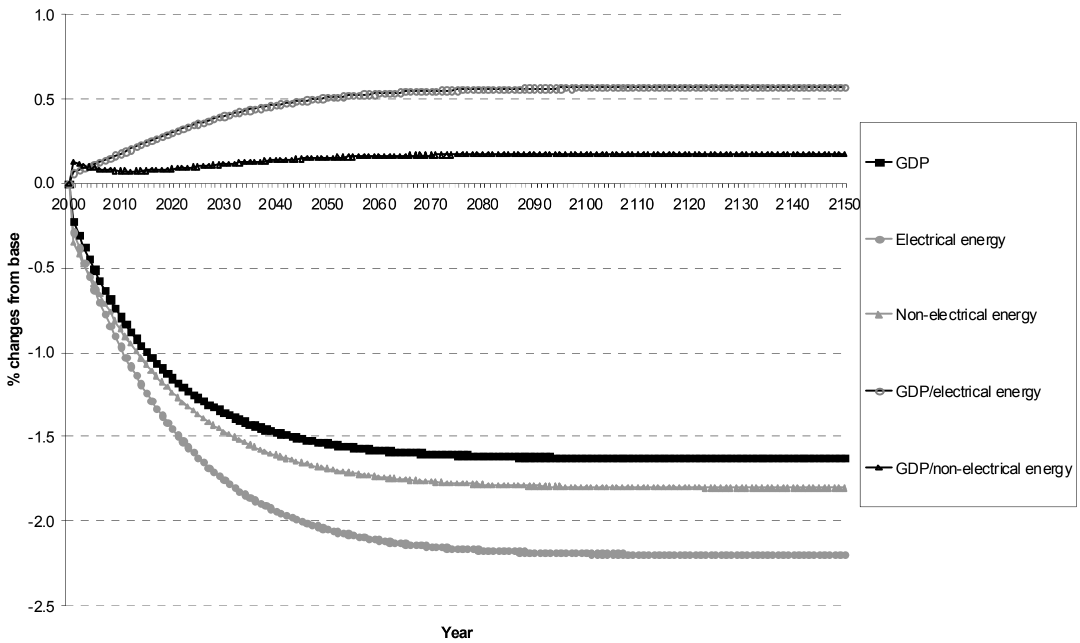
The environmental consequences of this policy are lower emissions in both the short and long-run, and the decreases in CO_2 emissions are greater than the falls in GDP. The CO_2 intensity of production thus decreases. The time path of the changes in GDP, CO_2 emissions and the sustainable prosperity measure are shown in Figure 4.2. The simulation is run over 150 periods in order that a long-run equilibrium is reached, although most of the adjustment to the long-run has occurred by period 120. The CO_2 intensity of production falls immediately and is lower again in the long-run, but does not decrease monotonically before reaching its long-run equilibrium.

Figure 4.2: GDP, CO_2 emissions and CO_2 intensity of production following a 1% decrease in household income, bargaining labour market, % changes from base



Energy demand (both electrical and non-electrical energy demands) is lower in the short- and long-run compared to the base year, with greater reductions in the long-run. The GDP/energy indicators show positive movements in sustainability, i.e. increasing GDP per unit of energy. Positive changes in this variable show greater economic output per unit of energy, and, despite total GDP being lower – both electrical and non-electrical energy use shows a greater decline. The profile of adjustment between the short-run and long-run equilibrium path for electrical and non-electrical energy demands – along with GDP and the GDP/energy indicators - is shown in Figure 4.3.

Figure 4.3: GDP, electrical energy and non-electrical energy demands following a 1% decrease in household income, bargaining labour market, % changes from base



Our sensitivity analysis of around this scenario suggests that the key driver of these results is out-migration from Scotland, due Scottish real (take-home) wages declining relative to those in the rest of the UK. Table 4.2 below shows that the effect of 'turning off' migration to examine the difference this makes to our results.

Table 4.2: Percentage changes in long-run for aggregate economic, energy and environmental indicators under 1% decrease in household income with and without migration, bargaining labour market, % change from base

	1% with migration	1% without migration
Gross Domestic Product (GDP)	-1.63	-0.66
Consumption	-1.80	-1.12
Investment	-1.67	-0.69
Exports	-1.14	-0.33
Imports	-0.73	-0.50
Nominal (before tax) wages	1.33	0.38
Real (take home) wages	0.00	-0.62
Total Population	-1.66	0.00
Total Employment	-1.66	-0.67
Unemployment Rate	0.00	5.67
Consumer Price Index (CPI)	0.44	0.13
CO_2 generation	-1.81	-0.82
CO_2 intensity of output	-0.19	-0.17
Electrical energy demand	-2.20	-0.94
Non-electrical energy demand	-1.80	-0.83
GDP/Electrical energy demand	0.58	0.28
GDP/Non-electrical energy demand	0.18	0.18

5. Simulation results: Impacts of Increasing Renewable Energy Supply 1 – Input-Output Analysis

(Sub-title: The economic and environmental impacts of alternative electricity generation technologies in Scotland: An Input-Output analysis)

Concerns about energy security and meeting environmental targets in Scotland are in the spotlight of academic, policy and public debate. As of 2000, fossil fuel (coal and gas) and nuclear technologies provided 34%, 22% and 34% respectively of the total electricity generated in Scotland. Scotland also has a history of developing electricity generation from renewable sources. A significant amount of electricity, around 9.5%, was generated by hydroelectric facilities in 2000, which were largely built in the post-WW2 years. At the same time, the last ten years have seen the development of a significant number of electricity generating facilities from other renewable sources, as well as some extension of the hydroelectric capacity. The geographical position of Scotland offers it significant renewable energy resources, including on- and off-shore wind, wave and tidal energy. A recent study for the Scottish Executive (Boehme et al, 2006) quantifies the potential scale of renewable energy resources available and extractable around Scotland. We do not seek to quantify the potential here, but to gauge the possible economic impacts of changes to the Scottish electricity generation mix.

There are likely to be significant changes to the electricity generation mix in Scotland in the coming decades. The two nuclear power stations at Hunterston B and Torness currently have lifetime licences until 2016 and 2023 respectively, while current large-scale coal facilities at Longannet and Cockenzie will come under the Large Combustion Plant Directive (LCPD) after 2015. In the case of nuclear, the Scottish Government has stated that it does not want any new nuclear facilities constructed in Scotland. The Scottish Government has also recently set out ambitious targets for renewable electricity generation. These are that by 2020, 50% of electricity generated in Scotland will come from renewable sources, with an interim target of 31% by 2011. No specific targets for any particular technology have been set for either time period, although it has been suggested that much of the renewable electricity will come from significant increases in the amount of onshore wind generation. On the other hand, recent consultations by the Scottish Government on reforms to the support for renewable energy projects have recognised the potential for Scotland to develop an indigenous marine electricity industry, and have sought to provide additional incentives through the "banding" of existing support mechanisms to the production of electricity from marine (i.e. wave and tidal) energy devices. Total electricity generated in Scotland from all renewable sources (hydro, wind, biomass, wave and landfill gas) has grown by 40 per cent between 2000 and 2006. The installed capacity of renewable energy (hydro, wind/wave, landfill gas and biomass) facilities increased over the same period from 1.4 GW to 2.4 GW. Some 0.9 GW of this increase has come from the development of wind energy projects, with an installed capacity in 2006 of 946MW, generating 2,022 GWh in 2006. [5]

This section of the report uses Input-Output (IO) techniques to examine the economic and environmental consequences of significant changes in the electricity generation mix in Scotland. The motivation in using IO rather than CGE analysis in this section is because of the availability of an IO model with a greater disaggregation of the electricity sector than is currently incorporate in AMOSENVI. However, at such a time as which we are able to incorporate such a breakdown to AMOSENVI model, it would be desirable to repeat the analysis in a more flexible CGE framework.

In the present analysis, we use the IO modelling framework to develop four scenarios for the Scottish electricity generation mix. In each of the scenarios we have developed, we assume that the total electricity generated in Scotland is the same as in 2000, and we vary the generation mix. In each of the scenarios, the Scottish Government's target of 50% of electricity from renewable sources is met, and we assume that there is no generation from nuclear generation technologies. The types of renewable technologies that contribute to the renewables target are different in each case, but the common modal renewable technology is wind generation. We model the impacts of four alternative scenarios for the electricity generation mix in Scotland (see Table 5.1 below). In

[5] Figures on the generation of electricity from different technologies in Scotland, and the capacity of renewable energy technologies, between 2000 and 2006 are given in Tables A4.1 and A4.2 of Technical Appendix 4.

each of these scenarios 50% of electricity comes from renewable energy sources, the majority of which comes from onshore wind. Further, in none of these scenarios is there any generation from nuclear sources in Scotland. None of these scenarios are referenced against expected or predicted changes in the pattern of electricity generation mix in Scotland, or make any assumptions about the costs or viability of any of the scenarios considered here – such as, for instance, whether each scenario provides sufficient generation to meet expected future demand or to provide appropriate margins between peak demands and supply capacity. We use these scenarios purely to illustrate the usefulness of the IO method for estimating the economic impact of large changes in the pattern of electricity generation. We begin by briefly sketching the features of each of the scenarios considered.

Table 5.1: Current (2000) shares of electricity generation by technology and four scenarios considered, %

	Base year (2000)	*Scenario A*	*Scenario B*	*Scenario C*	*Scenario D*
Nuclear	33.6	0.0	0.0	0.0	0.0
Coal	33.9	25.0	25.0	50.0	0.0
Hydro	9.4	15.0	15.0	15.0	15.0
Gas	22.4	25.0	25.0	0.0	50.0
Biomass	0.1	3.0	3.0	0.0	0.0
Wind	0.4	20.0	25.0	30.0	30.0
Landfill Gas	0.1	2.0	2.0	0.0	0.0
Marine	0.0	10.0	5.0	5.0	5.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Note: Shares may not sum 100% due to rounding.

Scenario A: Technology mix – high marine
Under this scenario, generation from coal falls slightly compared to its base year levels, while generation from gas technologies rises slightly. Together, these technologies provide 50% of electricity generated in Scotland under this scenario. Generation from hydroelectric facilities increases by fifty per cent, up to providing 15% of electricity generated. Biomass and landfill gas increase their contribution to the Scottish electricity generation mix, rising to provide 3% and 2% of total generation in this scenario. Marine provides 10% of electricity generation capacity, with wind providing the remaining 20%.

Scenario B: Technology mix – low marine
All technologies are assumed to provide the same share of electricity generated in Scotland under this scenario, with the exception of marine and wind. Under this scenario, the proportion of electricity generation from wind is 25%, and the proportion generated from marine sources is assumed to be 5%. Such a change from Scenario A could be consistent with a less successful outcome for marine-specific support mechanisms, in terms of bring forward marine electricity generation, with wind generation dominating.

Scenario C: No Gas
Under this scenario, 50% of electricity generated in Scotland comes from renewable sources – with wind providing 30%, and hydro and marine providing 15% and 5% of total electricity generated in Scotland respectively. The remaining 50% of electricity generation is met through coal generation, with gas generation providing 0%. Output of biomass and landfill gas falls from current levels to zero.

Scenario D: No Coal
In this final scenario, renewable technologies provide the same specific and aggregate proportions of Scottish electricity generation, but rather than coal providing the remaining 50%, this is met through gas generation. By comparing Scenario C with Scenario D, we can examine the economic and environmental impacts from coal, or gas, generation providing the non-renewable portion of future Scottish electricity generation.

Table 5.2 presents the main aggregate results on GDP, employment and CO2 emissions for each of these four scenarios.

Table 5.2: Aggregate results on GDP, employment and CO_2 emissions

		Scenario A	Scenario B	Scenario C	Scenario D
Type 1	Change in GDP (£millions)	263.24	153.69	202.43	109.42
	Change in employment (000s, FTE jobs)	24,984	13,172	13,173	11,375
	Change in CO_2 emissions, % from base year	-3.52	-3.59	0.82	-8.13
	% change in GDP	0.40	0.23	0.31	0.17
	% change in CO_2/GDP	-3.90	-3.82	0.51	-8.28
Type 2	Change in GDP (£millions)	416.41	247.78	287.91	180.11
	Change in employment (000s, FTE jobs)	29,572	15,957	15,738	13,502
	Change in CO_2 emissions, % from base year	-5.69	-5.89	-3.08	-8.86
	% change in GDP	0.63	0.38	0.44	0.27
	% change in CO_2/GDP	-6.28	-6.24	-3.50	-9.11

Recall that the only difference in Scenario A compared to Scenario B is that there are higher amounts of wind and lower amounts of marine electricity generated. In Scenario B there is 25% of electricity generation from wind and 5% from marine, while in Scenario A there is 20% of electricity from wind and 10% of electricity from marine sources. The higher amount of marine generation, combined with that sector's output multiplier being significantly higher than that for wind generation, result in a greater economic boost to Scotland than in the lower wind case. The impact of an additional 5% of electricity from marine sources, rather than from wind generation, is to increase GDP by £109.55 million, and increase employment by 11813 FTE jobs with Type 1 analysis, and, under the Type 2 IO model, to raise GDP by £168.64 million and employment by 13615 FTE jobs.

The increased economic impact, and activity, generated in Scenario A compared to Scenario B, comes at the expense of a slightly smaller decline in CO2 emissions, as is reflected in the smaller reduction in the CO2 intensity of Scottish production indicator (CO2/GDP) in Table 5.2. Under Scenario A, emissions of CO2 are 3.52% lower under Type 1 analysis, and 5.69% lower with Type 2. Under Scenario B, CO_2 emissions are down by 3.59% and 5.89% under Type 1 and Type 2 respectively. This greater decline under Scenario B is to be expected since economic activity is greater under Scenario A (due to the additional stimulus offered by the marine generation sector) and so CO2 emissions are slightly higher – although reduced relative to the base year. This is reflected in the results for the CO2 intensity of Scottish Production, which declines by 3.9% with Type 1 and 6.28% for Type 2 under Scenario A, and by slightly less, 3.82% and 6.24% respectively under Scenario B. Under Scenario C, when it is assumed that the non-renewable 50% of electricity generation in Scotland comes solely from coal generation, the GDP and employment impact is not as large as Scenario A – an additional £287.91 million on GDP and 15.738 FTE jobs under Type 2 results. The CO2 impact however is different, with Type 1 CO2 emissions actually increased relative to the base year, and an increase in the CO2 intensity of Scottish production of 0.51%. This arises due to the assumed CO2 emitting nature of coal generation technologies. The Type 2 change in CO_2 emissions shows a decline relative to the base year of 3.08% - a smaller fall in emissions than either Scenarios A or B – and a much smaller, 3.5%, decrease in the CO2 intensity of Scottish production. Under Scneario D, the smallest increased in GDP is observed (0.17% with Type 1 and 0.27% with Type 2) but the biggest Type 2 reduction in CO2 emissions (8.86%), which gives us the biggest Type 2 reduction in the CO2 intensity of Scottish production (9.11%). This is due largely to the absence of coal generation technologies.

These results suggest that the composition of the renewables technologies employed to meet the 50% target is important. Technologies with strong backward linkages back to the Scottish economy provide the greatest possibilities for an economic gain to be realised. What Scenarios C and Scenario D suggest is that it matters what is assumed about the technologies which provide the other 50% of electricity generated in Scotland. Without nuclear generation, this would be likely to be met through either a combination of gas and coal technologies, or, as extreme cases, from each technology alone (e.g coal in Scenario C and gas in Scenario D). As with the wind/marine results in Scenarios A and B, the economic results for these scenarios can be explained with reference to the initial linkages of each sector. Coal generation sector has greater employment-output and GDP-output multipliers than the gas generation sector in our initial IO framework. The scenario that assumes coal technologies, rather than gas generation, provides the non-renewable element of future Scottish electricity generation sees higher economic benefits, although these are associated with smaller declines in CO2 emissions.

Next, we focus on the sectoral differences in these results. Absolute sectoral changes in GDP (in £million) are shown for Scenarios A and B in Figures 5.1 and 5.2 respectively.

Figure 5.1: Absolute sectoral changes in GDP, £million, in Scenario A (high marine)

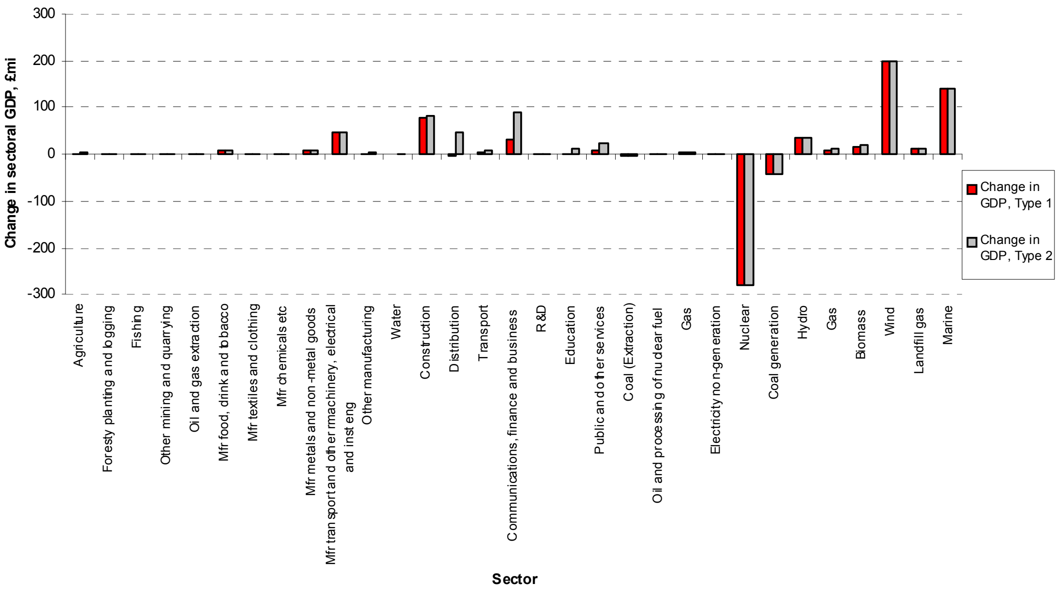
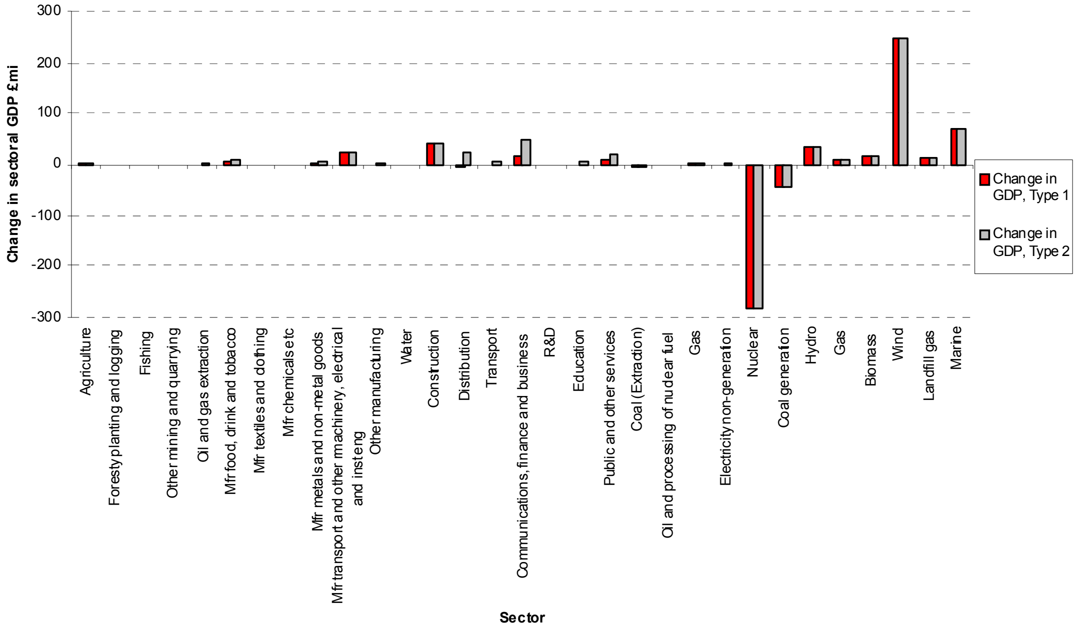


Figure 5.2: Absolute sectoral changes in GDP, £million, in Scenario B (low marine)



While the change in most sectors GDP is similar in Scenario A and B, it can clearly be seen that as well as significant changes in the wind and marine generation sectors, Scenario A sees significantly greater activity in the "Construction", "Communications, finance and business" and "Transport and other machinery". In both the Type 1 and Type 2 results, moving from Scenario A to Scenario B the change in GDP in these sectors decreases by almost fifty per cent. As seen in Section 5.2 above, these are sectors with which the marine generation sector has strong backward linkages.

The absolute change in sectoral employment in Scenarios A and B is shown in Figures 5.3 and 5.4. This shows the extent to which employment at the sectoral level is affected by the larger marine or wind generation in Scotland. The sectoral pattern of impacts may be different to that seen in Figures 5.1 and 5.2 since sectors that are GVA-intensive, are not necessarily employment intensive. As would be expected, in Figure 5.3, where the largest aggregate impact on employment is found, this is largely explained by the expansion of the marine sector, but also partly by the model, but significant, increase in employment in the "Construction" sector.

Figure 5.3: Absolute sectoral changes in employment, FTEs, in Scenario A (higher marine, lower wind)

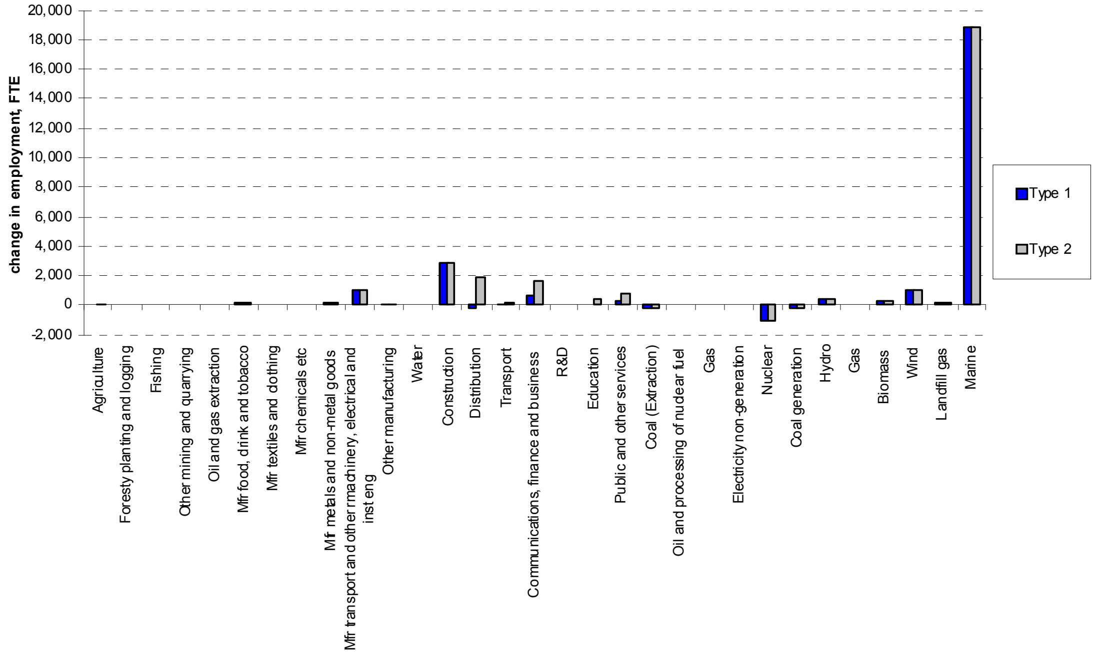
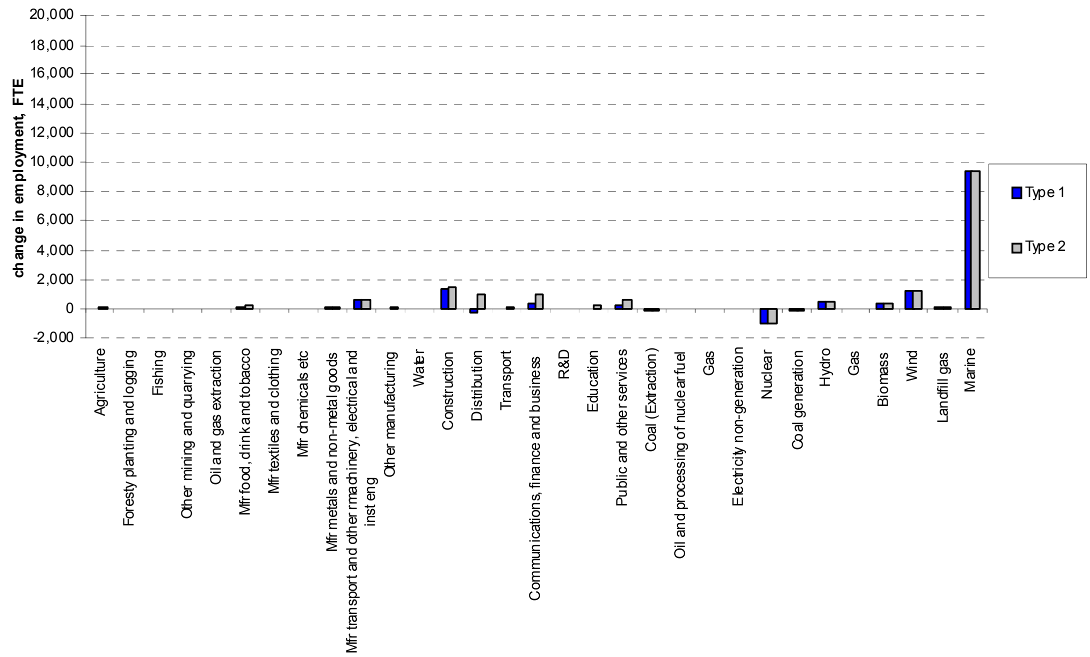


Figure 5.4: Absolute sectoral changes in employment, FTEs, in Scenario B (lower marine, higher wind)



In Scenarios C and D, we assume that the non-renewable element of future Scottish electricity generation comes from two extreme possibilities – purely coal generation, and then purely gas generation. Note again, that we assume that no electricity in Scotland is generated from nuclear sources, and that the total demand for electricity us unchanged, so Scotland remains a net exporter of electricity to the rest of the UK. The renewables' share of the future electricity generation mix in both Scenarios C and D remains the same in each scenario, with 30% from wind, 15% from hydro and 5% from marine technologies. The differences in results between Scenarios C and D therefore come solely from coal generation providing the whole of the remaining 50% of Scotland's electricity generation in Scenario C, while gas generation provides this 50% under Scenario D. While the aggregate economic and environmental results are discussed above, we focus here on the sectoral differences in these results. Absolute sectoral changes in GDP (in £million) are shown for Scenarios C and D in Figures 5.5 and 5.6 respectively.

Figure 5.5: Absolute sectoral changes in GDP, £million, in Scenario C

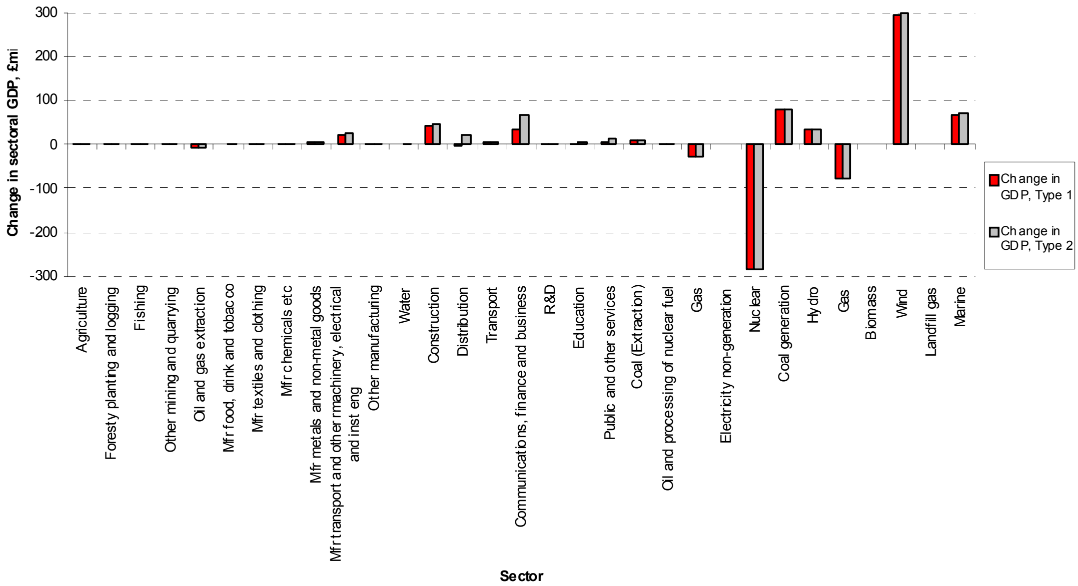
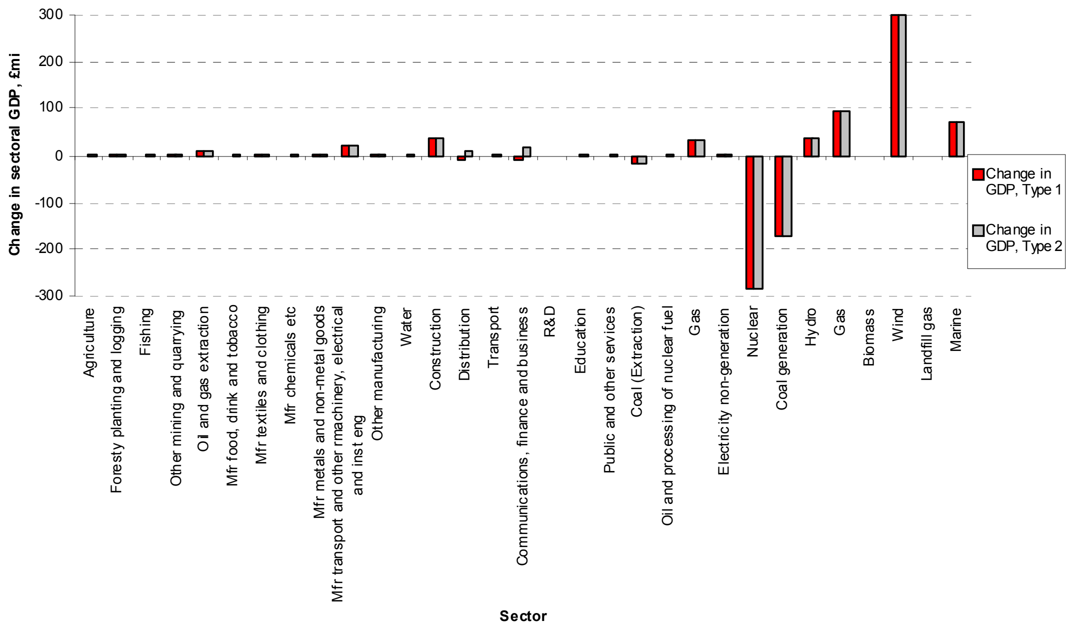


Figure 5.6:Absolute sectoral changes in GDP, £million, in Scenario D



While the results between Scenarios C and D are approximately the same for hydro, marine and wind generation sectors, there are considerable differences among the non-renewable sectors, and also in sectors that have strong links to the non-renewable sectors. The expansion of the "Coal generation" sector in Scenario B, with results in an increase not only in the "Coal generation" sector itself, but also sees an expansion in the "Coal extraction" sector (of almost 15%) and an expansion, large in absolute terms, in the "Communications finance and business" sector. Both these sectors have links to the "Coal generation" sector in the base year IO table. The "Gas refining" sector exhibits a contraction in Scenario C and an expansion in Scenario D, as would be expected. In Scenario D GDP in the "Gas refining" sector rises by over 21%, while it falls by almost 19% in Scenario C.

The absolute changes in sectoral employment in Scenarios C and D are shown in Figures 5.7 and 5.8. This indicates the extent to which employment at the sectoral level is affected by coal or gas generation providing the non-renewable portion of future Scottish electricity outputs. As with Scenarios A and B, the biggest employment impact is in additional jobs for the expanded marine generation sector. Employment in the construction sector is higher in both scenarios, while the same negative effect as found for GDP exists for employment in the "Coal extraction" sector in Scenario D and the "Gas refining" sector in Scenario C.

Figure 5.7: Absolute sectoral changes in employment, FTEs, in Scenario C

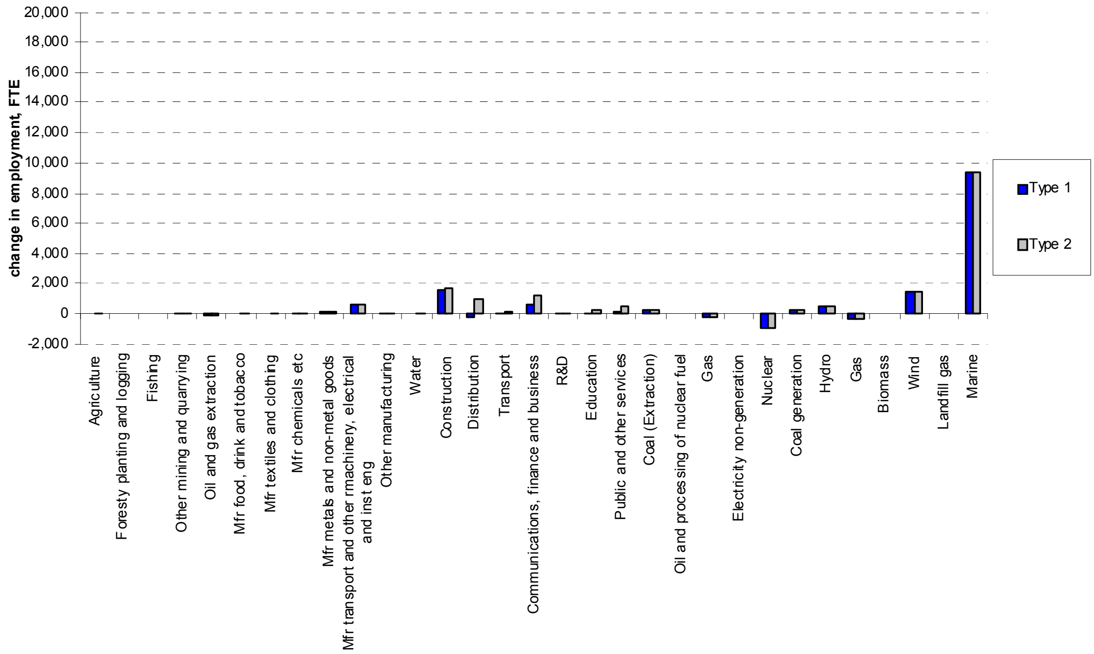
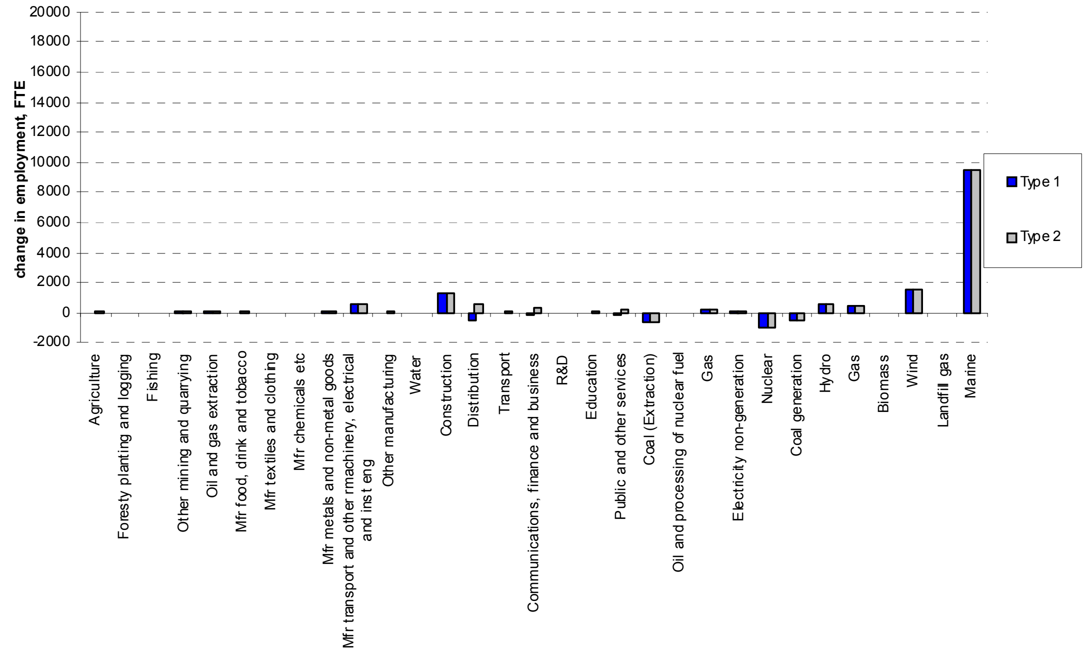


Figure 5.8: Absolute sectoral changes in employment, FTEs, in Scenario D



Technical Appendix 5 provides more detail on the IO multiplier analyses underlying the results presented here, as well as sensitivity analysis where we consider the impacts on the CO2 intensity of coal generation if carbon capture and storage is introduced.

6. Simulation results: impacts of increasing renewable energy supply 2 – CGE analysis

Our final set of simulations involves modelling the economic and environmental impact of increases in the share of electricity generated in Scotland from renewable energy sources. This section sets out some illustrative results from running the AMOSENVI model to simulate such an outcome. A number of practical problems have been encountered during the simulation of this outcome and we set these out here as well, before discussing the simulation strategy employed and the results of such policies. We have sought to model the effects of increases in the amount (and share) of renewable electricity generation in Scotland from the base year levels in the AMOSENVI model (1999). In the base year of the model (1999), we begin with a situation where renewable electricity generation provides 10.4% of all electricity generated in Scotland. In total, 42,482 GWh of electricity was generated in the base year of the analysis. In the core simulation which we present below we have sought to increase the share of electricity coming from renewable technologies, while maintaining the total amount of electricity generated in Scotland at levels as close as possible to the original figures for 1999. It would be possible, of course, to explore alternative assumptions about future consumption and production, so the present analysis should be regarded as indicative.

We carry out and report sensitivity analysis where in order to increase the proportion of the renewables, we relax the assumption that generation levels remain close to base year levels. There are a number of issues about the simulations which we report. Firstly, we assume that the underlying technology used to create the output of the renewable electricity generation remains unchanged. There is an extensive literature on learning rates, and the reduction in the costs of electricity generation from increased development and deployment of renewable energy technologies (e.g. Winskell *et al*, 2007). These simulations do not incorporate such developments. Secondly, we seek to make changes to the sectoral output of the renewable and non-renewable electricity generation sectors, so that total output of the electricity sectors remains close to existing levels. Results for electricity consumption relate to total electricity consumption by industries and final demand categories in Scotland, and as such, include imports of electricity. Thirdly, the database used for these simulations is that using an experimental disaggregation of the Electricity sector in the original IO table for Scotland. Fourthly, while long run results may in fact be more relevant here, it was not actually possible using the current (experimental) model to conduct period-by-period simulations as in the previous CGE simulations. We had to calibrate to a desired long-run increase in renewable and carry out a single (conceptual time) period simulation. In summary, features of the AMOSENVI model make the results presented no more than illustrative of the type of results which can be obtained from CGE analysis.

Our simulation strategy involves introducing subsidies to renewable electricity generation and taxes on non-renewable electricity generation. The intention is to choose the appropriate tax and subsidy rates such that the outputs of these two sectors adjust so that the combined "physical" electrical output of these two sectors remains approximately constant, but that the share of electricity produced by renewable electricity increases from its base year value. When we hold "physical" electricity output constant this is not equal to the combined real value of the output of the two electricity sectors being kept constant.

Ideally, the tax and subsidy raised should be revenue-neutral to the Government exchequer. We ensure this by allowing government expenditure to adjust so as to maintain the ratio of government deficit to GDP at its base year level. In all the simulations that follow, government expenditure is lower than in the base year, indicating that increased tax revenues in the non-renewable sector are not large enough to offset the subsidies required to stimulate the renewable electricity sector. The increases in tax necessary for the non-renewable sector to get the relative prices of renewable output to non-renewable output to shift, will have the effect of reducing the real wage, and in principle might increase government revenues. In the simulations which we report, however, the competitiveness effect of high prices is larger than the demand stimulus, and, in fact, government expenditure, and GDP, fall. The tax take is lower

Our discussion of results considers the economic implications of a Government policy package designed to increase the share of renewable electricity generation as a proportion of total electricity production. This is intended to explore the potential system-wide consequences of the Scottish Government's stated objective for 31% of total energy generation to be sourced from renewable energy technologies by 2011. We analyse alternative subsidy and taxation combinations that are applied to the renewable/non-renewable electricity generation sectors, respectively. Various model constraints, however, are such that we are not able to replicate exactly the magnitude of renewable electricity generation penetration that is implied by the Scottish Government's objective.[6]

As in our previous CGE modelling analyses, we examine the effects of the policy change subject to our benchmark equilibrium time period; that is, our results refer to percentage changes in variables compared to base. In this model framework, wages are determined according to our bargaining set-up, and we allow for migration of the labour supply to and from the rest of the UK. As noted above, we only report long-run results, where this represents a conceptual time period over which labour and capital stocks fully adjust to new equilibrium values. In the current model set-up, this corresponds to a timeframe whereby real wages and unemployment are restored to initial equilibrium values, and the capital rental rate is equalized across all sectors.

None of these scenarios are referenced against expected or predicted changes in the pattern of electricity generation mix in Scotland, or make any assumptions about the costs or viability of any of the scenarios considered here – such as, for instance, whether each scenario provides sufficient generation to meet expected future demand or to provide appropriate margins between peak demands and supply capacity.[7]

Our central scenario involves a subsidy package equivalent to 94.1% of value added for the renewable electricity generation sector, and a tax equivalent to 36.9% of value added to the non-renewable electricity generation sector. Table 6.1 reports the long-run impacts on key aggregate economic, energy and environmental variables. This policy change has the effect of reducing long-run GDP by 1.15%. The key factor underlying the negative impact on output are the price effects associated with the policy change. The extent of taxation in the non-renewable electricity sector is such that the price of output in this sector increases significantly (by 28.54%). This leads to a relative increase in the cost of the electricity composite, which combines with other energy inputs to form an overall energy composite. Increases in the price of the energy composite will serve to raise the cost of intermediate inputs, which will have negative implications for economic activity across the economy as a whole.

[6] In total, we ran approximately 500 simulations, with different levels of taxes and subsidies such that we held total electrical output approximately constant, and increased the share of electricity from renewable sources.

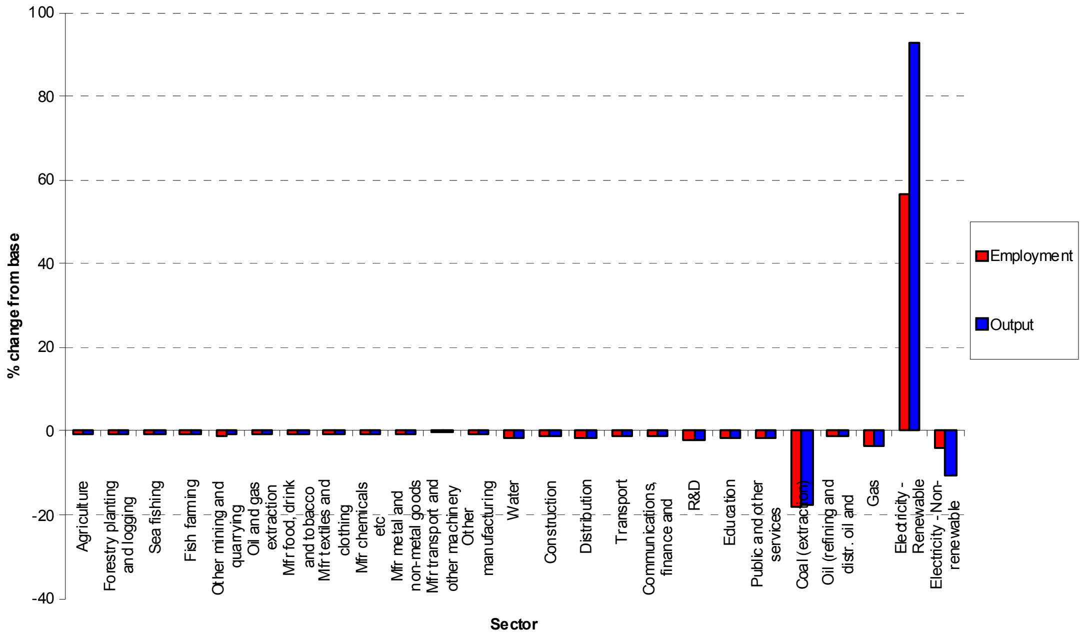
[7] As in the IO analyses in Section 5, we assume that total electricity output remains at its current levels. In the sensitivity analyses reported in Technical Appendix 6 we do allow for total generation to be lower, which would be consistent with projected deadlines in UK demand. It would be possible, of course, to also explore alternative assumptions about future consumption and production, so the present analysis should be regarded as indicative.

Table 6.1: Long-run aggregate economic, energy and environmental impact from "central" increase in renewable electricity generation in Scotland, bargaining labour market, % changes from base expect where indicated

	Long-run
% share of total electricity generation from renewable sources (base year = 10.4%	*20.06*
% change in total electricity generation from base year	*-0.04*
Gross Domestic Product (GDP)	-1.15
Consumption	-1.20
Government expenditure	-1.42
Investment	-0.90
Exports	-0.33
Imports	-0.24
Nominal (before tax) wages	0.51
Real (take-home) wages	0.00
Total population	-1.35
Total employment	-1.35
Unemployment rate (%)	0.00
Consumer Price Index	0.51
Renewable electricity generation	92.82
Non-renewable electricity generation	-10.82
CO_2 generation	-4.15
CO_2 intensity of output	-3.03
Electrical energy demand	1.96
Non-electrical energy demand	-3.18
GDP/Electrical energy demand	-3.05
GDP/Non-electrical energy demand	2.09

Figure 6.1 illustrates the long-run changes in output and employment across all sectors. It shows that those industries which are heavily dependent on the activity of the non-renewable electricity generation sectors (such as the coal extraction and gas sectors), are most negatively affected by the fall in output in that sector

Figure 6.1: Long-run impact on sectoral output and employment, % changes from base year



Significantly higher production costs mean that output contracts relative to base in the coal sector by 17.85% (higher even than the fall in output in the non-renewable electricity sector of 10.82%), and in the gas sector by 3.56%. The only sector to experience an increase in output is, as expected, the renewable electricity sector. In this sector the subsidy leads to a reduction in the price of outputs (by 49.79%), and is associated with an increase in sectoral output of 92.8%.

The effect of this reduction in the price of renewable electricity as an intermediate input, and the overall boost in activity in this sector is, however, insufficient to outweigh the negative effects in the non-renewable energy sector. The relative dominance of non-renewable electricity generation in the supply chain is such that all other sectors experience an overall increase in input prices. We hold "physical" electricity output constant, but the real value of output of the electricity sectors decreases as the increases in the price of the electricity composite is greater than the increase in the value of output. This leads to an economy-wide increase in prices: CPI increases by 0.51% relative to base. In the long-run, real wages return to their pre-shock level, but there is a lasting effect on nominal wages. Nominal wages increase by 0.51%, reflecting the increase in CPI, and a reduction in external competitiveness means that exports fall by 0.33%. Government expenditure falls by 1.42% in total, as the subsidies required to bring forward renewable electricity generation are greater than the taxes raised from non-renewable electricity generation, requiring government expenditure to contract to maintain the ratio of Government deficit to GDP, as described above.

The implications for the labour market are clear. In line with changes in output, employment falls across all sectors, except for the non-renewable electricity sector, and the highest relative reductions occur in the most energy-dependent sectors. Across all sectors, the percentage change in employment is closely comparable with changes in output, with the exceptions of the renewable and non-renewable electricity sectors, which reflects the fact that the tax and subsidy are effected on capital, and so incentivise a substitution towards/from capital in the renewable and non-renewable electricity generation sectors respectively. The overall fall in aggregate employment leads to outward migration, and a fall in Scottish population relative to base.

The environmental consequences of this policy are lower CO2 emissions. The fall in CO2 emissions outweighs the reduction in GDP, partly due to the shift in the composition of electricity generation from non-renewable to renewable sources. In the long-run, the share of electricity generation sourced from renewable technologies is 20.06%, compared to a share of 10.4% before the policy shock. This means that the CO2 intensity of Scottish production falls, along with total CO2 generation.

We conduct sensitivity analysis for this set of simulations in Technical Appendix 6, which involves looking at different subsidy/taxation rates. We should also note that in Allan et al (2008) we explore the impacts of local sourcing of components for a renewables industry. Whether these developments can be made (and components sourced) in Scotland, and whether technologies can be exported, would be expected to have a significant impact on the economic development potential of increased generation from renewable sources. However, we do not attempt to systematically model these issues here.

7. Conclusions and recommendations

This project was commissioned by the Scottish Government to use our experimental AMOSENVI energy-economy-environment CGE model of the Scottish economy to look at the economic and environmental impacts of a number of scenarios that may be expected to reduce the level of greenhouse gas emissions, with specific attention to CO2.

The analysis presented here is experimental and constrained by two broad factors:

1. The need to further develop the Scottish input-output tables for the purposes of examining energy-economy-environment issues.
2. The need to further develop the AMOSENVI CGE modelling framework to look at a wider range of issues.

We return to both of these points below and offer some recommendations for strengthening Scotland's analytical capacity in this area.

However, while the analyses presented here are constrained on both these points, they do demonstrate the potential contribution that applied empirical general equilibrium analysis can make to the policy process. For example, the energy efficiency analyses in Section 2 demonstrates why a general equilibrium framework is essential in assessing the nature and scope of rebound effects, even when improvements in energy efficiency are focussed in a single sector/activity. More generally, all the scenarios reflect the importance of capturing interdependences between different sectors and activities.

However, as emphasised from the outset, the current AMOSENVI CGE modelling framework should be regarded as experimental in nature as it is still at a very early stage of its development. It has not been possible to simulate all of the scenarios that Scottish Government expressed an interest in at the start of the project – for example, policies aimed at reducing household energy use (though, in Section 4, we do attempt to simulate the impacts of reduced household incomes that may result from such policies). We have also been unable to simulate scenarios involving carbon, capture and storage, which we hoped could be examined through changes in capital efficiency, but the current model, could not give us sensible results. However, it is important to stress that, in principle, a CGE modelling framework can be used to simulate a very wide range of scenarios (as reflected in the literature review in Technical Appendix 1). Development of the AMOSENVI framework is currently ongoing through various EPSRC and ESRC funded research projects being carried out by the regional and energy modelling teams at the Fraser of Allander Institute, University of Strathclyde. This development is being informed by the findings of the literature review reported in Technical Appendix 1 of this report. For example, we are exploring different ways of introducing energy as a factor of production. We will also directly explore energy use in final consumption (again, informed by the literature review findings). However, it is important that the policy community have and take opportunities to input their ideas and priorities to the model development process.

Recommendations regarding data issues

In terms of the first point raised above, the availability of appropriate data and need to develop the Scottish input-output tables, it is important to note that the benefits of doing so would not be limited to better informing CGE models. Turner (2008b) reports the following consensus among participants at a workshop held in March 2008, sponsored by the Scottish Environment Protection Agency to inform the Scottish Government's Steering Group on Additional Measures of Progress, to discuss the potential role of Scottish environmental input output accounts (with particular attention to carbon counting):

"Again, a number of interesting points/questions worthy of further consideration were raised:

- While the development of the IO framework is resource-intensive, if we have faith in market-based solutions to the problem of climate change, we absolutely need to adopt an IO approach.
- Uses of an environmental IO approach are not limited to footprint calculations. It would facilitate the construction of a wide range of environmental indicators. Therefore, it is likely to represent 'good value for money' to policymakers.
- IO analysis would allow us to develop a better understanding of domestic and direct emissions generation as well as the indirect effects that can be measured through multiplier analysis".

Turner (2008b, pp.5-6)

Turner (2003) considers the requirements of constructing Scottish environmental input-output accounts (perhaps adopting the NAMEA – National Accounting Matrix including Environmental Accounts – advocated by Haan, 2001, and developed for the UK by Vaze, 1999) and attempted to construct an experimental environmental input-output framework for Scotland. She concludes that there are two main problem areas that must be considered before a sectorally disaggregated economic-environmental database can be reported. "These are:

1. The availability of region-specific data for Scotland on sources and generation of emissions.
2. Even if region-specific emissions data of an acceptable quality are available, there is the question of whether these can be reported for a sectoral breakdown that is consistent the 1992 Standard Industrial Classification (SIC) used in the economic accounts. If policy is orientated towards influencing activity in economic sectors, clearly there are benefits to environmental data being presented in a format that is consistent with existing economic accounts."

Turner (2003, p.44)

We would add two further concerns/issues that should be addressed in developing the Scottish input-output tables for analysis of energy and environmental issues. First, aside from issues regarding environmental data and compatibility with economic accounting, there is also an issue over over-aggregation of key activities in the current 128 sector input-output classification (IOC). For example, for issues relating to recycling and reduction of waste, Allan et al (2007b) argue that it would be useful to disaggregate the waste disposal sector (SIC 90002) from the IOC sector 119, which also includes sewage, sanitation etc. For a number of the types of scenarios we have attempted to simulate here, and to better understand the link between electricity production and supply and greenhouse gas emissions, it would seem extremely important to consider breaking down the current IOC 85 electricity production sector to identify different elements of the supply and distribution chain and different generation technologies.

Second, it is important that any environmental input-output accounts be constructed in the analytical form that is appropriate for input-output multiplier analyses and other accounting and modelling techniques, such as CGE analysis. Vaze (1997) constructed such a framework for the UK. However, since then any economic-environmental and NAMEA accounting has been built around the supply and use tables. The lack of analytical IO tables for the UK since those reported for 1995 is a serious problem that is commonly raised in the policy and consulting arena. On the other hand, one of the key strengths of the Scottish input-output tables is the variety of formats accounts are made available, and we would argue that this should be extended to any environmental extensions.

A final point regarding data provision, the results of sensitivity analyses reported here highlight the need to generally improve the modelling infrastructure for Scotland. Model development is most likely best carried out within the expert research community, but this requires public support, for example, but not limited to, from the UK Research Councils (who are already supporting our own model development under our various current EPSRC and ESRC projects). However, there is also a need for wider data provision than the environmental input-output recommended above. For example, the availability of appropriate data for the econometric estimation of key model parameters, such as energy demand relationships.

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TECHNICAL APPENDIX 1. Review of literature on applying the CGE modelling approach to the problem of climate change mitigation and other environmental issues

A1.1 Introduction

Our objective in this section of the report is to identify the general issues that are likely to be important in applying a environmental computable general equilibrium (CGE) modelling approach to the problem of climate change mitigation for the specific case of Scotland. A comprehensive review of the literature, examining *all* issues that are relevant to a CGE modelling project, is out with the scope of this report. Instead, we focus on issues that are specific, or at least especially relevant to the case of *environmental* CGE modelling. This involves reviewing the current literature in order to examine how existing CGE models deal with questions of resource use, (particularly energy use) and pollution generation in production and consumption.

A basic introduction to CGE modelling

There is a wide range of general equilibrium model types. They share their roots in Walrasian general equilibrium theory though few CGE models nowadays assume full market clearing or universal perfect competition. The schematic of a typical CGE is reminiscent of the simplest macro-economic circular flow diagram, and is often characterised by disaggregation of households and industries/commodities. The requirement of general equilibrium is a simultaneous equilibrium in commodity and factor markets at an identifiable set of relative prices. However, within this framework the variation amongst model types reflects heterogeneity of views with respect to how markets function and the particular model focus (target economy(s), types of markets and transactors, macroeconomic closures/assumptions, dynamics etc).

Typically, the core database is a social accounting matrix (SAM), which describes the structure of the economy in terms of flows of income and expenditure between each production and consumption activity, and transfers of income to and from local and external transactors.[8] The parameters of a CGE model are generally determined in three ways. First, structural parameters (e.g. industry cost structures) are given by the base-year (SAM) data. Second, key parameters (e.g. substitution elasticities) are identified by econometric estimation and/or informed judgment involving literature review. These parameters are imposed in the model but may be subject to sensitivity analysis. Third, all the remaining parameters are determined through calibration to the base-year dataset. This involves assuming that the base-year SAM reflects a long-run equilibrium so that running the model with no change in exogenous variables will reproduce this equilibrium.

An excellent non-technical introduction to CGE modelling is given in Greenaway *et al* (1993). Here we focus on key factors that should be considered in the application of CGE models to environmental issues.

Environmental CGE modelling

The application of CGE models to examine environmental issues has grown substantially over the last two decades (the key milestone in the wider policy arena is likely have been the Rio Earth Summit in 1992). Environmental CGE models tend to fall into one of two categories (Bergman, 2005). The smaller of these is models designed to examine issues relating to the management of natural resources and is mainly relevant at a global level. However, the larger category of environmental CGE models focuses on the external effects of production and consumption, primarily through the emission of greenhouse gases. Within this there are two sub-categories. First, there are a number of global and multi-country models, which are mainly used to examine trans-boundary pollution problems and multi-lateral policies. Second, there are single country models (and, to a more limited extent, single region models), which tend to be more detailed at the sectoral level and have been developed for the purpose of analysing country-specific policy issues and proposals.

Bergman (2005) provides the most recent overview of the current ‘state of play’ in the field, identifying the different categories of environmental CGE model outlined above, identifying the main model

[8] A SAM is typically built around an input-output (IO) table that identifies the structure of the economy in terms of flows of goods and services and generation of GDP.

specification issues that should be considered in constructing different models for different purposes, and considering the types of analysis that are possible within an environmental CGE framework. An important point to make at the outset is that the case for using a CGE model for policy analysis can be made where proposed policy measures (or other potential or expected changes in economic conditions) are likely to have economy-wide (general equilibrium) effects. However, not all policy measures related to environmental issues are likely to have such effects. Some environmental problems are local and site-specific, or relate to specific substances or processes. While the resolution of such problems may be costly for some firms and households, the repercussions for the rest of the economy may be very small or non-existent.

Overview

The first issue addressed in this chapter, in Section 2, is a key one in terms of modelling climate change and broader 'sustainable development' policies: geographical/spatial focus and the 'small open economy' assumption. In Section 3 we examine the issues associated with introducing natural resource inputs, particularly energy, on the production side of the economy, alongside the standard capital, labour and material inputs. In Section 4 we examine the main issues involved in modelling the generation of pollution as a result of economic activity in general, and natural resource use in particular. We turn our attention to issues involved in modelling consumer behaviour in an economic-environmental context in Section 5. Finally we provide a summary and conclusions in Section 6.

In this review we have identified a number of studies that may provide a useful insight in considering how an environmental CGE approach may be useful in the case of Scotland. All of the studies identified in this review are summarised in Tables 1 and 2 at the end of the paper. The studies in Table 1 all fall under the global or multi-country category identified above, while the studies in Table 2 are all national or regional level applications. Where relevant, studies from these tables are cited in the text below, but full bibliographic details are provided so that individual studies of interest can be followed up independently. In the process of conducting our own review, we have also identified several review articles, which may be particularly useful to read alongside the current paper. The most recent of these is Bergman (2005), which provides an overview of the current 'state of play' in the field, but does not attempt to conduct an exhaustive survey of applications. For this purpose, Bergman (2005) refers the reader to Conrad's (1999) excellent survey article. More recently Conrad (2001) provides another review (but this latter study is more technical than the 1999 article). Wajsman (1995) provides an earlier review of environmental CGE studies. Reviews with a more specific focus on energy (rather than pollution generation) can be found in Bergman (1988) and Bhattacharyya (1996), and Lőschel (2002) provides a review that focuses on modelling technological change.

A1.2 Geographical/spatial focus and types of policies modelled

Global and multi-country models

As noted above, a number of environmental CGE models are global and/or multi-country models. Use of environmental CGE models has become a popular approach to examining the economic causes of the global climate change (global warming) problem. This is illustrated by the prevalence of CGE models in the OECD comparative modelling project (reported in Dean & Hoeller, 1992) on assessing the costs of reducing CO_2 emissions. Three of the global CGE models in Table 1 were included in this project: the GREEN model (Burniaux *et al*, 1992a,b), the Carbon Rights Trade Model, or CRTM (Rutherford, 1992), and the Whalley-Wigle Model (Whalley & Wigle, 1992). The approach of these global CGE models is to divide the world into a number of regions (they are essentially inter-regional CGE models), with groups of countries being treated as regions of the global economy.

Since the OECD project a number of global and sub-global multi-country CGE models (e.g. see Gottinger, 1998, Petersen, 2003 and Klepper and Petersen, unpublished, which all focus at the EU level) have been developed. Perhaps the most notable development in international CGE analysis has been through the modelling framework developed by the Global Trade Analysis Project (GTAP), based at Purdue University in Indiana in the United States.[9] The GTAP project invites

[9] The GTAP web-site can be found at http://www.gtap.org.

contributions of input-output tables for individual countries around the world and GTAP network subscribers can access and use the international CGE modelling framework developed around this database (where countries and regions can be aggregated as desired for specific applications). In recent years, a key focus of the GTAP project has been extension of the database and modelling framework for analysis of environmental issues and an increasing number of input-output and CGE modelling analyses based on the GTAP framework can be found in the literature (GTAP also holds an annual conference where delegates present their work using the framework).

National/regional models and the small open economy assumption
However, given the specific focus of the current project on modelling the impact on the Scottish economy of reducing greenhouse gas emissions in Scotland, the multi-country focus of the contributors listed in Table 1 is of more limited relevance. Rather, the national, regional and interregional national/sub-national applications identified in Table 2 are of more direct interest. In particular, it is from studies where small open economies are modelled that we can learn the most direct lessons for Scotland. Of particular importance is the application of the 'small open economy assumption'. When this assumption is made it implies that *the rest of the world is taken to be exogenous*, so that only the economy under consideration is modelled. The 'small open economy' does interact with the rest of the world, via trade, but its activity is assumed to have no significant impact on the rest of the world. This means that any spillover effects from the target economy to the rest of the world are trivial, given the scale of the rest of the world, which in turn implies that there are no significant feedback effects from the rest of the world to the target economy.

Of course, it may not be appropriate to assume that the *whole* of the rest of the world is exogenous. For example, in the case of Scotland, it may be appropriate to conduct an inter-regional analysis of the UK economy so that policies implemented at the national level can be considered, and feedback effects between UK regions can be modelled. This will be true of any sub-global or sub-national area where interregional interactions are thought to be important. In the case of environmental problems, political boundaries may be less important than ecological ones. For example, Abler *et al* (2000) conduct an interregional analysis of the Susquehanna River Basin area in the US, which includes areas of 3 states, to examine forest resource issues.

However, the key point of making the small open economy assumption in the context of *environmental* modelling is that the global environmental impact of the target region's economic activity is taken to be trivial. Thus, it can be assumed that there are no feedback effects from the global environment to the local economy arising from disturbances in the latter. In other words, the contribution from a small open economy like Scotland to, for example, the problem of climate change, is taken to be so trivial that we would not expect economic activity in Scotland to lead to significant climate change effects in Scotland through this mechanism. Such environmental feedback effects cannot be handled in a model of a small individual country or region (any environmental impact from the rest of the world on the local economy would have to be handled exogenously). The implication of this is that while a single country/region model can be used to assess the costs to the local economy of tackling global environmental problems, any resultant benefits of an improved global environment for that economy cannot be assessed. In effect we are assuming that there will be no environmental benefits to the local economy from its individual policy actions aimed at global problems such as climate change. Considering that any beneficial feedback effects would be expected to be very small, this is may be consistent with concerns that may be expressed locally regarding the costs of unilateral action to address the climate change problem (this is the public goods problem inherent in tackling global environmental problems).[10]

Types of policies commonly modelled in single country/region models
The studies in Table 2 that focus on other small open economies, and policies/disturbances that are more likely to occur, are perhaps of more direct interest in a Scottish context. Nonetheless, it is possible to draw lessons from global models and other international or multi-country (as well as from models of larger economies that may not be treated using the small open economy

[10] The point is that other countries feel most of the benefits derived from Scotland lowering its domestic emissions of greenhouse gases because climate change affects everyone. However, the benefit to Scotland of being part of a successful global environmental policy might be large.

assumption, such as the US) in terms of how to incorporate resource use and pollution into models of economic systems. However, such models would be expected to focus on different types of environmental issues than those addressed by single country/region models. The models in Table 1 tend to focus on the problem of global climate change in the context of trans-boundary pollution problems and multi-lateral policies. Greenhouse gas emissions resulting from economic activity are also a common concern of more locally focussed national and regional models. However, even in the case of modelling larger countries or groups of countries, this is often set in the context of *constraints on economic activity* resulting from commitments by individual economies to limit their share of global emissions; or, put another way, the *local costs* of pursuing global sustainability policies.

Similarly, global models like GREEN and CRTM may focus on the problem of depleting non-renewable natural resources, through inclusion of sub-models of resource depletion, specifically fossil fuels, as part of their dynamic structure. Again, fossil fuel depletion, like global warming, is a global sustainability concern, and one that has little meaning at the level of individual countries and regions, since such resources can be imported from elsewhere in the world. The issue of endogenous fossil fuel depletion is only likely to be a concern in non-global models if the country in question is a “producer” of fossil fuels (for non-producers, the effects of depletion will be transmitted through changes in exogenous prices). It may also be an issue in the form of a self-imposed constraint as individual regions or countries attempt to ‘do their bit’ in conserving global resources, and/or to limit the emission of pollutants resulting from their use. More locally-focussed models may, however, be more directly concerned with questions of resource depletion where the natural resources in question are of the type that cannot easily be imported, such as fish stocks (if the economy in question is significantly dependent on fishing industries) or land, though this is not apparent in the applications reviewed here.

The range of policies and other disturbances examined at a national (or regional) level using environmental CGE models can be seen in Table 2. A few of the papers - e.g. Adams *et al* (2003), Bőhringer and Lőschel (2006), and Fergusson *et al* (2004) - focus on methodological issues such as developing an environmental component on an existing CGE model, building sustainability indicators into environmental CGE models etc but most of these studies focus on particular disturbances. The most prevalent broad policy instrument modelled is energy or carbon taxation – e.g. Bőhringer *et al* (2001), who model a unilateral national carbon tax in Germany; Bőhringer and Rutherford (2007), also focussing on Germany, but extending for issues such as industry exemptions on carbon taxes; Sőderhom (2007), carbon taxes for Sweden; Boyd and Uri (1991) fuel taxes in the US; Gottinger (1998), GHG taxes in the Netherlands; and O’Ryan *et al* (2003, 2005), taxes on PM10 emissions and fuel use. While Scotland’s devolved fiscal powers do not extend to taxation beyond the limited income tax varying power, the applications in this area that may be of most interest are Wissema and Delink’s (2007) analysis of a (national) carbon tax in the Irish economy and Li and Rose’s (1995) analysis of a regional (state) carbon tax in Pennsylvania.

There are also a number of applications in Table 2 that focus on modelling the impacts of increased energy efficiency in production and/or consumption, with particular attention to the issue of economy-wide ‘rebound’ effects (where reductions in energy consumption from increased efficiency are partially or wholly offset due to the effects of reductions in effective energy prices) – e.g. Semboja (1994); Dufournaud *et al* (1994); Grepperud and Rasmussen (2004); Glomsrød and Taojuan (2005); Hanley *et al* (2006); Allan *et al* (2007a); and Barker *et al* (2007). Modelling rebound effects in an environmental CGE framework has actually been the focus of a programme of research directly commissioned in the UK by DEFRA, the results of which are reported in Allan *et al* (2006), and Herring (2006). Another study resulting from environmental CGE work commissioned by a government body that may be of interest in a Scottish context is Learmonth *et al*’s (2007) work on modelling the economic and environmental (local pollution) impacts of changes in population in the economy of Jersey (a UK crown-dependency). This is an example of examining the impacts of implementing a non-environmental, but sustainability-related, policy on other sustainability indicator variables.

However, the common problem for all models, whatever their geographical focus, is how to incorporate an economy's consumption of resources, particularly energy, and the resulting generation of pollutants, into a CGE model of an economic system. In this sense it is useful to draw on a wide variety of models, and this is the purpose of the following two sections on modelling energy use (Sections 3) and pollution generation (Section 4).

A1.3 Issues involved in modelling energy use in production

In a survey of general equilibrium approaches to energy modelling, Bergman (1988) identifies the crucial factor in determining the system-wide effects of changes in energy supply and demand as the elasticity of substitution between energy and other factors of production. He goes on to argue that this finding suggests that the representation of the substitutability of energy between other factors of production is one of the most basic issues that has to be addressed in energy/environmental CGE modelling. Our review of the literature on modelling energy before and since Bergman's (1988) survey demonstrates that this continues to be the key issue. A particular source of controversy is whether energy and other factors of production are in fact substitutes or complements, and whether this varies between the short and long run. It is outwith the scope of the current (non-technical) review to examine these issues in detail; here, we limit the discussion to identifying the key questions that would arise and to summarise what would seem to be the key points of debate in the literature.

The main questions would seem to be as follows:

- What is the best way to model the production structure so that, where appropriate, it can cope with the reality of multiple inputs and elasticities of substitution that differ over types of input, as well as between different sectors and over time?

- What *types* of energy input should be modelled to capture a full range of general equilibrium effects, including the pollution effects of different input choices and/or the response to environmental policies to reduce pollution? (since some inputs will be more polluting than others).

- How important is the country-specific context and institutional setting for which the model is being built? The economic, social and policy conditions present in the particular country/region being modelled will influence how the model is built.

Modelling the production structure

The main source of controversy lies in how different studies address the first of these questions. The most common approach to modelling production relationships in CGE models generally involves using nested production functions involving a hierarchy of Constant Elasticity of Substitution (CES), as well Cobb-Douglas (CD) and/or Leontief (where appropriate), relationships between different inputs. The motivation for using CES forms is that they permit more flexibility than CD, where the elasticity of substitution must be equal to unity, and Leontief, where the elasticity of substitution is equal to zero (i.e. no substitutability at all - fixed factor proportions). However the flexibility offered by the CES functional form is limited:

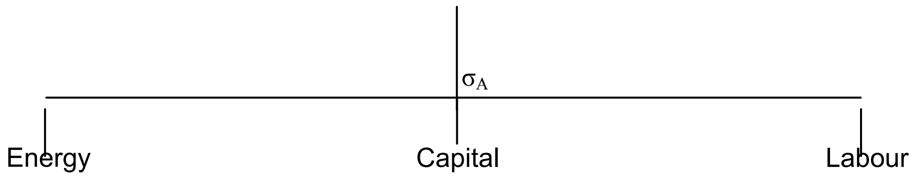
The name 'constant elasticity of substitution' derives from the fact that using CES means employing a production function where the elasticity of substitution is the same regardless of factor proportions and scale.

For any one CES relationship, the elasticity of substitution must be the same among all factors. This problem can be overcome by nesting a series of CES relationships within a hierarchical structure. However this requires imposing a set of separability assumptions.

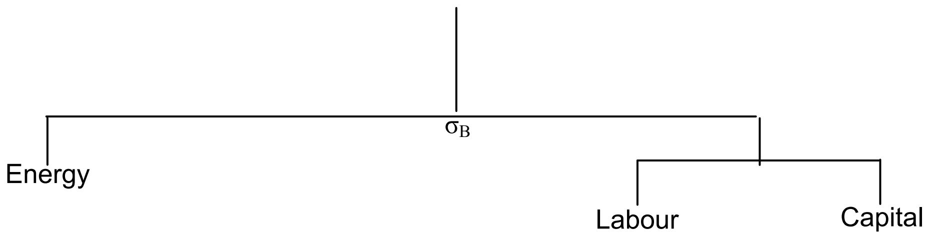
The models reviewed here demonstrate alternative ways of dealing with substitution between energy (E) and the other factors of production (mainly capital (K), labour (L), and intermediate materials (M) – known as KLEM production functions). Most of the studies employ nested production functions of one (or more, if different sectors are treated in different ways[11]) of the forms shown in Figure 1 below. This means that they employ separability assumptions among the KLEM inputs. Generally energy inputs (making up the energy composite, E) are produced by the energy sectors of the economy in question or imported, but are treated in a different manner to the non-energy (produced) intermediates.

Figure A1.1: Alternative specifications for production functions involving energy

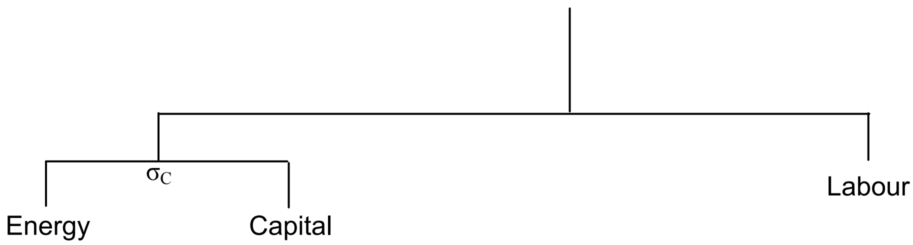
Function A



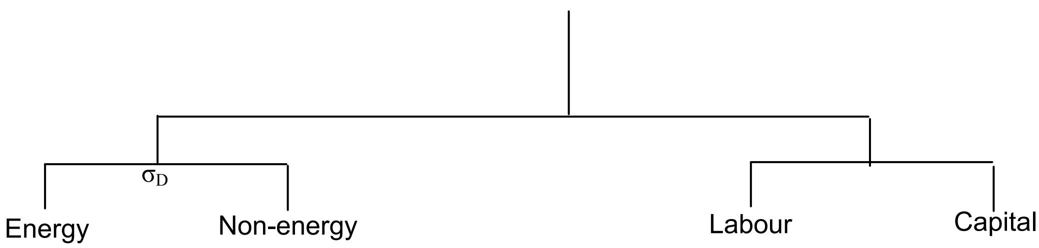
Function B



Function C



Function D



For exposition, it should be noted that each combination of two goods is normally termed a "composite" good, e.g. a energy-capital composite substitutes with labour in function C. The letters σ in the figure above correspond to the elasticity of substitution between the energy good and the other good with which it substitutes. In some models, the function shows above only corresponds to a section of the overall production structure.

[11] For example, in Wissema and Delink's (2006) Irish model, the production function for the electricity production sector has a distinctive structure.

However, while this is the most common approach, it can be argued that this type of nested production structure is still too inflexible because of the imposition of *separability* among the inputs. To avoid this problem, Hertel & Mount (1985), Depotakis & Fisher (1988) and Li & Rose (1995) adopt some type of flexible functional form (FFF) production function (using the dual to the production function, the cost function). The idea is to make the production function as flexible possible by minimising the number of prior assumptions about its form. In practice, however, this argument over whether to use CES or FFF is likely to boil down to a trade off between flexibility and tractability. In a model with a highly detailed treatment of energy, Naqvi (1998) argues that separability assumptions are necessary from a practical point of view, where there are multiple inputs and/or multiple sectoral outputs. Indeed, Hertel & Mount (1985), Depotakis & Fisher (1988) and Li & Rose (1995) all choose to employ two levels of cost functions, with substitution between KLEM inputs on the first level, then within the energy and/or materials aggregates on the second level. Thus, while advocating the employment of flexible functional forms to reduce the number of restrictions, including separability, that are imposed on the production function by use of nested CES functions, they are in fact prepared to accept *some* separability assumptions.

This highlights an important issue: why is separability acceptable in one case but not the other? *None* of the models reviewed here report on *testing* different separability assumptions (i.e. carrying out model specification tests). Therefore we can only presume that the decision over separability is based on some prior belief or judgement as to the appropriate assumptions to adopt. We would argue, however, that this decision would be better made as the result of actually testing alternative assumptions, where it is practical to do so, an issue that we are exploring in current research for Scotland and the UK.[12]:

The second main area of debate in, but not limited to, the environmental CGE literature is what has become known as the 'energy-capital complementarity controversy'. This problem has been a major issue and the source of considerable controversy in energy-economy modelling ever since research began in this area. Field & Berndt (1981) explain how the controversy arose from disparity in the estimates of the elasticity of substitution between energy and capital in early empirical studies. A detailed consideration of this debate is out with the scope of this review. The main point is that issues such as the non-homogeneity of capital, and different vintages/ages of machinery will be important, as will how capital and energy enter the production function (see the discussion above), differences in usages of capital and energy across different sectors and the time-frame under consideration. Once again, these are empirical questions that need to be addressed on a study-specific basis. However, as with issue of specifying production functions, addressing major model specification issues of this type, and estimation and sensitivity analysis of key parameter values, is generally more suited to longer term research programmes, such as the current ESRC and EPSRC-funded work being carried out at the Fraser of Allander Institute for the Scottish and UK economies.

Different types of energy input modelled

A variety of different types of energy input are modelled in the studies reviewed here. The most commonly identified energy types are oil, gas, coal (the three basic fossil fuel types) and electricity. However, the decision over what energy/natural resource types are modelled is largely dependent on the actual nature of energy/resource demand and supply in the economy in question (as well as the availability of energy use data in an appropriate format – i.e. that is consistent and compatible with the input-output tables, which form the core database for any CGE model).

The different types of energy identified would also seem to reflect the problem that the modeller is attempting to examine with respect to pollution. Models that focus mainly on CO2 emissions, and particularly policies to affect these using carbon taxes, appear to pay most attention to the relative carbon content of different types of fossil fuels. This is because CO2 emissions are primarily dependent on the fuel properties, with generation resulting from any economic activity relating directly to the amount and carbon content of fuel combusted. However, where models focus on a

[12] See project information on the ESRC funded project 'An empirical general equilibrium analysis of the factors that govern the extent of energy rebound effects in the UK economy' at http://www.fraser.strath.ac.uk.

wider range of pollutants, the generation of emissions from fuel use depends on a many more factors than carbon content. This is perhaps why Beauséjour *et al* (1994, 1995) emphasise the distinction between 'motive' and 'non-motive' fuels as the generation of non-CO2 greenhouse gases like methane (CH4) and nitrous oxide (N2O) depends heavily on combustion conditions and technology as well as on fuel types.

Prior to the possibilities for substitution between different *types* of energy, most of the models reviewed here first model the choice between domestic and imported sources for each energy type considered (and this is true in terms of consumption as well as production decisions). As is the case in CGE models in general, the 'Armington Assumption' is often employed for tradable commodities, in circumstances where foreign and domestically produced goods are imperfect substitutes for one another, allowing domestic (endogenous) and world (exogenous) prices to differ

A1.4 Modelling pollution generation

Modelling pollution generation is a more recent innovation in CGE modelling than modelling energy use and not all the models that reviewed here incorporate this element. Even though pollution generation is generally associated with energy use in an economy, a number of the energy-economy CGE models reviewed here appear to have been built solely for the purpose of analysing the *economic* effects of energy-use issues, such as changes in energy prices and taxes. Bergman (1988) explains that interest in energy-economy modelling arose in the 1970s and 1980s in response to public concern about the economic impact of changing energy supply conditions. This is an important research area in itself, and the focus of these models does not extend to how these effects feed through to the environment, or more generally the environmental effects of economic activity.

However, as international concerns grow over the problem of global climate change, and people become more concerned over local environmental quality, CGE modelling efforts have increasingly begun to focus on the problem of pollution generated during economic activity. Most of the models reviewed here focus on the generation of greenhouse gases, and the economic and welfare effects of environmental policies employed to combat this problem, rather than on the question of local environmental quality. Another general point is that, as in modelling energy use, the specific context for which the model is being built is important. That is to say, the nature of pollution problems differs across economies with different production and consumption patterns, as do the objectives of policymakers.

As well as focussing on the generation of pollutants, a few studies also give attention incorporation of 'end-of-pipe' pollution abatement technologies into the general equilibrium system. However, this topic is not well-advanced in environmental CGE modelling and treated fairly simply where it is considered. For example, Bergman (1990, 1991) and Beauséjour *et al* (1994, 1995) model pollution abatement services simply as a distinct form of capital services. In both these models, since capital is assumed to be the sole factor input to abatement activities, the marginal cost of abatement is taken to be equal to the cost of capital services for this purpose. Since there is no private return on undertaking abatement activities, there is no private demand for abatement capital in the absence of pollution policy. Where pollution policy does exist, firms will choose to undertake abatement activities if the marginal cost of an additional unit of abatement is less than or equal to the cost incurred in emitting an additional unit of pollution. For example, in Bergman's (1990, 1991) model pollution policy takes the form of an upper limit on total emissions, and government operates a market for tradable emissions permits to meet the target levels for each type of emission. This means that firms will only demand abatement if the marginal cost of emissions abatement is less than or equal to the market price for emissions permits.

Pollutants modelled

The main factor determining the choice of individual pollutants to be incorporated is the purpose that the model has been set up for. For example, the focus of global models like GREEN tends to be on global sustainability questions like the emissions of greenhouse gases, in particular CO2 (which is the biggest contributor to the global warming effect). Therefore Burniaux *et al* (1992) (GREEN) only models this single pollutant (the focus of this application of GREEN is to quantify the costs of curbing CO_2 emissions). Modelling of multiple pollutants seems to be more common in the case of individual region/country or sub-global inter-regional/inter-country models, most likely reflecting the different type of environmental concerns that exist at local (national/regional) levels. For example, Beghin *et al* (1995), a single country model of Mexico, models thirteen water, air and soil pollutants, and Lee & Roland-Holst (1997), a two-country CGE model of Indonesia and Japan, models eleven air, water and toxic pollutants. O'Ryan *et al*'s (2005) analysis of Chile focuses on local environmental and social policy issues, including consideration of local air quality and models emissions of PM10, SO2 and NO2.

Whether pollution is related to inputs or outputs

It should be noted that a number of the papers reviewed here do not make explicit just how pollution is modelled. However, there are two broad approaches – linking emissions to inputs or outputs. The simplest way to model pollution as a result of economic activity is through linear output-pollution coefficients, representing the amount of pollution per unit of output for each of the different sectors modelled. This approach was one of the earliest steps in environmental input-output modelling (Leontief, 1970), the most straightforward (but very restrictive) variant of CGE analysis. However it can still be observed in environmental CGE modelling thirty years on.

For example in Lee & Roland-Holst's (1997) model, each sector has pollution coefficients that are linear in output for seven air, two water, and two toxic pollutants. This means that pollution is proportionately related to sectoral outputs only. However the authors point out that a major limitation of this approach is that there is no scope for technical substitution *within* sectors, meaning that emissions are proportional to sectoral output regardless of relative prices and factors such as differential pollution taxes. Roland-Holst addresses this limitation in other work: in a co-authored paper, Beghin *et al* (1995), the point is made that if pollution coefficients are output-based and/or only pure Leontief technology is modelled, then the only way to reduce emissions within any sector is to reduce that sector's output. Beghin *et al* (1995) go on to identify three underlying components of changes in emissions levels over time:

(1) *Composition* – change in pollution induced by a change in the commodity composition of aggregate production (more or less dirty/clean goods)
(2) *Technology* – evolving cleaner technologies (which usually result in a change in the input mix)
(3) *Scale* – increase/decrease in pollution attributable to an increase in aggregate economic activity

Where modelling of pollution involves simply relating emissions of pollution to sectoral outputs, only the composition and scale effects will be captured. The easiest way of modelling the technology effect will involve linking pollution emissions to production techniques through input-based pollution coefficients. However, it may be more useful to split Beghin *et al*'s (1995) 'Technology' effect into two parts:

(a) *Technology* – evolving cleaner technologies, independent of the input mix (e.g. installing catalytic converters in cars – this would mean a change in the emissions factor applied to the combustion of petrol in cars).
(b) *Input substitution* - changing the input mix towards cleaner types of energy/fuel (e.g. changing from regular to low sulphur petrol) or towards non-energy inputs (e.g. reducing the amount of energy used per unit of existing capital).

Of course, there may be instances where both (a) and (b) would occur together – for example, in switching from oil to gas powered heating systems. However, it is useful to make the distinction because the manner in which (a) and (b) are captured in a CGE modelling framework differs. Input substitution, i.e. factor (b), will be captured endogenously in a production structure with fixed input-pollution coefficients and appropriate possibilities for input substitutions. Such input substitutions would typically occur in response to a change in relative prices. However changes in technology (i.e. case (a) above) are likely to involve adjustment of relevant input-pollution coefficients and/or changes to the production structure to reflect differing technical relationships in sectors and/or particular input mixes where adjustments have occurred.

Since this time, the input-pollution method has become common in environmental CGE models, to the extent that it is rarely explicitly discussed in applications. An explicit consideration of linking emissions of pollutants to input use can be found in Beghin *et al* (1995). The approach adopted in this model involves drawing on work reported in Dessus *et al* (1994) on econometrically estimating the relationship between the production of each type of pollution and the level of intermediate consumption of each type of input. However all this work seems to involve is using a basic estimation model in which the emissions of each pollutant are simply regressed on each of the intermediate material inputs used (including fuels and industrial chemicals), with no apparent investigation of causality.

A more common approach to input-pollution modelling involves using information on *emissions factors* associated with different types of fuel use that have been calculated elsewhere. That is to say, pollution coefficients tend to be based on actual technical relationships, rather than econometrically estimated ones. The application of emissions factors would appear to be the most straightforward in the case of CO2 emissions, as these are primarily dependent on the fuel properties rather than combustion conditions and/or technology. Most of the models reviewed here that adopt an input-pollution approach do tend to focus solely or primarily on CO2 emissions. For example, Burniaux *et al* (1992) (GREEN), Barns *et al* (1992), Stephan *et al* (1992) and Böhringer & Rutherford (1997) all explain that they use CO_2 emissions coefficients based on carbon content for the different fuel types modelled to model input-pollution relationships.

However, modelling input-pollution relationships becomes more complex when it comes to non-CO2 emissions. This is because non-CO2 emissions tend to be dependent not only on fuel type, but also combustion conditions and technology, with the implication that appropriate emissions factors are likely to be more difficult to identify and too numerous for models with a high level of sectoral detail. This may also be why some models follow Beaséjour *et al* (1994, 1995) in introducing the distinction between 'motive' and 'non-motive' fuels in their production structure (also note that the IPCC regard the distinction between stationary and non-stationary sources to be the key distinction in measuring emissions generated during any given activity).

Nonetheless, not all the models reviewed here adopt the input-pollution approach. However, this is likely to be related to data constraints and/or early stages of model development, rather than any specification debate. For example, in Ferguson et al's (2004) Scottish model, AMOSENVI, pollution is related to sectoral outputs. However, by the time of Hanley *et al*'s (2006) study, the model specification has been developed so that CO2 emissions are related to energy use.

However, Beauséjour *et al* (1994, 1995) argue that there is a role for modelling both input-pollution relationships, *and* output-pollution relationships. Beauséjour *et al*'s (1994, 1995) model uses output-pollution coefficients to deal with production processes that are inherently polluting, for reasons other than the combustion of fossil fuels, and where the only way to reduce pollution may be to reduce output. Therefore in this model emissions of (air) pollutants arise from (1) the combustion of fossil fuels in intermediate production and final demand, and (2) from some industrial processes that are inherently polluting (such as pulp and paper production) without actually burning fossil fuels.

1. In the case of burning fossil fuels, the model assumes that emissions are a linear function of the volume of fuel combustion.

2. In the case of polluting industrial processes, where emissions are not caused by burning fossil fuels, emissions are assumed to be a linear function of the level of output from polluting industrial processes. (The sectoral disaggregation used by Beauséjour *et al* (1994, 1995) separately identifies the most polluting industrial processes - e.g. 'pulp & paper', which generates CO2 pollution, and non-ferrous smelting, which generates SOX).

Bergman (1990, 1991) also makes this distinction, modelling emissions from combustion proportional to fuel use and emissions from polluting industrial processes proportional to output. Thus, industries can reduce emissions by:

(i) Altering use of inputs – substitution towards 'cleaner fuels' and/or reducing the overall energy-intensity of production
(ii) Reducing output levels – this is the only option where processes are inherently polluting (i.e. where emissions are not the direct result of input choice)
(iii) Using emissions abatement technologies if they exist and are economically feasible. This will reduce emissions from any given input-output combination.

However, since sectoral output-pollution coefficients are often derived from fuel use data, it could be argued that in the case (ii) of inherently polluting processes it would still be reasonable to use input-pollution coefficients but set the substitutability between inputs to zero. In other words, if by 'inherently polluting' production processes we mean that there is only one way to produce output and the input mix will not affect the generation of pollution, fixing input decisions by Leontief technology means that the input-pollution coefficients effectively act as output-pollution coefficients. The two would be equivalent in terms of impact. In order to study the potential for reducing pollution in the case of such processes, one possibility would then be to switch between alternative production processes or techniques with differential pollution characteristics for key sectors.

A1.5 Modelling consumption behaviour

We have not carried out a great deal of work on modelling consumption beheaviour to date. Therefore, here we use Conrad's (1999) review as a guide to what type of issues should be considered.

Conrad (1999) explains that the usual approach in CGE models is to assume that consumers perform a multi-stage budgeting procedure:

1. At the first level inter-temporal consumer behaviour allocates a lifetime wealth endowment across consumption in different time periods.

2. Then at the second level there is an intra-temporal choice between leisure (supply of labour) and consumption.

3. At the final stage consumption is then allocated among a number of consumption goods/categories.

Within this general framework, Conrad's (1999) survey finds several different ways of specifying the consumption decision, the most frequent being the use of linear expenditure system (LES), nested CES or translog demand functions. He also finds that most studies focus on efficiency issues, with all consumers aggregated into a single representative consumer. However some studies use household disaggregation, modelling several different types of consumer, in order to assess the distributional impacts of different environmental policy options.

The models reviewed in this chapter can generally be described within Conrad's (1999) framework, with some exceptions. Firstly, most of the models reviewed here are not inter-temporal optimisation models, so the first level described above tends to be a decision between consumption and saving, with savings generally being some fixed proportion of income in any given time period. Savings is generally listed as one of the available consumption goods or categories and its price relative to other (present) consumption choices is determined as the expected future return to capital. In static single- or multi-period models this is generally taken to be equal to the current return to capital.

However, the largest proportion of the models reviewed here simply model consumer preferences/utility using a nested CES/CD/Leontief specification as in the case of production, with substitution possibilities between energy and non-energy consumption goods. As in the case of production, particular specifications depend on the economy and policy issue being examined (and most likely on data availability). Moreover, in general less attention seems to have been given to modelling consumption relative to production in environmental CGE studies (to date anyway). However, there are some interesting examples from which lessons can be drawn.

For example, Stephan *et al* (1992), focus on the main sources of CO2 emissions in private consumption, which they identify as traffic and space heating. Through CES sub-nests of their CD utility function, they explain that consumers can substitute between (a) public and private transportation (identified as distinct consumption goods), and (b) in the case of space heating, both between different fuels, and between conventional and electric heating systems.

Conrad & Schröder (1991, 1993) also seem to be alone in highlighting another important issue: modelling the effect of some durable and non-durable goods being *complements* in consumption. This issue would be important, for example, if taxes were imposed on CO2 emissions resulting from the combustion of fossil fuels by private road-users will affect the use and demand for cars. Similarly, emissions taxes on the generation of electricity would affect the price of electricity to consumers, and hence their use and purchase of electric appliances. Generally, Conrad & Schröder (1991) argue that, since only part of the consumption of a non-durable good may be regarded as essential for the operation of a non-durable good, it is necessary to improve on the type of demand structure commonly used in environmental CGE models.

The argument regarding the importance of recognising the link between the demands for durable and non-durable goods is an entirely valid one. However, it is not clear to why this could not be handled in a more standard consumption structure by extending the disaggregation of non-durable goods such as gasoline into different 'types' for essential and recreational (non-essential) purposes. Moreover, all the arguments concerning testing of model specification in production apply in the case of consumption also.

Distributional analysis

The final issue raised by Conrad (1999) in his review is whether studies focus on efficiency issues, with all consumers aggregated into a single representative consumer, or whether there is disaggregation into several different types of household in order to assess the distributional impacts of, for example, different environmental policy options. In addition to differential distribution effects, it is also likely to be the case that patterns of consumption will vary significantly across income groups, with the implication that, among other things, the environmental impact of the consumption activities of different households will vary. Household/consumer disaggregation allows analysis and identification of which types of household contribute most to environmental problems, as well as distributional analysis to identify which households suffer the greatest economic impact from environmental policy actions.

However, as found by Conrad (1999), the majority of the models reviewed here assume a single representative consumer/household. Nonetheless a growing number of environmental CGE models do incorporate household/consumer disaggregation in order to address the type of issues raised above, generally differentiating households by income, expenditure and/or demographic categories. All the models reviewed here that incorporate household disaggregation - Boyd & Uri (1991), Stephan *et al* (1992), Weise *et al* (1995), Naqvi (1998), Kamat *et al* (1999) and O'Ryan *et al* (2005) – do so by allocating households into income bands.

Classification of households by income categories would appear to be the most common method of household disaggregation. However, where data permit, households should ideally be disaggregated to identify different demographic rather than income groups. This is because the latter will be variable if income is determined endogenously. For example, Naqvi (1998) attempts to introduce non-income classifications, allocating households to groups relating to employment and regional location within the defined income bands. Weise *et al* (1995) go one step further, mapping individuals to households to account for multiple job-holders and multiple earners in any one household, arguing that this is important for proper in-depth distributional analysis.

Where households are disaggregated by income, Weise *et al* (1995) argue that this should be done using income *bands* (e.g. £10,000 - £20,000, £20,000 - £30,000 and so on) rather than breaking the population into equal-sized groups (e.g. into quintiles or deciles as in O'Ryan *et al*, 2005). They explain that this is because the latter method tends to result in over-aggregation of important groups (such as high earners). This of course will depend on how many households are likely to fall into different classifications. All of the models I review here that incorporate household disaggregation according to income do appear to do so by income *bands*. In fact, Weise *et al*'s (1995) point is illustrated in Stephan *et al*'s (1992) model of Switzerland, where 66% of the population are captured in the lowest income band, with the highest three income bands containing only 10% of Swiss households in total. Stephan *et al* (1992) are concerned with the effects of varying responses of different households to changes in relative prices brought about by a carbon tax, due to the varying inclination of different income groups to substitute away from private transport towards public transport. These are the type of effects that Weise *et al* (1995) argue may be hidden if distinct income groups are not identified in the disaggregation process.

The important issue, whether income or non-income criteria are used, would seem to be determination of the homogeneity of households that are classified together in one household group. The general approach observed here is to specify distinct preference structures/demand systems for each income band (meaning that preferences, and the timing of consumption choices, are taken to be function of income). Thus, in grouping households in a given demographic or income band, it will be important to attempt to ensure that consumption preferences are in fact fairly homogenous among the households contained therein. (in the models reviewed here, differences in preferences and demand across different income bands are generally modelled via differences in elasticity of substitution parameter values, rather than by having distinct structures for consumption decision process for each type of consumer.)

One of the key issues that Boyd & Uri (1991), Stephan *et al* (1992) and Naqvi (1998) focus on is whether the type of results found in partial equilibrium analysis of energy/fuel taxation – i.e. that such taxes are likely to be regressive - carry over to a general equilibrium analysis. This is one of the most important questions associated with distributional analysis and sustainability policy concerns – whether the burden of environmental taxes is unfairly borne by low income groups, since essential expenditure on energy/fuel is likely to account for a larger proportion of their income. However, in contrast to what is commonly reported from partial equilibrium analyses, the general equilibrium results of Boyd & Uri (1991), Stephan *et al* (1992) and Naqvi (1998) all suggest that the distributional effects of various energy taxation changes are minimal. Boyd & Uri (1991) explain that this does not imply that the direct effects of, in their case, an increase in fuel taxes are not regressive. Rather they explain that, mainly because of changes in relative prices, in a general equilibrium setting indirect effects are likely to mean that such a tax increase may not, on balance, be a regressive one in terms of the redistribution of the tax burden.

Weise *et al* (1995), whose paper is the only one of those reviewed here that focuses specifically on distributional issues (in the context of motor fuel taxes and household welfare), identify what appear to be the two most important influencing factors in a distributional analysis. The first is what happens to energy/fuel tax revenues – i.e. how these are redistributed/spent by government. Weise *et al* (1995) consider several different expenditure patterns for fuel tax revenues and find that the distributional effects are conditional on what government does with increased revenues. How the revenues are spent will impact on what Weise *et al* (1995) identify as the second key factor in determining distributional effects: the different sources of income available to different income groups. They find that the distributional impacts of energy/fuel taxes depend on whether the tax change *and* expenditure of revenue lead to increased or decreased rates of return to capital and skilled labour services, which are important sources of income for upper-middle and high income households. They report that, where the incomes of these households suffer from a decline in the rates of return to capital and/or skilled labour services, the distributional impacts of increased motor taxes tend to be smoothed out (or in some situations, are actually found to be progressive). Therefore, Weise *et al* (1995) conclude that to model distributional effects properly attention should be given to how environmental tax revenues are redistributed back to households. Specifically, they argue that the key issue is whether revenues are used to purchase goods and services, capital and labour, and to the different sources of income (and factor endowments) of different households.

A1.6 Summary and conclusions from literature review

The purpose of this review is to identify and consider issues that are likely to be important in conducting an environmental CGE analysis of the impacts on the Scottish economy of reducing greenhouse gas emissions in Scotland. Given that the current Scottish model (AMOSENVI) is an environmental CGE model for a single small open economy, the first issue discussed is the nature of the effects that we should hope to be able to capture. In Section 2 we explained how in the case of a model based solely on data for a single small regional economy, it is necessary to adopt the 'small open economy assumption'. This means only attempting to model the target (local) economy with the rest of the world assumed to be exogenous. The key implication of this, in terms of economic-environmental modelling, is that it is not possible to take account of any feedback effects from the global environment to the local economy resulting from disturbances in the latter. In other words, while it is possible to assess the economic effects of global environmental policies on the local economy, it is not possible to assess any environmental feedback effects resulting from any consequent improvement in the global environment. However, by employing the small open economy assumption, what we are saying is that we assume that these feedback effects would be so small (because the target economy is so small relative to the rest of the world) that they can be considered negligible.

In Section A1.2 we also argued that another implication of the target economy being a small open economy is that issues like modelling resource depletion are not likely to be relevant. We argued that resource depletion will only be an issue in modelling a small open economy if the resource in question cannot be easily imported from elsewhere in the world. The main way in which natural resource issues will enter into such a model will be in addressing problems of resource constraints and/or the effects of resources prices that are set elsewhere in the world (i.e. exogenously).

In Section A1.3 we went on to consider issues that have been identified in the literature as being important in modelling energy use, which is the main source of environmental problems that are attributable to economic activity. A number of important issues were discussed, including the question of whether energy is a complement or a substitute for other factors of production, and appropriate functional forms. However, our main conclusion is that, while many important arguments have been put forward for how production involving energy use should be modelled, none of the models reviewed here properly addressed the issue of model specification by actually testing a full range of alternatives. Sensitivity analyses are largely limited to parameter values, not to the production structure itself. This conclusion will also apply to the discussion of consumption structures in Section 5. Nonetheless, our arguments on this issue are qualified by the admission that such an ideal approach to model specification is likely to be highly resource intensive and often not feasible in practice. However, the problem of the judgmental nature of model specification in CGE applications (or any type of complex system-wide model), should be considered explicitly when assessing alternative specifications.

We then went on to discuss how the problem of modelling production with energy inputs has been approached in existing models of economic-environmental interactions. The main conclusion here is that the detail and nature of energy modelling is very much case dependent – i.e. the detail of energy modelling depends very much on the nature and structure of the specific economy being modelled, and most likely on the availability of appropriate data for this purpose.

In Section A1.4 we considered the question of modelling pollution, where many of the same type of issues arise. In terms of what pollutants are modelled, we again conclude that this tends to depend on the specific economy being modelled and the purpose of building the model – i.e. whether the focus is on global or local environmental concerns, on specific types of policy etc. We note that the main model specification issue is whether pollution is related to inputs to or outputs from production. If there are opportunities for reducing emissions through input substitution (i.e. if production technology is sufficiently variable), it is necessary to model input-pollution relationships in order to quantify environmental impacts. For example, if we want to assess the implications of changing/imposing energy taxes such as carbon taxes, then it is necessary to directly model the relationship between input use and pollution. This is because the aim of this type of tax is to induce substitution away from polluting inputs (by affecting relative prices). Therefore, input-pollution coefficients will be necessary if this type of policy is being model if we want to capture any consequent change in the output of pollution. However, we also stress the importance of recognising that not all emissions in the economy in question will be directly related to input use, since many production processes involve non-combustion related emissions generation.

Section A1.5 focussed on how the consumption side of the economy is specified in the models reviewed. In terms of issues relating to the appropriate choice of functional forms and how energy use and pollution generation are modelled, we find that the same type of issues arise as in the case of production. We argued that the main consumption-specific issue, particularly if the model is intended to analyse sustainability questions, is the scope for distributional analysis. Our conclusion is that, while a number of the models reviewed do attempt to address distributional issues by incorporating household disaggregation according to income, clearly this is an area that has not yet received a great deal of in-depth attention in the environmental CGE literature. Nonetheless some important modelling issues are identified, such as the importance of the sources of income available to different households.

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TableA1.1: Global and multi-country applications

Author/ Year of Publication	Single Region/ Inter-regional/ International Analysis	Type of Policy/ Disturbance	Comments
Beauséjour *et al*, 1994	Inter-regional: Canada; United States; Rest of the World.	Uniform tax on fossil fuels; carbon tax; industry-specific emission standards; economy-wide emission standards; imposition of emission charge to reduce SOX emissions; tradable permits inter-industry.	Emissions target is set at stabilising CO2 emissions in Canada at their 1990 levels by the year 2000. This means achieving 15% lower aggregate emissions than previously forecasted for the year 2000.
Beauséjour *et al*, 1995	Inter-regional: Canada; United States; the Rest of the World	Uniform tax on fossil fuels; carbon tax; industry-specific emission standards; economy-wide emission standards; imposition of emission charge to reduce SO_x emissions; tradable permits inter-industry.	Carbon taxes are shown to be more cost-effective in terms of impact on real income than fossil fuel taxes or emissions standards and sector impacts very greatly depending on the policy instrument chosen.
Burniaux *et al*, 1992a	International: United States; Japan; EC; Other OECD; Central and Eastern Europe; Former Soviet Union; Energy-exporting LDCs; China; India; Dynamic Asian Economies; Brazil and Rest of the World.	Overview of the GREEN model and its ability to simulate distortions (such as in tax and subsidies) over the 1985-2050 period.	Non-technical explanation to complement a series of studies running policy simulations with the model.
Burniaux *et al*, 1992b	International: United States; Japan; EC; Other OECD; Central and Eastern Europe; Former Soviet Union; Energy-exporting LDCs; China; India; Dynamic Asian Economies; Brazil and Rest of the World.	Removal of existing distortions on primary energy markets in all regions; application of a global carbon tax; combination of a removal of energy subsidies with carbon tax schemes.	
Burniaux *et al*, 1992c	International: United States; Japan; EC; Other OECD; Central and Eastern Europe; Former Soviet Union; Energy-exporting LDCs; China; India; Dynamic Asian Economies; Brazil and Rest of the World.	Carbon tax; energy tax; tradable emissions rights.	Simulated over 1985 – 2050.
Burniaux *et al*, 1992d	International: United States; Japan; EC; Other OECD; Central and Eastern Europe; Former Soviet Union; Energy-exporting LDCs; China; India; Dynamic Asian Economies; Brazil and Rest of the World.	Emission reduction targets using carbon taxes, energy taxes and tradable permits.	Effects of removing existing distortions in inter-regional energy prices also examined.
Goulder and Pizer, 2006	International	Emissions instruments such as carbon taxes and auctioned permits; abatement technologies.	
Hertel *et al*, 2006	International: US economy relative to the world economy.	Reductions in land-based greenhouse gas emissions and forest sequestration by means of carbon taxation.	
Kemfert and Truong, 2007	International: 25 world regions aggregated into 11 trading regions (countries)	Comparison of emissions stabilisation scenarios with and without technological change. Baseline has a 2% improvement in energy efficiency and emissions at 550, 500, 450 and 400 ppm are modelled as percentage reductions in each time period.	
Klepper and	International: Belgium; Luxembourg; Netherlands;	EU Emissions Trading Scheme (ETS) (country group emissions	Analysis of the impact of the EU ETS using the simulation

Peterson, 2004	Germany; France; UK; Italy; Denmark; Finland; Sweden; Greece; Portugal; Spain; Austria; Ireland; Bulgaria; Czech Republic; Hungary; Poland; Romania; Slovakia; Slovenia; USA; Former Soviet Union; Other Annex B-countries; Middle East; North Africa; China; Hong Kong; India; Rest of World.	caps and tradable permits).	model DART.
Lee *et al*, 1994	International: United States; Japan; EC; Other OECD (Canada, Australia and New Zealand); Central and Eastern Europe; Former Soviet Union; China; India; Brazil; Dynamic Asian Economies; Major Energy-Exporting countries and Rest of the World.	Simulation of carbon and/or energy taxes and tradable permits with an updated version of the GREEN model.	Simulations demonstrate key mechanisms of the model and its ability to address policy issues.
Nordhaus and Yang, 1996	Inter-regional: 10 regions consisting of US, Japan, China, EU, Former Soviet Union, India, Brazil and Indonesia, 11 large countries, 38 medium-sized countries and 137 small countries.	Carbon taxes.	
Peterson, 2003	International analysis	EU Emissions Trading Scheme.	The DART model is used to estimate the direct economic costs for business in Europe as well as costing the effect on trade and competitiveness internationally.
Rutherford, 1992	International: United States; other OECD; China; USSR and Rest of the World.	Reduction in global carbon emissions from the business as usual case by: 1%, 2% and 3%.	Use of the Carbon Rights Trade Model.
Van der Mensbrugghe, 1998	International: United States; Japan; EEC-12; Rest of OECD; Eastern and Central Europe; Baltic Republics and CIS Countries; China; India; Brazil; Dynamic Asian Economies; Energy-Exporting Economies and Rest of the World.	Implementation of the Kyoto Protocol (of 5-10% reduction in carbon emissions by 2010) using domestic carbon taxes, regional carbon taxes and tradable permits.	Limited analysis only allows the model to incorporate carbon dioxide, and not the remaining five critical greenhouse gases.
Whalley and Wigle, 1992	International: European Community; North America: Japan: Other OECD; Oil Exporters: Rest of the World.	Reductions in carbon emissions from the baseline growth case by: 1%, 2% and 3% and a stabilisation of emissions at 1990 levels.	Emission target reductions are taken as regional targets and achieved through carbon taxing.

Table A1.2: National, regional and interregional national/sub-national applications

Author/Year of Publication	Single Region/ Inter-regional/ International Analysis	Type of Policy/ Disturbance	Comments
Abler *et al*, 2000	Inter-regional: Susquehanna River Basin (South-Central New York, middle third of Pennsylvania and small portion of Maryland)	10% increase in forest resources set as base case. Sensitivity analysis carried out for 20%, 30% increases and 10%, 30% decreases.	
Adams *et al*, 2003	Single region: Australia	Explanation of the MMRF-GREEN model detailing enhancements to facilitate environmental analysis.	The following issues are considered: tax rates and revenues, handling back of tax revenue, fugitive-reducing technological change, substitution between effective units of intermediate inputs and emissions related to core model variables and aggregate emissions.
Allan *et al*, 2007a	Single region: UK	5% increase in energy efficiency in all production sectors: coal, oil, gas and renewable and non-renewable electricity.	
Allan *et al*, 2006	Single region: UK	5% increase in energy efficiency in all production sectors: coal, oil, gas and renewable and non-renewable electricity.	CGE model of the UK economy using the UKENVI framework.
Barker *et al*, 2007	Single region: UK	Energy efficiency policies (as detailed in the 2000 Climate Change Programme by Defra) such as reductions in GHG emissions.	Analysis of policies for the domestic, business, commercial, public and transport sectors for the period 2000-2010.
Barker and Ekins, 2004	Single region: United States	Carbon tax and tradable emissions permits.	Comparison of three top-down studies on the costs of Kyoto for the US economy.
Bergman, 1991	Single region: Sweden	Reductions in CO_2 emissions by: 10%, 20%, 30% and 40% of base case.	
Bergman, 1990	Single region: Sweden	Imposition of a constraint on total SO_x emissions; constraint on total NO_x emissions.	Policy aims to reduce SO_x emissions by 80% of the 1980 level before 1983 and NO_x emissions by 65% of the 1980 level.
Böhringer *et al*, 2001	Single region: Germany	Unilateral national carbon tax in Germany.	CGE model of Germany used to examine effects of environmental taxes under both perfect and imperfect competition.
Böhringer and Löschel, 2006	Single region and multi-regional	No particular policy mentioned.	Survey of computable general equilibrium models for sustainability impact assessment.
Böhringer and Rutherford, 1997	Single region: West Germany	Uniform carbon taxes; carbon taxes with exemptions for selected industries; uniform carbon tax with wage subsidy for exempt industries.	
Boyd and Uri, 1991	Single region: United States	Increase in gasoline tax: 10 cents per gallon; 25 cents per gallon. Imposition of a tax on crude oil and natural gas: $1.00 per barrel; $5.00 per barrel.	Sensitivity analysis proves results are robust.
Dellink *et al*, 2004	Single region: the Netherlands	Stabilisation of emissions through tradable pollution permits.	
Despotakis and Fisher, 1988	Single region: California	Doubling the price of crude oil.	CGE model developed to simulate the long-run impact of oil price shocks on regional economies.

Dixon and Rimmer, 1998	Single region: Australia	Reductions in motor vehicle tariffs.	Examines the use of dynamic CGE models in the forecasting and analysis of policy in Australia, using the MONASH model. A case study of the Australian motor vehicle industry is used to describe the model's features. This may facilitate understanding of the MMRF model, concerned with environmental policy analysis.
Dufournaud *et al*, 1994	Single region: Sudan	Introduction of more efficient wood stoves into households in Sudan. Simulations for: 100%; 150% and 200% improvements in efficiency	
Ferguson *et al*, 2004	Single region: Scotland	2.5% increase in general public expenditure; increase in basic rate of income tax; setting environmental targets for Scotland.	
Glomsrød and Taoyuan, 2005	Single region: China	Deregulation of market for cleaned coal; CO_2 emissions taxes.	Model of the coal cleaning markets in China using the CNAGE framework, up to 2020.
Gottinger, 1998	Single region: Netherlands	Emissions standards and quantity restrictions; auctioned tradable permits; GHG tax; net national emissions quota.	
Grepperud and Rasmussen, 2004	Single region: Norway	Introduction of energy efficiency improvements in the six sectors: manufacturing of pulp and paper; manufacture of metals; chemical and mineral products; finance and insurance; fisheries; road transport.	Model of the Norwegian economy: Rebound effects found to be significant for manufacturing sectors whereas other sectors show weak or insignificant effects.
Hanley *et al*, 2006	Single region: Scotland	5% increase in energy efficiency across all sectors.	
Herring, 2006	Single region: UK	Analysis of rebound effects of increased energy efficiency	
Hertel, 1988	Single region: New York State	Removal of hydropower subsidies to the manufacturing sector.	Analysis of the impact of the policy using a 2 X 3 model.
Hertel and Mount, 1985	Single region: New York State	Equal cost labour subsidies; equal cost production subsidies; removal of electricity subsidies.	
Kamat *et al*, 1999	Single region: Susquehanna River Basin (South-Central New York, middle third of Pennsylvania and small portion of Maryland).	Stabilisation of CO_2 emissions at year 2000 levels with carbon tax of $8.55 per ton of carbon; maintaining 1990 emissions with carbon tax of $16.96 per ton of carbon.	Sensitivity analysis also carried out with: increased government expenditures; lump sum return of revenues to households; Keynesian closure rule with fixed wage rate; increased government expenditure with Keynesian closure rule.
Learmonth *et al*, 2007	Single region: Jersey	Nil net migration with no change in exports; expansion of labour force and population through net immigration; 50% expansion in export demand in Finance sectors with nil net migration.	
Li *et al*, 2000	Single region: Taiwan	Carbon tax simulations with and without the technology bundle approach.	The technology bundle approach models energy intensive industries. It provides a set of substitutes for electricity generation taking into account response to changes in their relative costs. However, in order to prevent infeasible input combinations being chosen as solutions, the model restricts substitution to known technologies.
Li and Rose, 1995	Single region: Pennsylvania	Carbon tax simulations.	Simulations demonstrate the negative overall impact of carbon taxes on the Pennsylvania economy. This is mainly due to its heavy industry and the fact it is a major producer and user of fossil fuels.
Naqvi, 1998	Single region: Pakistan	Removal of import tax on high speed diesel.	Energy-economy model of the Pakistan economy using the GE-PAK framework, which is based on the ORANI model.

O'Ryan *et al*, 2005	Single region: Chile	Taxes on PM10, SO_2 and NO_2 emissions respectively.	
O'Ryan *et al*, 2003	Single region: Chile	Taxes on PM10 emissions and fuel taxes to reduce emissions by 10%.	
Otto *et al*, 2006	Single region: the Netherlands	Differentiated CO_2 emissions constraints; differentiated R&D subsidies and combination of both policies.	
Palatnik and Shechter, 2008	Single region: Israel	Carbon taxes on emissions and auctioned emissions permits. In addition, to test for double-dividend, two further scenarios were simulated: a revenue-neutral proportional cut in existing taxes and a cut in income tax.	
Semboja, 1994	Single region: Kenya	Improved production efficiency in the energy sector; increase in oil fuel use efficiency.	In both simulations output production initially rises, then reduces domestic unit production costs at every level. Dependency on foreign energy sources is thus reduced and demand for domestic energy increases.
Söderholm, 2007	Single region: Sweden	Reduction of greenhouse gas emissions by 4% during the period 2008-2012, by means of carbon taxes and carbon emissions trading.	Sweden opted to focus on domestic emissions, rather than EU ETS targets and imposed a carbon tax in 1991. This has been progressively raised since its imposition and is now comparatively higher than environmental taxes in other countries.
Stephan *et al*, 1992	Single region: Switzerland	Carbon taxes on imports with compensation policies: no compensation; full redistribution; partial redistribution of 80% of income redistributed to households; subsidising electricity generation.	
Vikström, 2004	Single region: Sweden	15% increase in energy efficiency in non-energy sectors and 12% increase in efficiency in energy sectors.	Static CGE model of the Swedish economy for 1957, using a social accounting matrix as a benchmark for calibration. The model is implemented using the GAMS/MPSGE system and aims to investigate the change between 1957 and 1962, also taking into account factor growth and TFP growth.
Washida, 2004	Single region: Japan	1% increase in energy efficiency in production, consumption, Government Expenditure and Investment.	
Wiese et al, 2005	Single region: US	Motor fuel taxes (distributional issues)	
Wissema and Dellink, 2006	Single region: Ireland	Comparison of the effectiveness of carbon taxes and uniform energy taxes to reduce CO_2 emissions.	
Xie and Saltzman, 2000	Single region: China	Pollution emission taxes; pollution abatement subsidies.	Computable general equilibrium approach for developing countries.
Yang and Wang, 2002	Single region: Taiwan	Carbon tax with compensation policy (transfer of carbon tax revenues or decrease in income tax rates); 5% decrease in total carbon emissions.	
Zhang, 1998	Single region: China	Carbon taxes to achieve: 20% reduction in CO2 emissions in 2010; 30% reduction in CO2 emissions in 2010; 20% reduction in emissions with indirect tax rates for all sectors cut by 5% and 10%;	

		30% reduction in emissions with indirect tax rates for all sectors cut by 5% and 10%.	
Zhang and Folmer, 1998	Single region: China	Carbon tax set at level of 205 and 400 Yuan per ton of carbon to achieve 20% and 30% cuts in emissions, respectively, by 2010.	

Table A1.3: Surveys of CGE Modelling and Environmental Policy

Author/Year of Publication	Single Region/ Inter-regional/ International Analysis	Type of Policy/ Disturbance	Comments
Bhattacharyya, 1996	Single region and multi-regional	Carbon taxes.	Survey of applied general equilibrium models for energy analysis.
Bergman, 2005			Overview of the use of computable general equilibrium models to examine environmental issues
Conrad, 1999			Overview of the use of computable general equilibrium models to examine environmental issues.
Conrad, 2001	Single region and multi-regional	Discussion of Double Dividend Policy; Kyoto Protocol; removal of environmental regulation; tradable permits for CO_2; monitoring technical standards; forestation and deforestation; cost-effective tax policies and international treaties on climate protection.	Overview of the use of computable general equilibrium models to examine environmental issues.
Löschel, 2002		Technological progress and carbon taxes.	Survey of technological change in economic models.
Kremers et al, 2002	Multi-regional	Climate change policies, however no particular policy mentioned.	Comparison of six CGE models: GTAP-E (static); WorldScan (dynamic); GTEM (dynamic); GREEN (dynamic); RICE (dynamic); MERGE (dynamic).
Robaina Alves and Marvão Pereira, 2006	Inter-regional: Norway, Germany, US, Netherlands, Austria, India, Sweden, Canada, Hungary, Japan, Pakistan, Nigeria, Italy, Belgium and Turkey.	Carbon tax; CO_2 emission permits; energy-carbon tax; increase in tax on raw material; pollution rights and investing in abatement; backstop technology policies; emissions taxes, quotas; fuel taxes, performance standards and mandated technologies; environmental load fees on emissions; removal of import tax on high-speed diesel.	Survey of applied general equilibrium models for energy and environmental studies.
Wajsman, 1995	Single region: US; US-Midwest; Sweden; Norway; Germany International: 5 regions; 3 regions	Energy taxes; exogenous changes in oil prices; environmental regulation; carbon taxes; 50% increase in CO2 concentration; command-and-control regulations; taxes on agricultural chemicals; direct controls on use of farming chemicals; global CO2 emissions limits; 1990 Clean Air Act amendments; closure of Swedish nuclear plants; limiting or reducing SO2, NOx, CO and CO2 emissions or particulates by fuel taxation; impact of German emissions standards; replacing standards with emissions taxes.	Review of developments in computable general equilibrium models to analyse environmental policy.

Technical Appendix A2 Simulation results: impacts of increased energy efficiency

A2.1 Introduction

In the recent AEA report to the Scottish Government (Mitigating Against Climate Change in Scotland: Identification and Initial Assessment of Policy Options), one policy option suggested to reduce GHG emissions (in the context of reducing emissions from the electricity generation sector (Section 4.1.2)) is to reduce demand for electricity through efficiency improvements. However, as some of our recent work has shown (see Hanley et al, 2008, and Turner, 2008a), the relationship between efficiency in energy use and demand for energy may not be so straightforward. This work reflects the wider debate in the academic and policy communities regarding potential 'rebound' effects of improvements in energy efficiency.

Therefore, a useful starting point for the modelling work in this project is to use the economy-wide AMOSENVI computable general equilibrium (CGE) modelling framework to examine the impacts on domestic energy use and emissions generation and on economic activity in Scotland as a result of an illustrative 5% improvement in energy efficiency introduced to different sectors of the economy. To aid comprehension we link our analysis to an environmental input-output (IO) analysis for Scotland. As noted in Section 1 of this report, it is important to be aware (as in the case of all the simulations in this project) that the quantitative results of both the IO and CGE analysis must be qualified by the fact that both rely on the 1999 Scottish IO tables. These tables are used because the IO data for this year were developed to permit more useful economic environmental analyses (with inclusion of experimental data on physical energy use and emissions at the sectoral level and disaggregation of the electricity sector by generation type). However, these data are somewhat dated now, and the environmental augmentations are very experimental. Both of these factors will impact on the reliability of results for policy analysis. Nonetheless, it is hoped that analysis illustrating the potential usefulness of IO and CGE analysis in the area of climate change policy will draw attention to areas that may merit investment in improved data collection and reporting.

A2.2 The issue of potential 'rebound' effects

A more efficient use of energy is often cited as the key to increasing economic productivity and growth, whilst reducing environmental damage at the same time (a decoupling effect). In addition, a more efficient use of energy is generally less costly than switching to new forms of energy and takes less time to implement. However, while in principle the idea of doing more with less satisfies the criteria of increasing output whilst decreasing the environmental damage of economic activity, there is growing evidence in the academic and policy literature about the so called rebound effect and, at its extreme, the backfire effect. The presence of such effects, which can be observed from the results presented here suggests that any positive environmental effects of efficiency improvements may be partially or wholly offset in the presence of rebound or backfire effects. In such situations there is an offsetting increase in demand for energy when there is an improvement in energy efficiency. This is due to the impact on effective and actual (where there is domestic energy production) energy prices and the subsequent economy-wide response to changing prices.[13]

Hanley et al (2008) and Turner (2008a) identify five distinct types of system wide effects in response to an energy efficiency improvement. These comprise (i) a need to use less physical energy inputs to produce any given level of output (the pure engineering or efficiency effect); (ii) an incentive to use more energy inputs since their effective price has fallen (the substitution effect); (iii) a compositional effect in output choice, since relatively energy-intensive products benefit more from this fall in the effective price; (iv) an output effect, since supply prices fall and competitiveness increases; and (v) an income effect as real household incomes rise. While (i) reduces energy demand, (ii)-(v) increase it.

[13] Hanley et al (2008) and Turner (2008) provide a more formal and detailed introduction to the literature on and basic theory of rebound effects.

However, our more recent research on the nature and magnitude of potential rebound effects in the Scottish and UK economies (Turner, 2008a) has drawn attention to another type of effect that may occur in response to changing prices, partially or wholly offsetting rebound effects in some cases, but with implications for economic development. This is occurrence of disinvestment in the energy supply sectors that may also occur as a response to improvements in energy efficiency. Disinvestment occurs because output prices in the energy supply sectors (domestic energy prices) fall in response to the increase in energy efficiency. Where profitability falls, capital rental rates (the return on capital) fall and disinvestment occurs. The presence of disinvestment helps to constrain/dampen rebound effects as the economy adjusts to improvements in energy efficiency. In short both rebound (increased demand) and disinvestment (supply-side contractions in capacity) effects occur in response to falling energy prices, though the latter solely in response to falling actual prices of domestically produced energy, and which type of effect dominates (as with rebound versus the pure efficiency effect) depends on the degree of price responsiveness throughout the system.

A2.3 Simulation strategy

Using the AMOSENVI energy–economy-environment Scottish CGE model we simulate a 5% improvement in energy efficiency as an exogenous (and costless) increase in energy-augmenting technological progress to all production sectors. While this may not be the most ‘realistic’ scenario to simulate, it allows us, in the first instance, to consider and develop an understanding of the basic underlying drivers of rebound effects. The work reported here builds on our previous work for Scotland, reported in Hanley et al (2006, 2008) and Turner (2008a), where the exogenous 5% improvement in energy efficiency is initially applied to all 25 sectors in the Scottish economy, and on our previous work for the UK (Allan et al, 2006, 2007a) where a similar shock is applied using the UK variant of AMOSENVI, UKENVI.

However, in the current project, we develop on our previous work by simulating the energy efficiency improvement on a sector-by-sector basis and in groups of sectors: the results are additive but taking this approach allows us to identify the key sectoral drivers of the rebound and backfire effects previously reported for Scotland. In each case, we examine the impacts on the five energy supply sectors, on total energy consumption and on CO2 generation in the Scottish economy, as well as the impacts on key variables such as GDP, total household consumption, employment, imports and exports. In general, we would expect that a beneficial supply-side policy such as an improvement in energy efficiency will lower the unemployment rate, increase real wages and have a positive impact on Scottish economic activity that is greater in the long run than the short run. However, in the simulations reported below, we see that the extent of the positive economic effects, and nature, magnitude and direction of effects on environmental indicator variables, depends on the type of activity targeted with the efficiency improvement.[14]

It is important to note that the system-wide response to improvements in energy efficiency (or any shock) also depends on the configuration of the model. Due to the number of sectoral shocks reported in the energy efficiency simulations reported here we do not attempt the type of comprehensive parametric sensitivity analysis reported in Turner (2008a) for the 25 sector case, or even a more limited variant, such that reported in Hanley et al (2008) or for other simulations conducted in this project. The default model configuration is as explained in Hanley et al (2008); however, in summary, we assume elastic export and import direct and derived energy demands (i.e. for an X% change in relative prices, demand will change by more than X%) but inelastic local intermediate demands (i.e. for an X% change in relative prices, demand will change by less than X%). However, Turner (2008a) shows that as price responsiveness increases in any part of the system, rebound effects will also increase. We highlight this below in the case of the commercial Transport sector.

Selected simulation results are presented in the tables and charts below and (as with all simulations in this project) are reported in terms of percentage changes from base year values

[14] Note that we focus on modelling improvements in energy efficiency in production activities. Future research under Dr Turner’s ESRC First Grant Project (grant reference RES-061-25-0010) will develop the AMOSENVI framework to allow us to model the impacts of efficiency improvements in the household (final consumption) sector.

given by the 1999 SAM data for Scotland. This allows us to examine the impacts of this shock in isolation (i.e. assuming no other changes in the economy). The base year (1999) SAM is assumed to represent a long-run equilibrium in the Scottish economy. The short and long run time periods that are referred to are conceptual. The short run is the first period after the shock where labour and capital stocks are assumed fixed at the sectoral level. In the long run, labour and capital stocks have fully adjusted to their desired sectoral values. We present results of multi-period (year by year) simulations, showing the process of adjustment to a new long-run equilibrium.

A2.4 Overview of results of energy efficiency shocks

Occurrence of rebound and/or backfire effects

If we have a rebound effect, this means that there is a fall in energy consumption in response to an increase in energy efficiency, but this is less than proportionate. For example, if energy efficiency increases by 5%, we would expect the direct (engineering) efficiency effect to be a 5% decrease in energy consumption. However, if the change in the effective and/or actual price of energy triggers substitution, output/competitiveness, composition and/or income effects (which all act to increase energy consumption) we would expect to see a decrease in energy consumption that is less than 5%. If, for example, energy consumption only falls by 2.5%, we have 50% rebound. However, if there is sufficient price responsiveness in the system (through direct and indirect, or derived, demands for energy) coupled with features such as the direct and/or indirect energy intensity of the sector targeted with shock, the increase in energy consumption may act to more than fully offset any pure efficiency gains, which would give us backfire effects (rebound effects of more than 100%). This will lead to an increase in energy-related emissions generation at the economy-wide level. As noted above, the strength of rebound effects is governed by the direct and indirect/derived elasticities of demand for energy throughout the economic system, as well as features such as direct and indirect energy intensities, openness to trade, elasticity of supply of factors of production etc. Backfire effects are observed for Scotland in previous work by Hanley et al (2008) and Turner (2008a). However, as explained below, these are mainly driven by the response to changes in energy efficiency in the electricity generation sectors, and are a function of the trade in electricity between Scotland and the Rest of the UK. The GDP, CO2 and rebound effects of targeting the energy efficiency shock at each sector, or groups of sectors, in turn (the simulations run specifically for this project) are shown in Tables A2.1 - A2.4 on the four following pages (followed by discussion of the results reported therein).

Table A2.1- Short and Long Run Impacts on GDP and CO2 from a 5% Increase in Energy Efficiency in Each Sector of the Scottish Economy

Production Sector	Short Run GDP	Long Run GDP	Short Run Co2	Long Run Co2	Short Run CO2/Y	Long Run CO2/Y
Agriculture	0.00	0.01	-0.03	-0.03	-0.03	-0.03
Forestry Planting and Logging	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Sea Fishing	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Fish Farming	0.00	0.00	0.00	0.00	0.00	0.00
Other Mining and Quarring	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Oil and Gas Extraction	0.00	0.00	0.00	0.00	0.00	0.00
Mfr Food Drink and Tobacco	0.00	0.02	-0.04	-0.04	-0.04	-0.05
Mfr Textiles and Clothing	0.00	0.00	0.00	-0.01	0.00	-0.01
Mfr Chemicals	0.00	0.02	-0.03	-0.02	-0.03	-0.04
Mfr Metal and Non-metal goods	0.00	0.01	-0.02	-0.02	-0.02	-0.04
Mfr Transport and other machinery	0.00	0.02	-0.02	-0.03	-0.02	-0.04
Other Manufacturing	0.00	0.01	-0.03	-0.03	-0.03	-0.04
Water	0.00	0.00	0.00	0.00	0.00	0.00
Construction	0.00	0.03	-0.04	-0.02	-0.04	-0.05
Distribution	0.01	0.10	-0.09	-0.06	-0.10	-0.16
Transport	0.00	0.02	-0.11	-0.11	-0.12	-0.13
Communications, business and finance	0.00	0.03	-0.10	-0.10	-0.10	-0.13
R&D	0.00	0.00	0.00	0.00	0.00	0.00
Education	0.00	0.01	-0.02	-0.02	-0.02	-0.03
Public and Other Services	0.01	0.02	-0.25	-0.31	-0.26	-0.33
Coal (Extraciton)	0.01	0.10	-0.09	-0.06	-0.10	-0.16
Oil (Refining and distr oil and nuclear)	0.00	0.01	-0.02	-0.02	-0.02	-0.02
Gas	0.00	0.00	-0.01	-0.01	-0.01	-0.01
Electricitity-Renewable	0.00	0.05	-0.01	0.07	-0.01	0.02
Electricity- Non-renewable	0.02	0.52	-0.17	1.18	-0.19	1.29

Table A 2.2- Short and Long Run Impacts on GDP and CO2 from a 5% Increase in Energy Efficiency in Selected Groups of Sectors in the Scottish Economy

Production Sectors	Short Run GDP	Long Run GDP	Short Run CO2	Long Run CO2	Short Run CO2/Y	Long Run CO2/Y
Agriculture and Primary 1-6	0.00	0.01	-0.05	-0.05	-0.05	-0.07
Manufacturing 7-12	0.01	0.07	-0.14	-0.14	-0.15	-0.22
Energy Supply Sectors 21-25	0.03	0.58	-0.21	1.86	-0.24	1.27
Energy use Sectors 1-20	0.14	0.59	-0.81	-0.82	-0.84	-1.11
All sectors 1-25	0.06	0.87	-1.01	1.05	-1.07	0.17

Table A 2.3 – Short and Long Run Rebound Effects from a 5% Energy Efficiency Improvement Targeted at Each Sector of the Economy

Production Sector	**Electricity Rebound**		**Non- Electricity Rebound**		**Disinvestment in**	
	Short Run	Long Run	Short Run	Long run	Electricity Sectors	Non- Electricity Energy Sectors
Agriculture	36.4	37.6	34.5	36.0	✓	✓
Forestry Planting and Logging	31.7	47.8	34.0	37.6	✓	✓
Sea Fishing	7.3	323.8	37.1	47.3	X	✓
Fish Farming	33.0	43.5	33.5	46.9	✓	✓
Other Mining and Quarring	35.0	30.3	34.3	31.1	✓	✓
Oil and Gas Extraction	31.7	27.2	16.5	13.1	✓	✓
Mfr Food Drink and Tobacco	35.6	39.3	33.5	40.8	✓	✓
Mfr Textiles and Clothing	43.2	41.5	42.1	39.4	✓	✓
Mfr Chemicals	49.7	54.6	48.0	55.3	✓	✓
Mfr Metal and Non-metal goods	46.9	46.3	43.5	42.2	✓	✓
Mfr Transport and other machinery	36.4	31.6	28.9	13.2	✓	✓
Other Manufacturing	41.4	38.9	36.8	34.3	✓	✓
Water	53.7	53.8	60.6	64.0	✓	✓
Construction	31.9	93.2	30.6	78.8	X	✓
Distribution	46.7	55.6	31.6	59.7	✓	✓
Transport	34.9	44.4	34.9	44.4	✓	✓
Communications, business and finance	34.5	35.0	32.2	32.9	✓	✓
R&D	37.6	27.6	28.3	7.3	✓	✓
Education	39.2	35.9	23.6	18.1	✓	✓
Public and Other Services	36.6	25.9	30.6	18.7	✓	✓
Coal (Extraction)	35.8	36.5	35.3	35.7	✓	X

Oil (Refining and distr oil and nuclear)	45.3	65.8	46.6	65.8	✓	✓
Gas	52.2	89.6	46.3	53.8	✓	X
Electricity-Renewable	81.0	194.3	29.1	807.3	X	X
Electricity- Non-renewable	96.5	263.5	80.9	253.3	X	X

Table A 2.4- Short and Long Run Rebound Effects from a 5% Energy Efficiency Improvement Targeted at Selected Groups of Sectors

Production Sector Groups	**Electricity Rebound**		**Non- Electricity Rebound**		**Disinvestment in**	
	Short Run	Long Run	Short Run	Long run	Electricity Sectors	Non-Electricity Energy Sectors
Agriculture and Primary	35.0	36.4	34.2	37.1	✓	✓
Manufacturing	41.8	41.7	38.7	39.2	✓	✓
Energy Use Sectors 1-20	86.6	88.8	92.5	95.6	✓	✓
Energy Supply Sectors 21-25	93.3	250.0	78.0	244.3	X	✓
All Sectors 1-25	92.4	93.6	96.0	97.7	✓	✓

Discussion of results

Table A2.3 shows that when the energy efficiency shock is introduced to either of the two electricity supply sectors, large backfire effects occur in the long run. However, if it is introduced solely to any one of the other 23 sectors, while some extent of rebound is observed in all cases, backfire is only observed in the Sea Fishing sector, and only in the long run in the case of electricity use. The first implication, and a key one in the current project, is that we do in fact observe reductions (or no net change) in CO_2 emissions when energy efficiency increases in any sector except the electricity supply sectors (where backfire occurs for all types of energy use). Even in the case of Sea Fishing, where the largest electricity rebound effect is observed (see below), there is a net fall in CO_2 emissions because other types of energy use are reduced.

Figure A2.1. Impact of a 5% increase in energy efficiency in the Non-renewable Electricity sector on key indicators

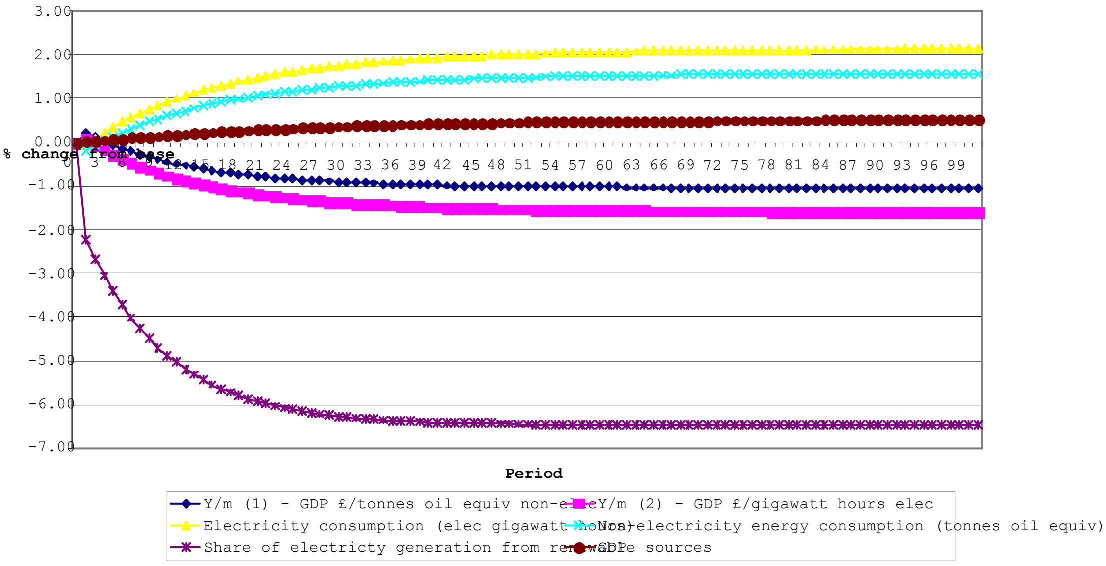
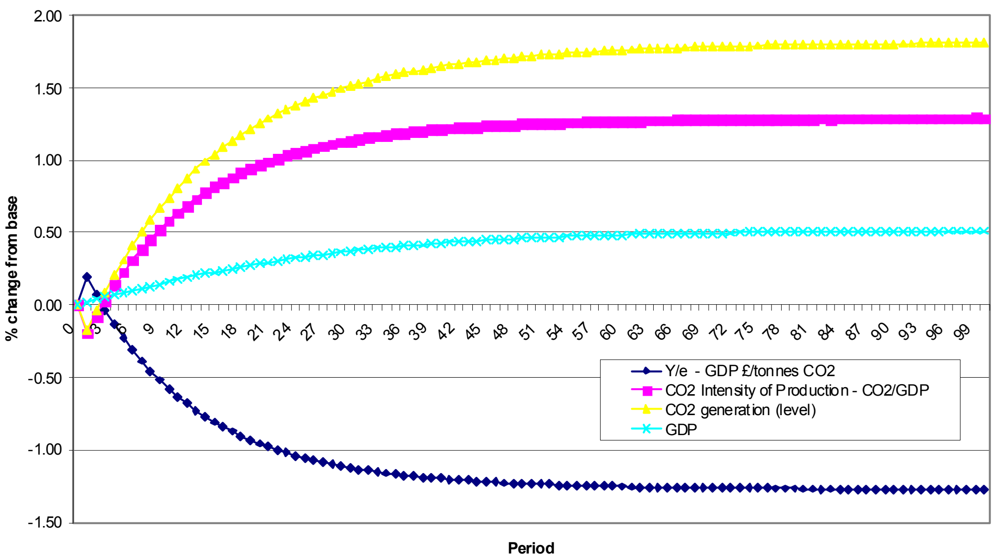


Figure A2.2. Impact of a 5% increase in energy efficiency in the Non-Renewable Electricity sector on environmental indicator variables



It is useful to look more closely at the cases where backfire is observed as the nature of this effect is different in each of the three cases. Backfire in the Non-renewable Electricity sector follows the patterns expected in the existing literature. This is the most directly energy-intensive production sector and, in our 1999 database, accounts for around 25% of total electricity use and around 20% of total non-electricity energy use in the Scottish economy. Table A2.1 and Figures A2.1 and A2.2 show that, while there is a significant positive impact on GDP (0.5% over the long run), the proportionate increases in all types of energy consumption at the economy-wide level are much bigger (2.1% for electricity and 1.6% for non-electricity energy consumption), with a resulting negative impact on all the key 'sustainability' indicators reported. In the case of Renewable Electricity, on the other hand, while the backfire results in Table A2.3 are also very large, this sector is much less energy intensive and accounts for (again, according to our 1999 database) only 0.2% of total non-electricity energy use and 4.5% of electricity use in the Scottish economy. Figures A2.3 and A2.4 show that, while both types of energy consumption rise over the long run - by 0.2% for electricity and 0.07% for non-electricity – these increases are much smaller than in the case of Non-Renewable electricity, with the large backfire effect driven by the fact that such a small share of energy use is directly affected by the shock. However, the impact on key indicator variables, such as the energy and CO2 intensity of GDP (see Table A2.1) is smaller when the shock is targeted at the Renewable sector. Thus, there is a trade-off to be considered - both positive economic and negative environmental effects are smaller. However, there are a wide range of variables to be taken into account; for example when the Renewable Electricity sector is targeted, there is a fairly rapid and significant increase in the share of electricity generated from renewable sources (see Figure A2.3), but this is assuming no constraints on the growth of this sector in response to the positive supply stimulus.

Figure A2.3-Impact of a 5% increase in energy efficiency in the Renewbale Electricity Sector on Key Indicators

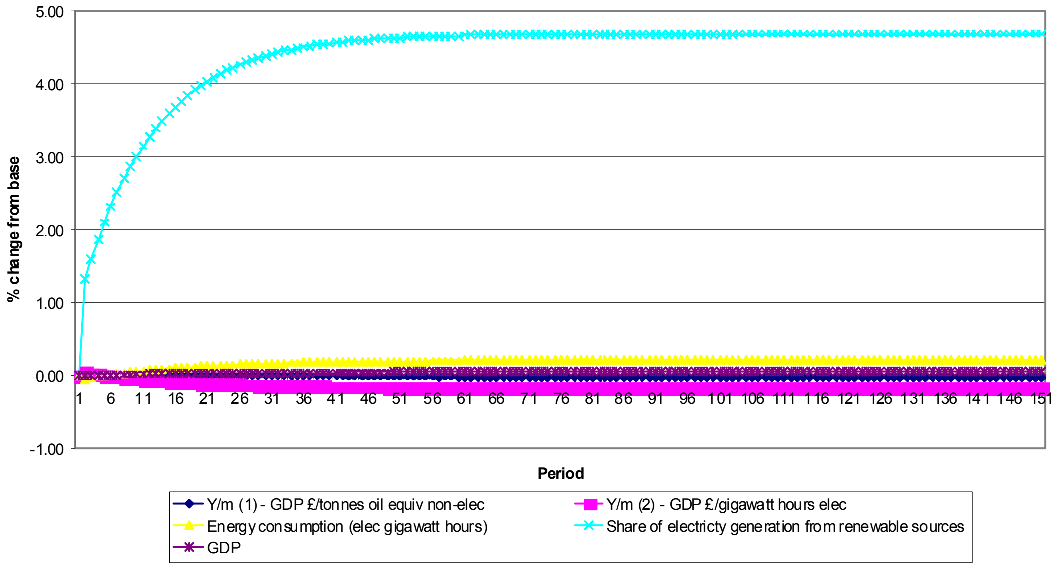
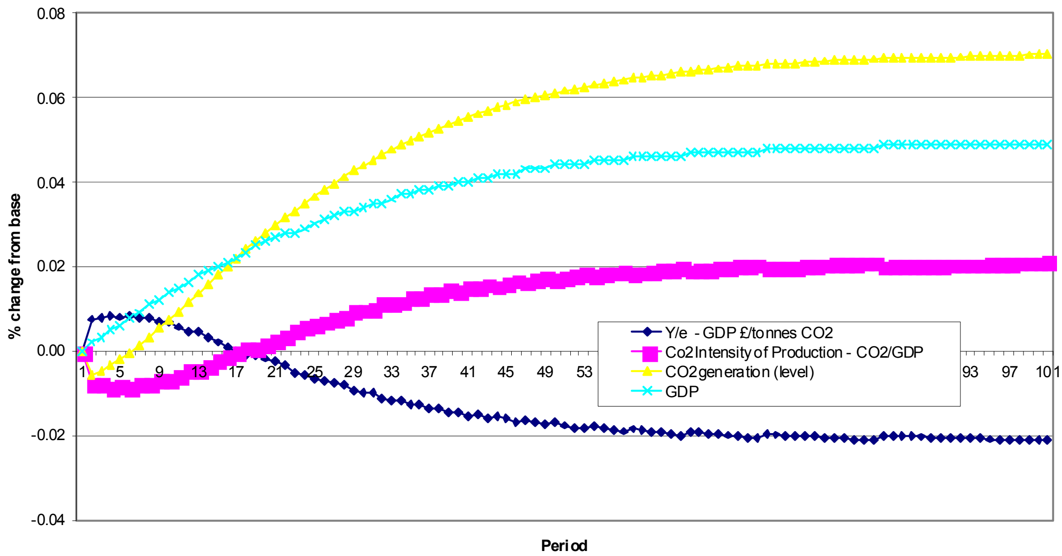


Figure A2.4 Impact of a 5% increase in energy efficiency in the Renewable Electricity Sector on Environmental Indicators

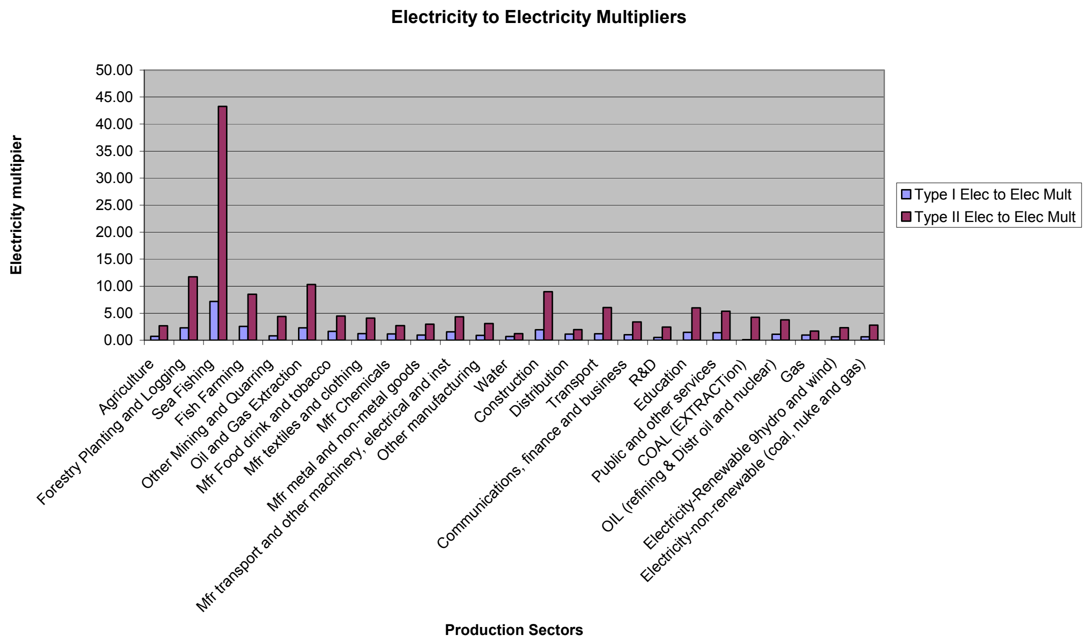


The Sea Fishing sector is an interesting case. This is the least electricity-intensive sector in the Scottish economy. Table A2.3 shows that here we observe the smallest electricity rebound effect in the short-run, but the biggest long-run backfire effect (bigger even than in the electricity sectors). Again, the changes in energy consumption underlying this dramatic result are very small in the case examined here. Electricity consumption in the Sea Fishing sector itself falls in response to the increase in efficiency, but there is a small increase in aggregate electricity consumption of 0.0008% (over the long-run). This is mainly driven by increases in imported and domestic electricity used by the 'Transport' and 'Textiles and Clothing' sectors, both of which are direct intermediate suppliers of inputs to the 'Sea Fishing' sector. The increase in aggregate energy consumption is small but the efficiency shock is applied to a small share of total energy use. This means that there is in fact a sizeable backfire effect in terms of electricity consumption (323.8% over the long run) even though the shock is limited to the least (directly) electricity intensive production sector in the economy. This demonstrates why a general equilibrium framework is essential in assessing the nature and scope of rebound effects, even when improvements in energy efficiency are focussed in a single sector/activity.

Use of environmental IO analyses in understanding and anticipating CGE results

The electricity rebound result for the Sea Fishing sector may be surprising to readers who associate large rebound effects mainly with direct energy intensities. However, if we begin our analysis with a basic environmental IO accounting analysis, the results are not so surprising. Environmental IO analysis allows us to examine different types of multipliers for energy use and pollution generation, which take into account the target sector's backward linkages in the economy and the pollution and energy use embodied therein. The most striking IO results for the Sea Fishing sector are its Type 1 and Type II 'electricity to electricity' multipliers (see Figure A2.5). These show us how much electricity use in the economy arises per unit of direct electricity use for the sector in question. In the case of Sea Fishing both of these multipliers are the largest of the 25 Scottish production sectors identified in our framework, with 7.2 gigawatt hours arising per 1 gigawatt directly consumed in the Type I case and a huge 43.3 gigawatt hours per 1 gigawatt in the Type II case. These multipliers suggest that there will be large multiplier effects in terms of electricity use at the economy-wide level for any unitary direct change at the sectoral level.

Figure A2.5 Type 1 and Type II 'electricity to electricity' multipliers

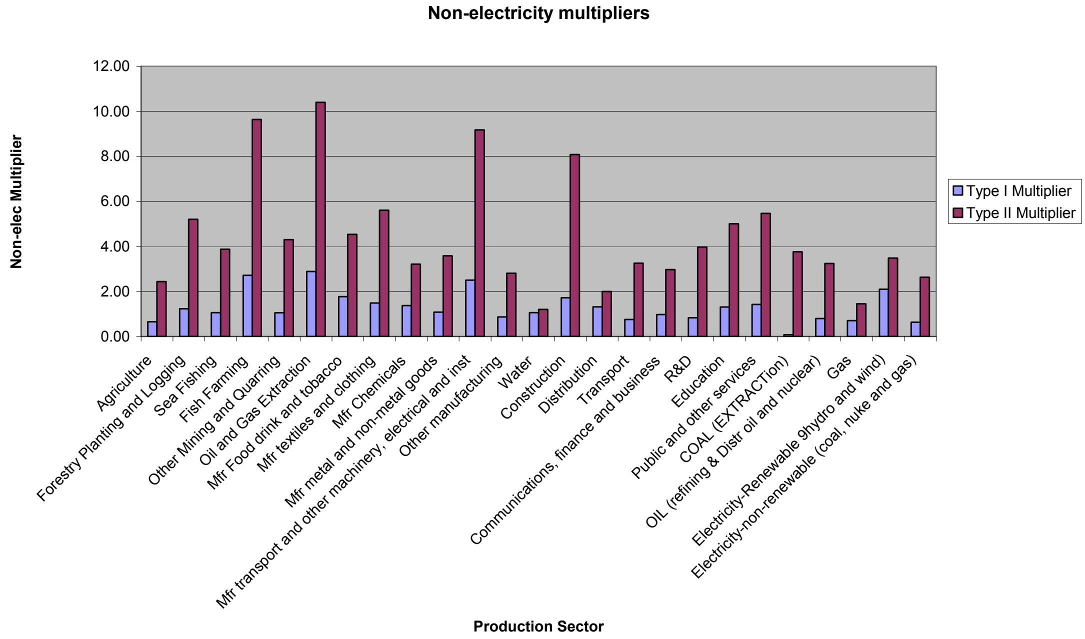


The role of CGE analysis in modelling the impacts of shocks that affect prices and supply-side behaviour

While IO analyses are undoubtedly useful in understanding the importance of sectoral linkages, where we expect price effects to be important – for example, where rebound and disinvestment effects in response to a change in energy efficiency.[15] The value-added from CGE in identifying and analysing such effects can be shown if we continue with the example of improved energy efficiency in the Sea Fishing sector. The IO results in Figure A2.6 (direct, Type I and Type II non-electricity intensities for the non-energy supply sectors – i.e. non-electricity inputs, measured in tonnes of oil equivalents per unit of output - show that the Sea Fishing sector has the highest *direct* intensity among the non-energy supply sectors. Therefore we may expect the explanation of the non-electricity rebound effect to be more straightforward (as in the case of the Non-renewable Electricity sector), although the Type I and II multipliers in Figure A2.6 show that indirect and induced effects will again be important.

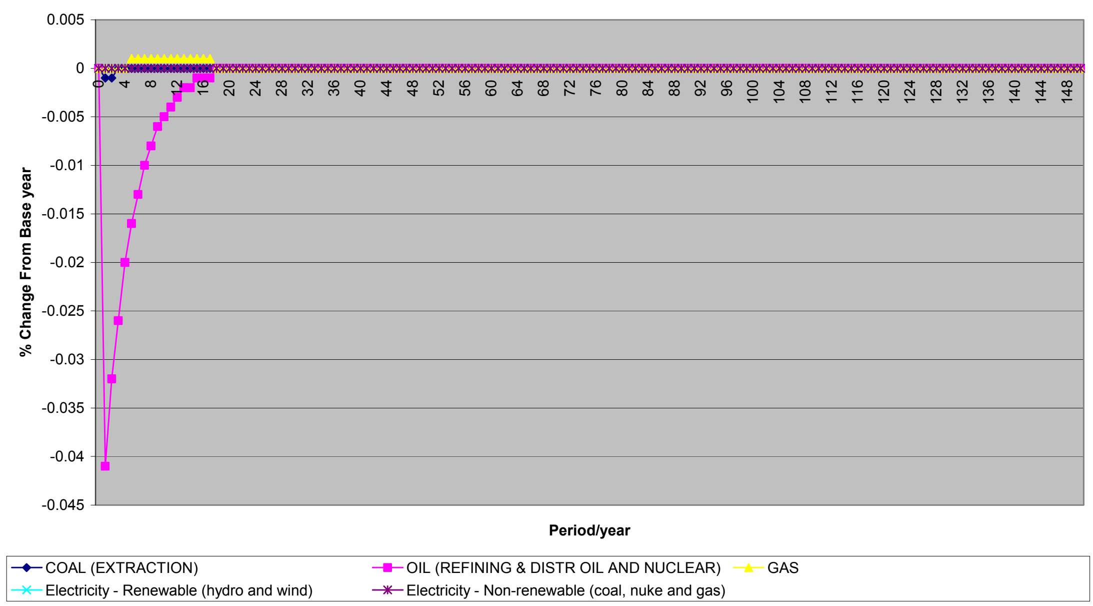
[15] A more general point to note is that any change in efficiency is a supply-side shock that cannot be effectively modelled in an IO framework (given the assumptions of passive supply and universal Leontief – fixed proportions – technology).

Figure A2.6 Type 1 and Type II 'non-electricity to non electricity' multipliers



However, Table A2.3 shows much smaller short and long run rebound effects for Sea Fishing relative to those for Non-renewable Electricity. Part of the explanation will be that the latter is much more intensive in terms of non-electricity energy inputs. However, the disinvestment effect discussed above is important in the case of Sea Fishing, particularly in the case of oil (diesel) as an input to production, the local supply of which comes from the Oil (Refining and Distribution and Nuclear) sector, hereafter simply referred to as the Oil sector. When the output price of the Oil sector falls in response to the initial contraction in demand from the pure efficiency effect in the Sea Fishing sector, this is sufficient to lower profitability to such an extent that the capital rental rate decreases sharply, as shown in Figure A2.7, triggering disinvestment.

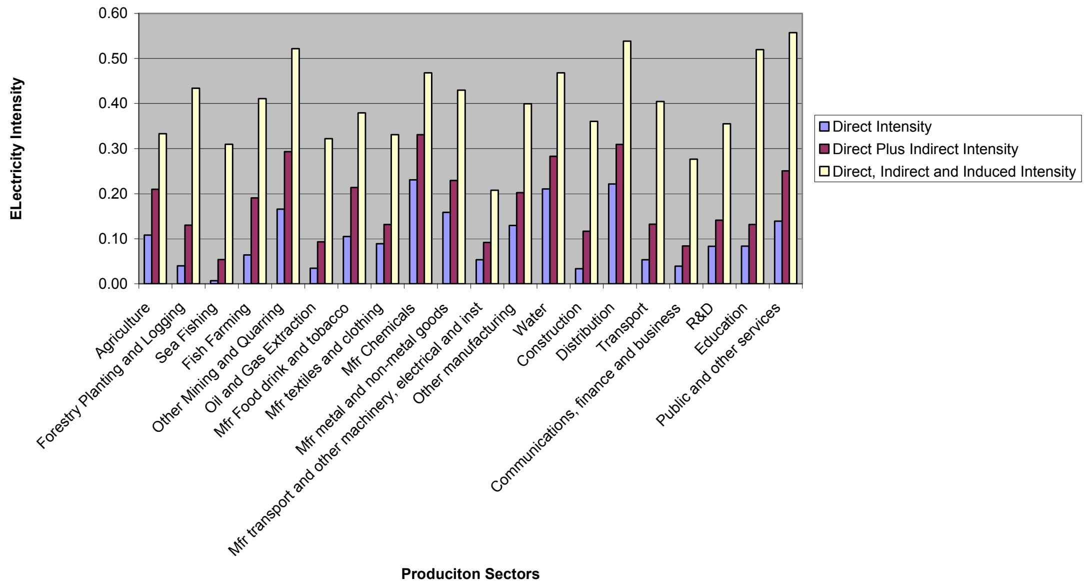
Figure A2.7 Percentage Change in Capital Rental due to a 5% improvement in the sea fishing sector



The reason why the disinvestment effect his does not occur in the case of Non-renewable Electricity is that (in our model configuration), demand for output is sufficiently elastic to increase revenues as prices fall and prevent profitability from decreasing to the extent that the capital rental rate collapses (i.e. as explained above, it is the *net impact* of different effects that is key to the outcome in any one case). In the case of what happens to the Oil sector when the Sea Fishing sector is targeted the energy efficiency shock, while demand throughout the system for Scottish Oil outputs does respond to the initial drop in prices (for example, with an increase in export demand), this is not sufficient to prevent profitability from decreasing and disinvestment occurs. In order for the return on capital and profitability to recover, the price of locally produced oil has to begin rising again - 12 years after the shock it is back to its initial level – which will dampen the rebound effect. This process occurs in all of the cases where disinvestment is reported in Tables A2.3 and A2.4. However, note that in some cases, the rebound effect is constrained to such an extent that it is smaller in the long run than in the short run.

Other sectors of interest: public and other services

Figure A2.8 Electricity Intensities



Part of the motivation of reporting the energy efficiency simulations is to demonstrate how CGE results can be interpreted, with input from a more straightforward IO analysis. To take another example, given the focus on reducing electricity consumption through improved energy efficiency in the recent AEA report, combined with the summary results in Tables A2.1 and A2.3 and our IO analyses, the Public and Other Services sector (hereafter referred to as POS) is of interest. Figure A2.8 shows that POS has the largest Type II electricity-output intensity (electricity required per unit of final demand for POS output) among the non-energy supply sectors and also a relatively high direct intensity. Table A2.1 shows that (of the sectors we identify) the 5% increase in energy efficiency leads to the largest long run drop (-0.31%) in total CO2 emissions, accompanied by one of the largest long-run increases in GDP (0.02%). Figures A2.9 and A2.10 show that, in contrast to the results where the electricity sectors are targeted (Figures A2.1-A2.4), there is also a desirable impact on all the sustainability indicators identified (i.e. energy consumptions and emissions fall, while the GDP-intensity of energy use and emissions generation rises). However, Figure A2.11 shows that the impact on capacity in the energy supply sectors (all of which suffer from disinvestment effects) should also be taken into account. Indeed, the strength of the disinvestment effect is such that this is one of the cases where rebound effects actually decline over time.

Figure A 2.9 Impact of a 5% increase in energy efficiency in the Public and Other Services Sector on Key Energy Indicators

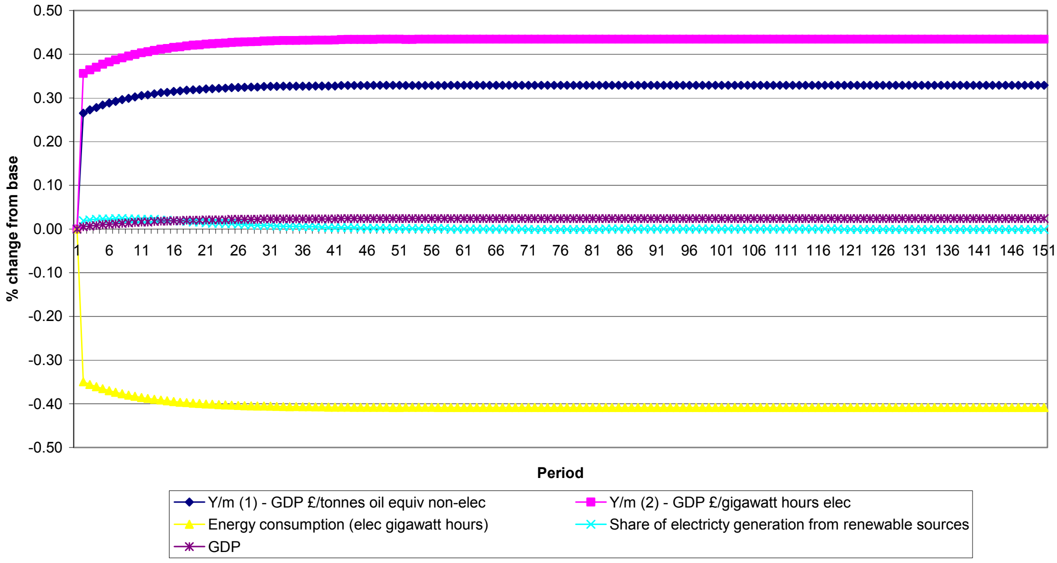


Figure A 2.10 Impact of a 5% increase in energy efficiency in the Public and Other Services on Environmental Indicator Variables

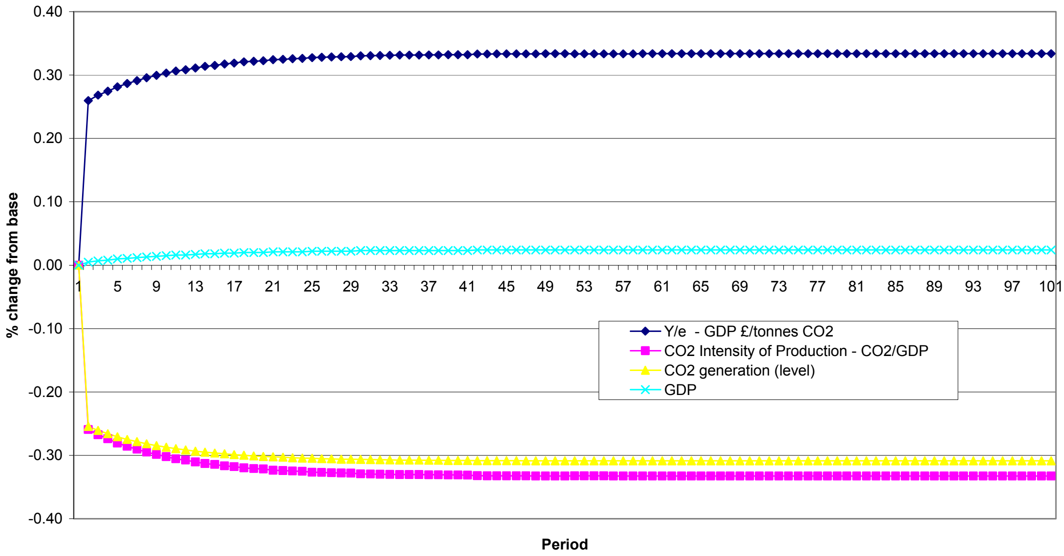
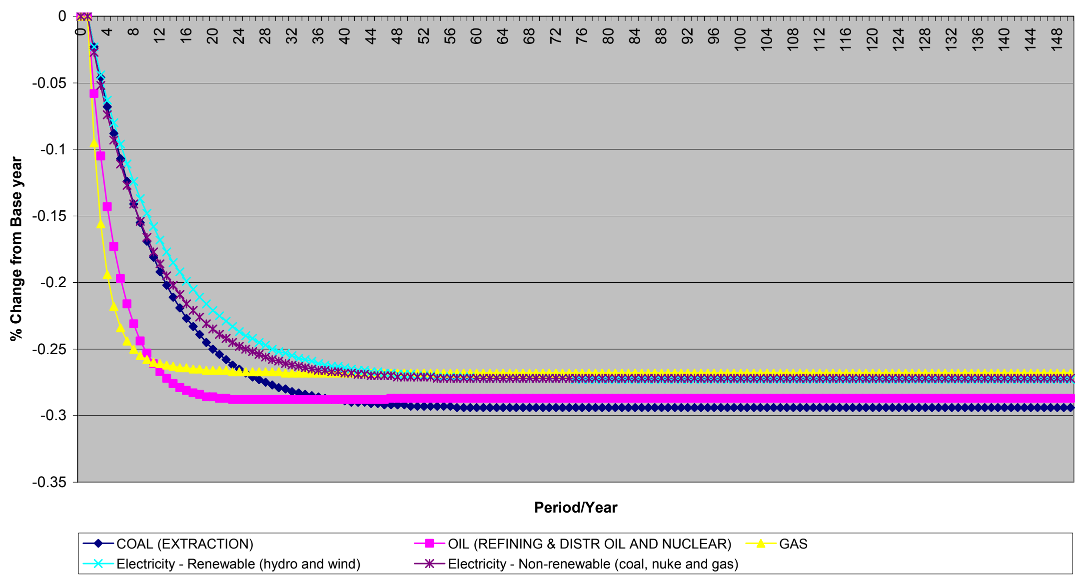


Figure A2.11 Percentage Change in Capital Stocks in the Energy Sectors due to a 5% improvement in the Public and Other Services



Other sectors of interest: the aggregate manufacturing sector

In the AMOSENVI model 6 manufacturing sub-sectors are identified. When these are shocked individually all show some extent of rebound effect, dampened by disinvestment effects, but with decreases in CO2 generation. However, the identification of these sub-sectors is ours and there may be interest in what happens if we introduce the energy efficiency improvement to Scottish manufacturing as a whole. Therefore, we have run another simulation where all 6 manufacturing sectors are shocked together. Summary results are presented in Tables A2.3 and A2.4 (along with some other grouped sectors that may be of interest). Note that the positive effects of improved energy efficiency in manufacturing are amplified when the whole sector is affected, with a long run increase in GDP of 0.07% accompanied by a 0.14% decrease in total CO2 emissions Figures A2.12 and A2.13 show period-by-period (year-by-year) results for the energy and environmental indicators identified in this study. Again, these show that the effects of improved energy efficiency in manufacturing are generally positive, with absolute decreases in all types of energy consumption and CO2 generation, and fall in the energy and CO2 intensities of economic activity.

Figure A2.12-Impact of a 5% increase in energy efficiency in the Aggregate Manufacturing Sector on Key Energy Indicator Variables

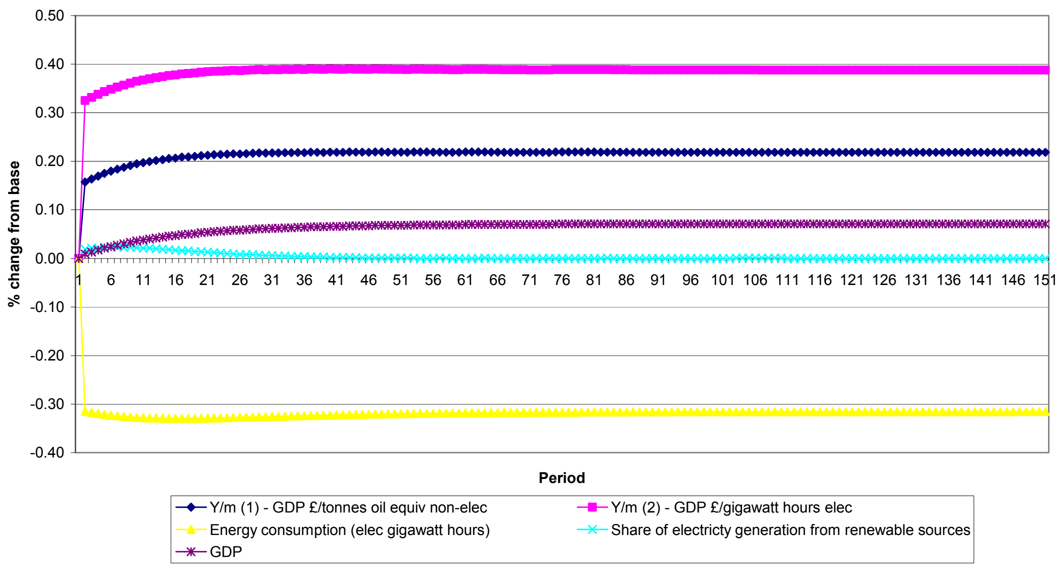
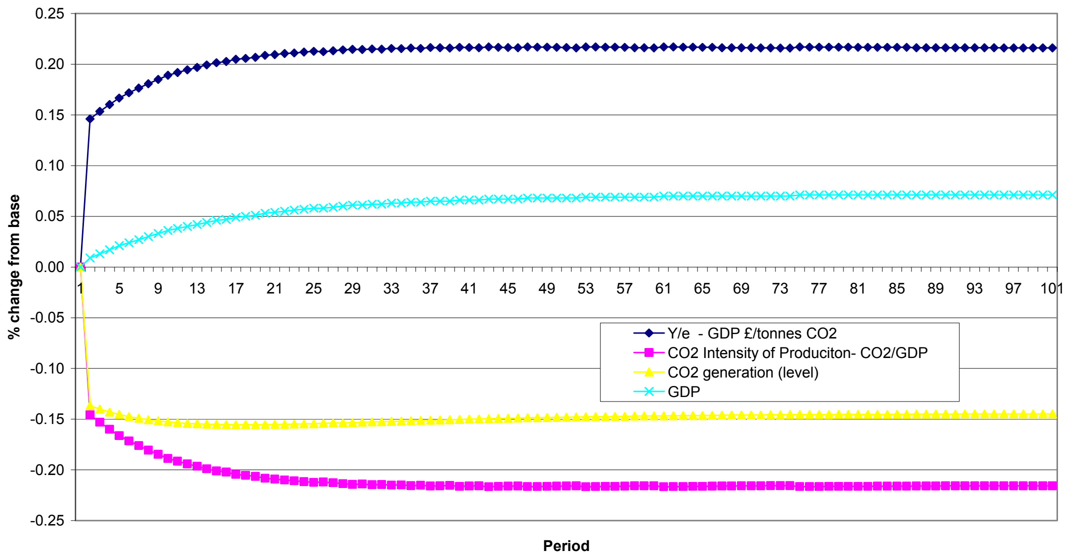
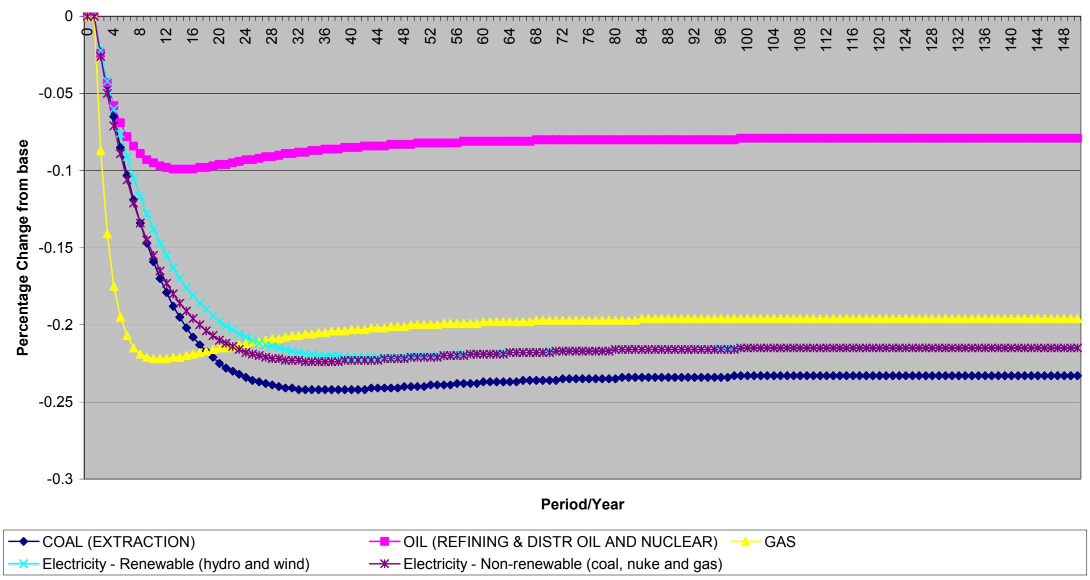


Figure A2.13- Impact of a 5% increase in energy efficiency in the aggregate Manufacturing sector on environmental indicator variables.



The only negative effects are that the share of electricity generated from renewable sources falls (this is a result of the great stimulus to the competitiveness of the more energy intensive Non-renewable electricity sector) and there is a contraction in capacity in all five Scottish energy supply sectors due to the disinvesment effect (see Table A2.4 and Figure A2.14).

Figure A2.14- Percentage Change in Capital Stocks in the Energy Sectors due to a 5% Improvement in the Aggregate Manufacturing Sector



A note of caution

The results presented in this appendix serve the dual purpose of indicating the likely nature of effects on key economic and environmental variables in response to an improvement in energy efficiency in different sectors of the Scottish economy and to help developing understanding of how to interpret CGE results using other information, such as results of IO accounting exercises. However, aside from the qualification noted at the outset regarding the age of the dataset used for both the IO and CGE analysis, it is also important to note that the configuration of the model (i.e. assumptions regarding behavioural relationships, labour and macroeconomic closures etc) will impact on results of energy efficiency simulations. This is demonstrated in the sensitivity analyses reported by Hanley et al (2008) and Turner (2008a). Of particular importance in examining rebound effects are factors determining the general equilibrium elasticity of demand for energy as prices change. As noted above, we have made some broadbrush assumptions in the absence of econometric estimates of key energy demands etc, a problem we aim to address to some extent through the current programme of research into rebound effects under the ESRC First Grants Initiative. However, sensitivity analyses conducted so far have begun to indicate what are likely to be key parameters on which to focus our efforts in this respect. For example, we have recently carried out (as yet unpublished) work extending the simulation work for the commercial Transport sector (the base simulation for which is reported in Tables A2.1 and A2.3).[16] This focuses on rebound effects for the key energy input of oil, shows that if one parameter, the elasticity of substitution between energy and non-energy intermediate inputs to production in this sector is raised from the current value of 0.3 to 1 (i.e. unitary elasticity of demand), we get rebound effects of around 100% (and the disinvestment effect disappears) and if we raise it any further we get backfire. Similar changes would be expected if we were to increase the responsiveness of different elements of direct and derived energy demands to changes in prices in any one of the sectors for which results are reported here. This conclusion emphasises the need to improve the modelling infrastructure for Scotland, with attention to, and availability of appropriate data for the econometric estimation of key energy demand relationships.

A2.5 Extended analysis of the impacts of improved technological progress: the potential impacts of the existing policy emphasis on improving labour productivity

Our initial work in this component of the project has focussed on the impacts of improved energy efficiency, as this is often taken to be the natural target of attempts to improve technological progress where our concern lies with reducing reliance on energy and the generation of greenhouse gas emissions. However, in another work stream currently being carried out in our project under the ESRC 1st Grants Initiative (in collaboration with Professor Nick Hanley at the University of Stirling), we have begun to look at the impacts of increasing labour productivity as another form of technological progress that may be expected to shift the economy onto a different path of development with respect to the CO2 intensity of GDP (i.e. its position on what is known as the Environmental Kuznets Curve)*.*This stream of work is as yet incomplete and unpublished. However, our initial findings suggest that considering the environmental impacts of current policy actions to improve labour productivity may provide a very valuable contribution to the policy debate on meeting the challenges of climate change. In short, while, as the results and discussion above suggest, the impacts of improved energy efficiency on the CO2 intensity of GDP are ambiguous (due to the likelihood of rebound, and even backfire effects), our initial results suggest that the impacts of increasing labour productivity may be more predictable and the *direction* of effects less sensitive to parameters governing price responsiveness in the system. Broadly our results suggest that, while boosting all activity, including CO2 generation, increased labour efficiency is likely to shift the input mix in production away from energy towards labour, and the composition of activity at the aggregate activity in favour of activities that are more labour than energy intensive, so that the CO2 intensity of Scottish production is likely to fall overall.

Using the AMOSENVI energy-environment Scottish CGE model we simulated a 5% improvement in labour efficiency, which is also termed labour productivity. As with the 5% improvement in energy efficiency this was introduced to the model as an exogenous and costless increase in labour augmenting technical progress to all production sectors and to groupings of sectors. Results for introducing the shock to each of the aggregate groupings of sectors introduced in Tables A2.2 and A2.4 above in turn are reported in Table A2.5 below, and for the full 25 sector breakdown in Table A2.6.

The results in Table A2.5 and Tables A2.6 (comparable with Tables and A2.1 and A2.2 respectively for the energy efficiency simulations) suggest that increasing the productivity of the labour force would have an adverse effect on the policies in place to reduce the level of CO2. CO2 emissions increase along with the boost to activity. However, when we look at the CO2 intensity of production, which uses CO2 as the numerator and GDP as the denominator, we can see more positive results for the economy inline with both objectives of the Scottish administration. This is because, as activity increases, due to the falling effective price of labour (mirroring the process

[16] This work was carried out with Sam Anson, an Economic Adviser with the Scottish Government, and student on our MSc in Economic Management and Policy, for his dissertation in the summer of 2008.

with increased energy and effective energy prices), producers shift their input mix in favour of labour.

With a 5% improvement in labour productivity we observe a positive change in GDP across all the 25 production sectors, except for the Sea fishing sector. As expected the level of CO2 emitted rises as a result of this efficiency improvement over the same time period. As labour productivity increases more output is produced which leads to higher emissions of CO2 at new levels of production for each sector or groups of sectors. While this is not a desirable outcome as the policy objective is to reduce the level of CO2 emitted over the long run period, there is a more positive result if we look at the CO2 intensity of Scottish production. With CO2 as the numerator and GDP as the denominator for this indicator we are looking at CO2 levels over the level of GDP. When there a positive number is reported, the level of CO2 is increasing faster to that of GDP, which shows that the 5% improvement in labour efficiency is having an adverse effect on the environment while productivity is increased. If a negative number is reported, this shows that while output across the economy is growing the levels of CO2 have not risen as fast as GDP.

An important point to note is that the GDP effects are significantly bigger in Tables A2.5 and A2.6 relative to their energy efficiency counterparts in Tables A2.1 and A2.3, with the exception of the cases where efficiency improvements are introduced to the Electricity sectors. This is largely explained by the fact that labour is a more important input to production than energy in most sectors. As noted above, in most cases, the absolute level of CO2 emissions increases. However, in a number of cases the greater growth in GDP under the labour efficiency shocks brings with it a bigger long run decrease, or smaller increase, in the CO2 intensity of Scottish production. For example, if the efficiency improvement is directed at the Communications, Business and Finance sector (which contains a number of the key sectors identified in the Scottish Government Economic Strategy), the long run decline in the CO2 intensity of Scottish production is 0.24% with the labour efficiency improvement, compared with 0.13% in Table A2.1 (energy efficiency). When efficiency improvements are directed at the Non Renewable Electricity sector, the increase in the CO2 intensity of Scottish production is 0.68% when this takes the form of an increase in labour productivity compared with 1.29% for energy efficiency.

However, it is important to bear in mind that improved labour productivity does increase CO2 emissions in most cases. The exceptions are where the efficiency improvement is aimed at Sea Fishing and Public and Other Services sectors (at least over the long run). Generally, over the long run, if all sectors experience a 5% improvement in either labour or energy efficiency, our initial results suggest that improved labour productivity gives better aggregate results in terms of GDP and the CO2 intensity of Scottish production, but not levels of CO2 production. However, if we focus the shock only on energy use sectors (i.e. omit the five energy supply sectors), the results are mixed in terms of the CO2 intensity of production and the larger increases in GDP from improving labour productivity need to be set against larger increases in Scottish CO2 production. However, two points should be noted. First, Table A2.6 shows that at the aggregate level, if we shock all 20 non-energy supply sectors, the CO2 intensity of Scottish production falls. Second, and perhaps more importantly, some initial sensitivity analyses suggest that if we make it easer to substitute between different types of input in production (including labour and energy), the results in terms of the CO2 intensity of production become more favourable for labour productivity and less so for energy efficiency. Therefore, further research is required. Nonetheless, the initial results presented here will hopefully stimulate discussion and consideration of potential positive and negative spillover effects of existing labour productivity policies and objectives to addressing the problem of climate change.

Table A2.5 Short and Long Run Impacts on GDP and CO2 from a 5% Increase in Labour Efficiency in Each Sector of the Scottish Economy

Production Sector	Short Run GDP	Long Run GDP	Short Run CO2	Long Run CO2	Short Run CO2/Y	Long Run CO2/Y
Agriculture	0.018%	0.035%	0.01%	0.03%	-0.01%	0.00%
Forestry Planting and Logging	0.005%	0.015%	0.00%	0.01%	0.00%	0.00%
Sea Fishing	0.007%	-0.035%	-0.14%	-0.09%	-0.14%	-0.06%
Fish Farming	0.005%	0.028%	0.00%	0.02%	0.00%	-0.01%
Other Mining and Quarring	0.005%	0.014%	0.00%	0.01%	0.00%	0.00%
Oil and Gas Extraction	0.031%	0.179%	0.02%	0.13%	-0.02%	-0.05%
Mfr Food Drink and Tobacco	0.062%	0.247%	0.04%	0.21%	-0.03%	-0.04%
Mfr Textiles and Clothing	0.029%	0.050%	0.01%	0.03%	-0.02%	-0.02%
Mfr Chemicals	0.025%	0.075%	0.02%	0.08%	-0.01%	0.00%
Mfr Metal and Non-metal goods	0.078%	0.147%	0.05%	0.14%	-0.02%	-0.01%
Mfr Transport and other machinery	0.142%	0.313%	0.02%	0.14%	-0.12%	-0.17%
Other Manufacturing	0.060%	0.120%	0.03%	0.10%	-0.03%	-0.02%
Water	0.006%	0.017%	0.01%	0.02%	0.00%	0.00%
Construction	0.147%	1.542%	0.04%	1.61%	-0.11%	0.07%
Distribution	0.446%	1.392%	0.31%	1.39%	-0.14%	-0.01%
Transport	0.164%	0.481%	0.08%	0.35%	-0.08%	-0.03%
Communications, business and finance	0.390%	1.123%	0.15%	0.88%	-0.24%	-0.24%
R&D	0.006%	0.006%	0.00%	0.00%	0.00%	0.00%
Education	0.158%	0.354%	0.03%	0.27%	-0.12%	-0.09%
Public and Other Services	0.464%	0.638%	0.13%	-0.33%	0.39%	-0.24%
Coal (Extraciton)	0.002%	0.002%	0.00%	0.00%	0.00%	0.00%
Oil (Refining and distr oil and nuclear)	0.003%	0.011%	0.01%	0.02%	0.01%	0.01%
Gas	0.004%	0.012%	0.00%	0.01%	0.00%	0.00%
Electricitity-Renewable	0.002%	0.016%	0.00%	0.03%	0.00%	0.02%
Electricity- Non-renewable	0.018%	0.166%	0.22%	0.85%	0.20%	0.68%

Table A2.6 Short Run and Long Run Impacts on GDP and CO2 from a 5% Increase in Labour Productivity in Selected Groups of the Scottish Economy

Production Sectors	Short Run GDP	Long Run GDP	Short Run CO2	Long Run CO2	Short Run CO2/Y	Long Run CO2/Y
Agriculture and Primary 1-6	0.072%	0.301%	0.05%	0.24%	-0.02%	-0.06%
Manufacturing 7-12	0.395%	0.954%	0.17%	0.7%	-0.22%	-0.26%
Energy Supply Sectors 21-25	0.029%	0.211%	0.23%	0.92%	0.20%	0.71%
Energy use Sectors 1-20	2.23%	7.16%	0.96%	6.19%	-1.24%	-0.91%
All sectors 1-25	2.26%	7.39%	1.19%	7.21%	-1.04%	-0.18%

Technical Appendix A3 Simulation results: impacts of demographic change

A3.1 Introduction

This section (as in the former) involves exploring and extending previous applications of the AMOS modelling framework in order to allow us to provide some detail on the properties of the model, and on what types of simulations and sensitivity analysis can be carried out. In this section we extend previous work done at the Fraser of Allander Institute on the impact of demographic change on the Scottish economy. In recent work for the Scottish Government, colleagues at the University of Strathclyde examined the economic impact of demographic change on the Scottish economy, through linking a demographic model with the AMOS CGE model for Scotland. The findings and results of this work are discussed in Lisenkova *et al*. (2008).

Here, we extend the previous analysis by using the AMOSENVI model, rather than the AMOS model, for a set of anticipated changes to the Scottish total and working age population consistent to those modelled in this previous work. The AMOSENVI model has a more sophisticated treatment of energy inputs and a set of linked environmental accounts for Scotland. This provides considerably more detail on the relationship between economic activity in Scotland and energy and environmental impacts, and allows us to construct and report environmental and sustainability indicators. Further details on the AMOSENVI model of Scotland, and the use of environmental and sustainability indicators can be found in Section 1 of this report and in Learmonth *et al*. (2007) and Hanley et al. (2008). In this section, we describe an application of the type of analyses that can be carried out, and the type of results that can be obtained from, using the AMOSENVI model to explore the impacts of demographic change on the Scottish economy.

While the literature on the economic impacts of demographic change are well researched, the literature on the environmental and energy impacts of demographic change is small, indeed an initial literature search found little directly relevant material. A number of studies linking demographic change to energy consumption and environmental indicators have been carried out. However these tend to be statistical relationships between demographic variables and energy/environmental impacts. York (2007) uses regression analysis to calculate the impacts of a number of factors – per capita incomes, population, urban population and population over the age of 65 – on energy consumption for European Union nations from 1960 to the present day. Their results indicate that both total population and the age of that population are important for total energy consumption, with a 1% rise in total population indicating a 2.665% increase in energy consumption, while the population aged over 65 also has positive effects on energy consumption. Using projections for each of these variables York (2007) presents predictions for total energy consumption for European Union companies by 2025. While not using projections to predict future emissions, Cole and Neumayer (2004) similarly include demographic factors in their analysis of the factors driving emissions of CO_2 and SO_2. They find that a 1% change in total population produces a roughly similar change in CO_2 emissions, but that the marginal impact of total population on SO_2 emissions is an increasing function of the level of population. For both CO_2 and SO_2 emissions, the age structure of total population does not give statistically significant results. From our initial reviews of the literature, there appears to be little work focusing on the energy and environmental impacts of anticipated changes in working age and total population on the labour market, and, through wages, to economic activity. We seek to make a contribution to this literature with the simulations reported in this note.

Previous work (Lisenkova *et al*., 2008) found that for Scotland, forecasted changes to the level and age structure of the population of Scotland will produce significant impacts upon the Scottish labour market, and the competitiveness of Scottish industries, which will include energy industries. Changes in the size of total Scottish output, the composition of that output across industries and the structure of production within industries will have impacts on energy demand and environmental impacts, including on emissions. In this note, we explore these impacts of anticipated population change using the AMOSENVI CGE model.

In Section A3.2 below we follow material presented in Lisenkova *et al*. (2008) and very briefly set out the anticipated theoretical impact of demographic change on Scottish labour market. In a sub-section of Section A3.2 we set out one set of predicted changes to total and working age population in Scotland, and which form the basis for the inputs to the AMOSENVI CGE model. We term these predicted changes our "Central" scenario. Section A3.3 sets out the simulation strategy we follow, while in Section A3.4 we set out the key economic, energy and environmental results. Section A3.5 reports the results of sensitivity analyses, including to the assumed structure of the Scottish labour market, three alternative scenarios for population change – which we term "High", "Medium-High" and "Low" – and variations in the values of key parameters within the AMOSENVI model.

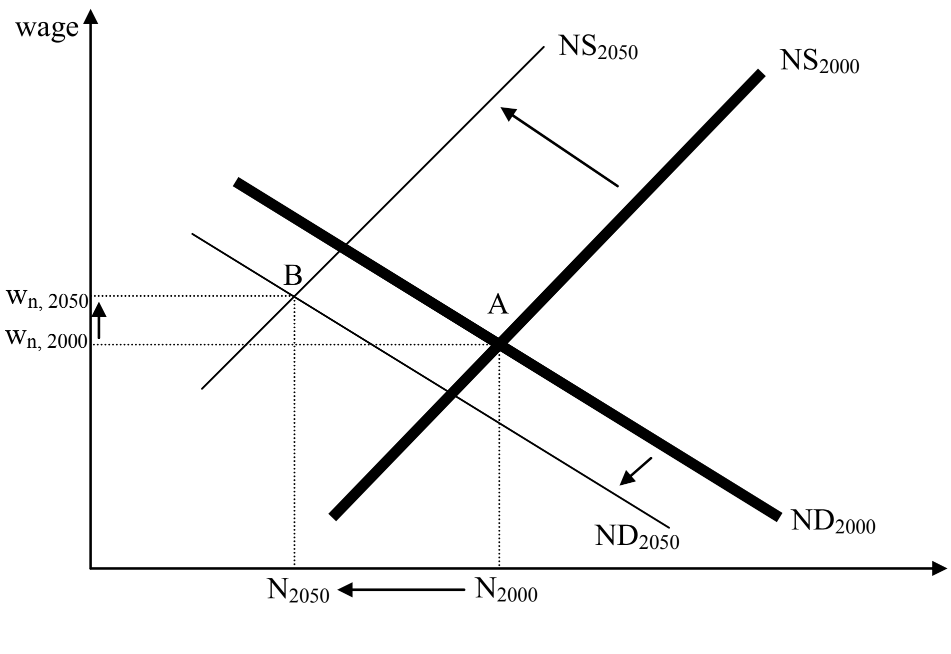
A3.2 Theoretical impacts of population change on the Aggregate Scottish labour market and details of the empirical "Central" scenario

Theoretical analysis

In this section we provide the conceptual underpinning for the simulation results which follow. We direct our attention at the labour market, given than we are interested in the way in which an ageing and declining population produces changes in the labour market. We focus on the long run, so that the equilibrium wage and employment rate are those towards which the economy is being attracted over time.

Figure A3.1 uses an aggregate labour supply and demand framework to represent the Scottish labour market. The wage is the real consumption wage. Labour is mobile between sectors we do not attempt to consider no skill or geographic "sub-markets" within Scotland. We take a comparative static approach here to describe the stages through which exogenous demographic changes might impact upon the labour market. The labour supply curve in this market is assumed to be upward sloping. As real wages rise, more people are attracted into the labour force. The labour demand curve slopes downwards as for higher levels of real wages, Scottish output becomes less competitive, and with falling output (including exports), household incomes and consumption fall and there will be a reduction in the labour intensity of production, and so a fall in the quantity of labour demanded.

Figure A3.1: The Scottish labour market in 2000 and 2050 under alternative population projections



In Figure A3.1 we compare the long-run labour market equilibrium after fifty years of demographic change with that in 2000, under the assumption that total and working age population changes are as anticipated and that real *per capita* government expenditure in Scotland remains constant. The initial equilibrium is represented by point A, where the base period labour demand and supply curves intersect. This generates the initial equilibrium employment and real consumption wage level as given by $w_{n,2000}$, N_{2000}.

According to recent population projections for Scotland carried out by Government Actuaries Department (GAD), over the next fifty years the population of Scotland will decline and age. These exogenous changes in population size and age composition will have an effect upon both the labour supply and demand schedules shown in Figure A3.1. Firstly, the fall in the working age population reduces labour supply at each real consumption wage level, generating an inward shift of the labour supply curve. This is shown on Figure A3.1 by the new labour supply curve NS_{2050}, which lies to the left of the original supply curve NS_{2000}.

The change in population also affects labour demand. We follow Lisenkova et al (2008) in assuming that real government expenditure per head remains constant, so that Scottish real government expenditure varies in line with the changes in total Scottish population. In the AMOSENVI model, any exogenous change in product demand shifts the labour demand curve in the same direction. The demand curve shifts by the extent of the exogenous employment change plus the appropriate Type II IO employment multiplier. Because total population is lower in 2050, labour demand is also lower at each real consumption wage rate. The labour demand curve, therefore, is shifted to the left (ND_{2050}) compared to its previous level (ND_{2000}).

The new equilibrium is at point B, the intersection of the general equilibrium labour demand and supply curves NS_{2050} and ND_{2050}. Both the labour demand and supply shifts lead to lower employment, but the impact on the real wage depends on the relative size of the shifts. Our prior expectation is that the reduction in labour supply will be much greater than the reduction in labour demand. This will be due to, firstly, the proportionate fall in working age population being less than the fall in total population and, secondly, government expenditure being only one element of Scottish final demand. This would lead us to expect to see a tightening of the labour market and an increase in real wages.

In sensitivity analysis, we have three alternative scenarios in total, one of which is for greater population decline, and greater population ageing – i.e. a scenario consistent with lower net migration or lower fertility rates (*ceteris paribus*). Under such a scenario, the fall in working age population would be greater again, with greater tightening of the Scottish labour market following a larger fall in labour supply than outlined above. We would expect a greater rise in real wages and fall in employment under this scenario. Also in sensitivity analysis we have two scenarios for higher population growth than under the central scenario. Under these, such as would be consistent with increases in net migration or higher fertility (*ceteris paribus*), we might expect the opposite to be the case.

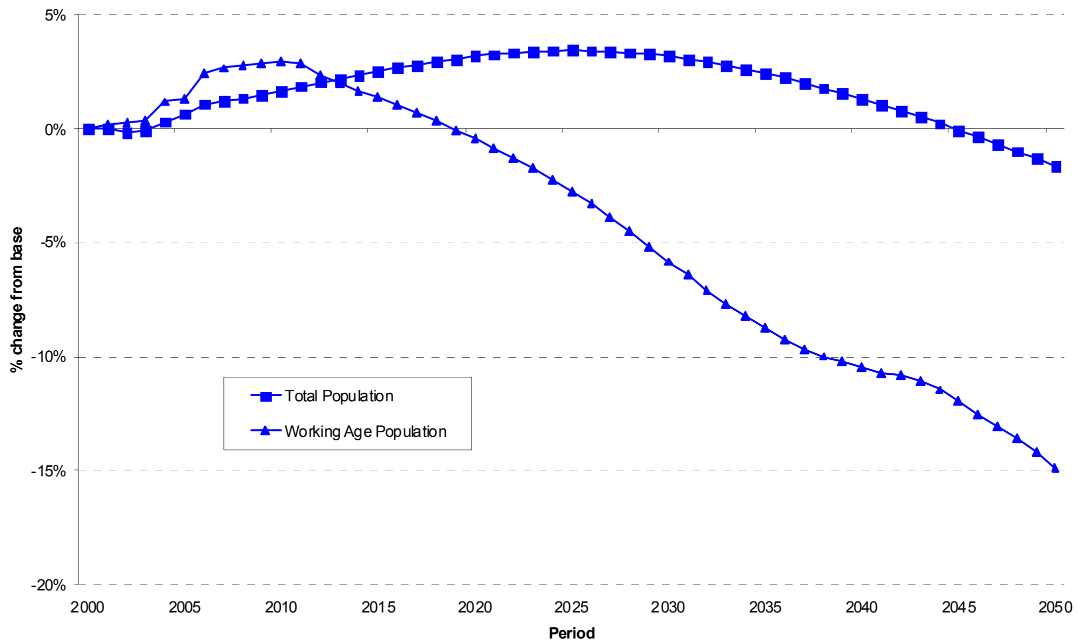
Under our two population growth scenarios, the Scottish working age population and labour force is going to be higher than that assumed under the “Central” scenario, meaning that there will be an outward shift in the labour supply curve. Labour demand will also shift outwards as total population is higher. Under these scenarios, we would expect the equilibrium level of employment to be higher. With a greater increase in labour supply than total population we would expect the labour market to see a fall in the wage rate.

Central total and working age population scenario

The AMOSENVI model is currently calibrated for a base year of 1999. Colleagues in the Fraser of Allander Institute have estimated a number of alternative projections for the Scottish population from 2000 to 2050. These use the same assumptions for key demographic parameters as are used by the Government Actuaries Department (GAD) in their projections, but allow us to make annual projections, and create alternative projections, annually to 2050. For the simulations reported in this chapter, we therefore assume that our models base year of 1999 also represents the Scottish economy in the year 2000.

The demographic changes estimated by our projections are used as the exogenous disturbances in the model simulations which follow. The population scenarios used therefore differ slightly from those produced by the General Registers Office for Scotland (GROS). We use a scenario of net migration to Scotland of 5000 per year as our "Central" projection[17]. This is similar, although not identical, to the assumed rate of net migration in the "Principal Projection" for the Scottish population used by GROS. Assumed changes in the total and working age population for Scotland from 2000 to 2050 under our "Central" scenario are shown in Figure A3.2.

Figure A3.2: Percentage changes from base year for working age and total population under "Central" projection



In 2050, under our "Central" scenario, total Scottish population is 1.68% lower than in 2000, however this is a significantly older population than in 2000, with the working age population down 14.91%. We describe the assumed changes in three alternative sensitivity scenarios in Section A3.5.

A3.3 Simulation strategy

We follow the method employed in Lisenkova *et al*. (2008) in estimating the impact on Scotland of population decline and ageing. Beginning with the labour supply effect, there will be changes in the labour supply schedule as the fall in the working age population reduces labour supply at each real consumption wave level, implying that the labour supply curve would shift inwards. As the model is currently configured, we enter the changes in the labour force by means of a linear trend between 2000 and 2050, so that the change in the working age population over the 50 years is modelled as a linear reduction.

The labour demand effect is treated in the identical way to Lisenkova *et al*. (2008), where it is assumed that real per capita government expenditure remains constant, so that the level of government spending changes with the size of the Scottish total population. As noted in the earlier paper, this assumption is realistic since Government expenditure in Scotland is mainly financed through the Westminster Parliament and the experience of the Barnett formula over recent years is that per capita Government expenditure figures for Scotland have remained fixed relative to the level in England.

As in Lisenkova *et al*. (2008), any changes in the composition of government and household consumption demand which occur because of demographic changes described above are not

[17] The most recent GROS figures for their "Principle" scenario assumed a net migration of 8500 p.a. Details of the differences between the scenarios presented here and the GROS projections can be found in Lisenkova et al. (2008) and Lisenkova et al. (forthcoming).

considered in this analysis. The results presented here will be driven by general demand side factors, such as movements between public and private consumption as population structure changes, as well as supply-side factors operating through the tightening of the Scottish labour market and the impact of this on the competitiveness of individual sectors.

A3.4 Results from "Central" population projection with AMOSENVI

Aggregate economic impacts

We present the change in total and working age population under our "Central" population projection in Figure A3.2. The demographic data represented in Figure A3.2 are used to convert exogenous disturbances to labour supply and labour demand in the AMOSENVI model as discussed earlier. From running the AMOSENVI model for these exogenous disturbances to total and working age population, we get the simulation results summarised in Table A3.1.

The results in Table A3.1 should be interpreted as variations away from what would have occurred but for the changes in total and working age population. As expected following the earlier theoretical discussion, in the results for 2050 we see a fall in employment of 9.89% with a corresponding fall in GDP of 9.30 %.

Table A3.1: Percentage change of aggregate economic and demographic variables under the central projection, bargaining labour market closure

	2000	2005	2010	2020	2030	2040	2050
GDP	0.00	-0.41	-0.99	-2.60	-4.59	-6.88	-9.30
Real Wage	0.00	0.95	1.90	3.69	5.30	6.65	7.89
Consumption	0.00	-0.21	-0.49	-1.37	-2.63	-4.25	-6.08
Working Age Population	0.00	1.29	2.91	-0.45	-5.85	-10.48	-14.91
Total Population	0.00	0.63	1.66	3.16	3.16	1.28	-1.68
Total Employment	0.00	-0.54	-1.20	-2.87	-4.94	-7.32	-9.89
Competitiveness Index	0.00	0.23	0.62	1.52	2.44	3.25	4.00
Consumer Price Index	0.00	0.18	0.48	1.16	1.83	2.40	2.93
CO_2 generation	0.00	-0.31	-0.83	-2.33	-4.26	-6.45	-8.76
CO_2 intensity of output	0.00	0.09	0.17	0.27	0.35	0.45	0.60
Electrical energy demand	0.00	-0.47	-1.21	-3.26	-5.72	-8.38	-11.10
Non-electrical energy demand	0.00	-0.31	-0.82	-2.28	-4.18	-6.34	-8.63
GDP/electrical energy demand	0.00	0.06	0.22	0.68	1.19	1.64	2.02
GDP/non-electrical energy demand	0.00	-0.10	-0.18	-0.32	-0.44	-0.57	-0.73

Two important points can be noted from the results in Table A3.1. Firstly, the fall in employment (9.89%) is less than the fall in working age population (14.91%). This suggests that there is an increase in the labour market participation rate, and a fall in the unemployment rate. The tightening of the Scottish labour market is clear from the 7.89% rise in real wages by 2050. Secondly, the decline in GDP closely follows the observed reduction in employment. The reduction in GDP is driven by the reduction in the labour force, and increase in real wages, causing a reduction in Scottish exports generated by the reduced competitiveness of Scottish output.

In 2050 the consumer price index is 2.93% higher, but the increase in the export price index (Competitiveness Index) is higher at 4.00%. As a consequence the demand for exported goods falls in the central projection by 7.55%. The capital stock will adjust to changes in output demand but this will occur more slowly than the change in employment in particular sectors so that the change in GDP will slightly lag the change in employment. There will also be a tendency for production to be more capital intensive given the increase in the nominal wage rate, so that there is some substitution of capital for labour.

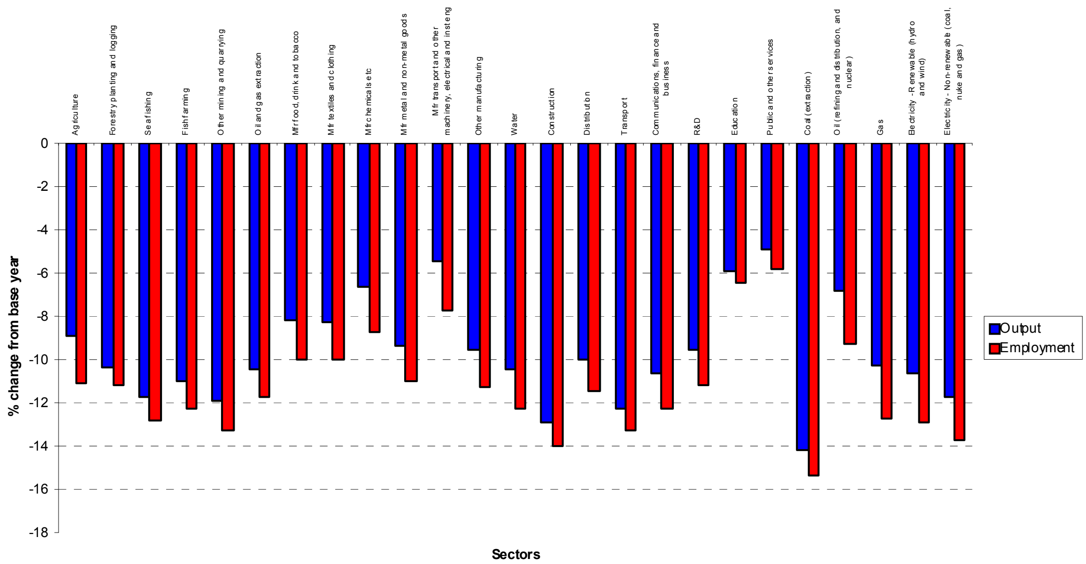
Public consumption, e.g. by Government in Scotland, is exogenously shocked in line with total population, but private consumption, e.g. by households, is endogenous within the AMOSENVI model, and can give a useful indication of the welfare of Scottish households. By 2050, the fall in private consumption is 6.08% - less than the fall in GDP and employment. This reflects the increase in the real wage for those in employment. As in Lisenkova et al (2008), private consumption falls by more than the reduction in total population, meaning a decline in *per capita* private consumption.

Sectoral economic impacts

Looking at the pattern of sectoral impacts, note firstly that the sectoral disaggregation of the AMOSENVI model is different to that used by Lisenkova et al (2007). The AMOSENVI model is calibrated around a SAM for Scotland in 1999, and for a set of economic and environmental accounts built around a consistent sectoral aggregation. We are particularly interested in the energy and environmental impacts of population change. We begin by discussing the sectoral economic results.

Figure A3.3 shows that by 2050 the output of, and employment in, all sectors in the Scottish economy are negative affected. There is, however, wide variation in the impacts across sectors, with the output of 'Education' and 'Public and Other Services' sectors falling by 5.9% and 4.9%, while 'Coal Extraction' and 'Construction' see a decline in output by 2050 of 14.2% and 12.9% respectively. The sectors in which government demand is concentrated in the base year IO – 'Education' and 'Public and Other Services' – are least affected since government expenditure *per capita* remains constant over the period simulated, and in total falls by 1.68% by 2050 (in line with the fall in total population).

Figure A3.3: Impact on sectoral output and employment, % changes from base year values by 2050



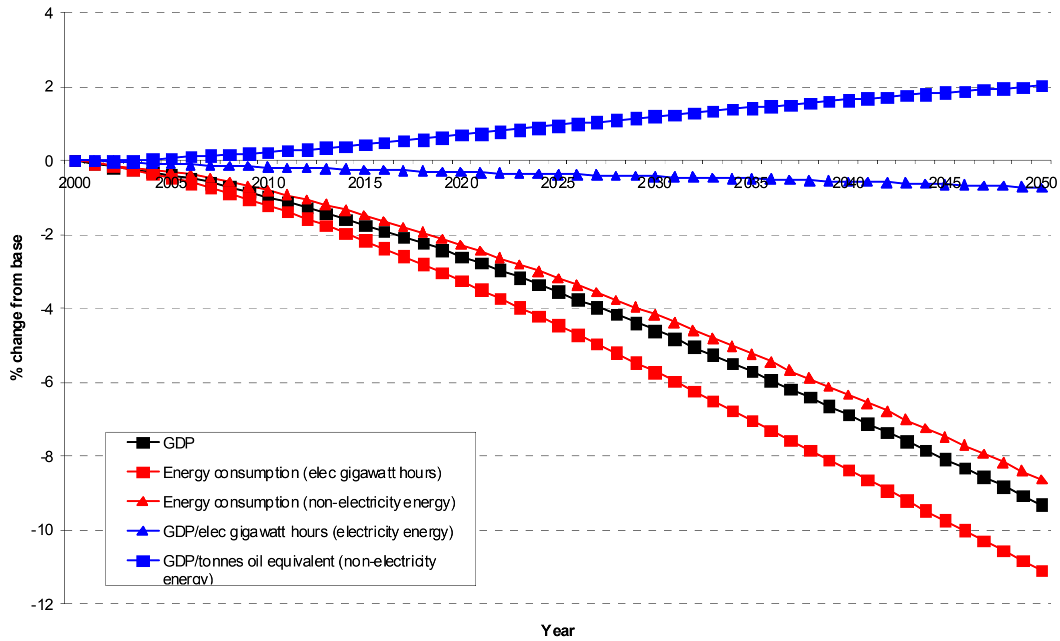
The extent of the negative impact upon other sectors is determined by two factors. Firstly, labour intensive sectors are worst affected because of the now increased cost of labour. Second, the sectors which are more exposed to international trade feel the negative effects on competitiveness more strongly. For example, sectors such as 'Sea Fishing', 'Fish Farming', 'Oil and Gas Extraction', 'Chemicals' and 'Transport and Other Machinery' suffer these negative export competitiveness effects, with each of these sectors having exports constituting more than 80 per cent of sectoral output in the base year SAM. 'Sea Fishing', which is the most export intensive sector, sees the biggest decline in output of these sectors because is it also the most labour intensive.

Of the five energy sectors identified in AMOSENVI, the largest fall in output by 2050 (14.2 per cent) is observed for the 'Coal Extraction' sector. Of the five energy sectors, the output of the 'Oil Refining' output falls by the smallest amount, caused by it having the lowest employment intensity of all sectors in AMOSENVI. In all sectors, employment falls by more than output because as the price of labour rises, firms substitute capital for labour. Also, it takes more time to optimally adjust the capital stock.

Energy and environmental indicator impacts

Changes in the energy and environmental indicators can be seen in Figure A3.4. Looking firstly at GDP, we can see that under the central simulation for the change in total and working age population, GDP reduces by 9.30% per cent by 2050. As observed above, the output of each sector contracts by 2050 as competitiveness suffers, particularly for export- and labour-intensive sectors. The level of energy demands also fall as output declines, as shown by the two red lines in Figure A3.4. Electrical energy consumption (measured in GWh) and non-electrical energy consumption (measured in tonnes oil equivalent) fall by 11.09% and 8.63% respectively.

Figure A3.4 : Energy indicators, % changes from base year under the central population projection, bargaining labour market closure



The other indicators of sustainability, detailed in Figure A3.4, show mixed results. These two measures relate the amount of energy consumption divided by GDP, and use electrical energy and non-electrical energy as the respective numerator. Note in these measures that GDP is the numerator, rather than the denominator as in the ‘CO2 intensity of Scottish production’ measure. A positive change in these indicators therefore indicates a positive movement in sustainability of economic activity, while a negative change indicates the opposite. As mentioned above the fall in electrical energy consumption is greater than the fall in GDP, and so the GDP/electrical energy consumption indicator moves in a positive direction, indicating greater sustainability. On the second measure, the fall in non-electrical energy consumption is less than the falls in GDP, and so on this indicator, there is a negative movement showing a fall in sustainability.

Figure A3.5: CO_2 emissions and CO_2 intensity of production indicator, % changes from base year under the central population projection, bargaining labour market closure

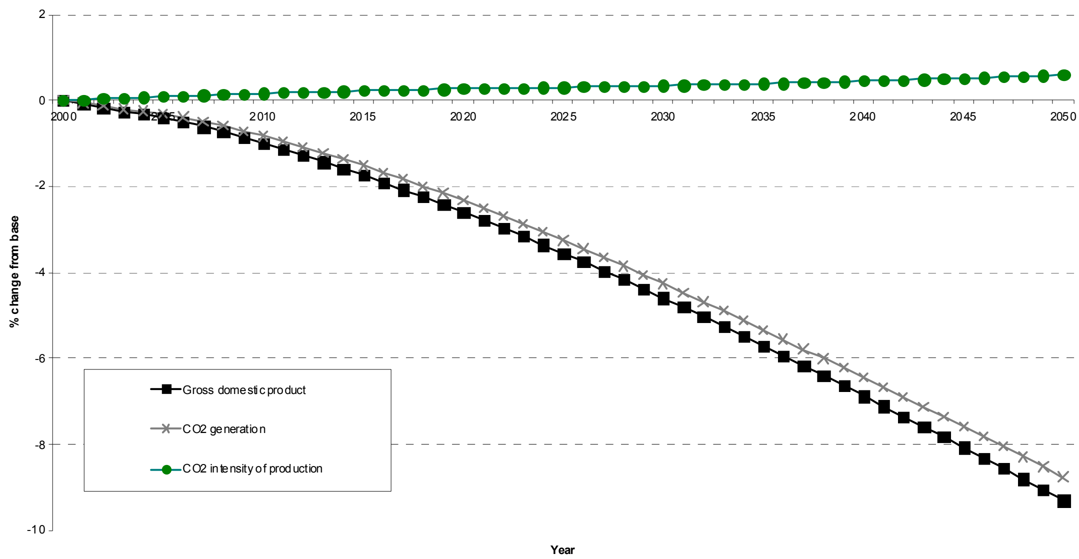


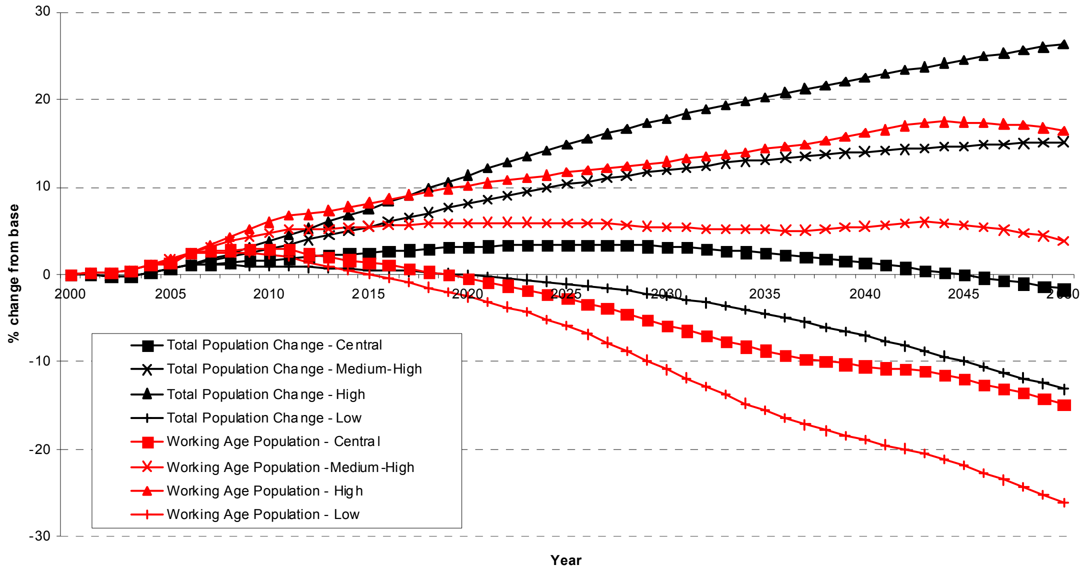
Figure A3.5 shows the changes in GDP and CO2 emissions as well as the CO2 intensity of Scottish production. Emissions of CO2 are 8.76% lower by 2050, a smaller fall than the decline in GDP. This means that the CO2 intensity of production – defined as CO2 emissions divided by GDP output (£million) – shows a small increase, i.e. consistent with decreasing sustainability of output. The carbon intensity of Scottish output is rising; however this is due to the greater relative decline in output than decline in CO2 emissions by 2050.

A3.5 Sensitivity analysis

Alternative population scenarios
As in Lisenkova et al. (2008), the assumptions made about demographic parameters are important for the shape of the projected total population and working age population profiles for Scotland. The birth rate, male and female life expectancy and the rate of net migration will all be important demographic parameters for the scale of the economic impacts. Lisenkova *et al*. (2008) found that the demographic parameter with the biggest economic impact is the assumed rate of net migration.

For the simulations in this project, three alternative scenarios for Scottish population change have been modelled. taken two extremes of population change for Scotland to demonstrate the usefulness of the modelling approach to understanding the dynamics, through the Scottish labour market, of changes in total and working age population. The variants are consistent with the central scenario, but in each scenario one of the demographic parameters has been adjusted. We label these three scenarios “High”, “Medium-High” and “Low” respectively. In the first of these – the “High” scenario – the rate of net migration is revised upwards from 5000 per year to 30000 per year. The second (“Medium-High” scenario has the rate of net migration at 20000. The final (“Low”) scenario keeps the rate of in migration constant at 5000 but lowers the birth rate from 1.65 births per woman to 1.45 births per woman. The profile for total and working age population under our Central, High, Medium-High and Low population scenarios are shown in Figure A3.6.

Figure A3.6: Percentage changes from base year values for working age and total Scottish population under four population scenarios



Under the “High” scenario for Scotland, total and working age population is higher in 2050, up 26.3 and 16.4 per cent respectively compared to 2000, while under the “Medium-High” scenario, total and working age population in 2050 is lower than the “High” scenario, up 15.3 and 3.9 per cent respectively compared to 2000. The “Low” scenario, total population in 2050 is 13.1 per cent lower than in 2000, while working age population is 26.2 per cent lower.

In Figures A3.7 to A3.13 we present the changes in GDP, employment, real wage, consumption, CO_2 generation and electrical energy and non-electrical energy demands for these three alternative population scenarios.

Beginning with GDP and employment figures, Figure A3.7 and Figure A3.8 show that for the “High” scenario, GDP and employment are higher in 2050 by 11.2 and 12.7 per cent respectively, compared to the base year, and the “Medium-High” scenario also shows increases in GDP and employment relative to 2000. In the “Low” scenario, GDP and employment fall by around double the fall seen for the “Central” case, by 18.5 and 19.9 per cent respectively. As with the results presented for the “Central” scenario above, the mechanisms driving these results stem primarily from the labour market and the subsequent impact on the competitiveness of Scottish industries.

Figure A 3.7: Trends of Gross Domestic Product for "Central", "Medium-High", "High" and "Low" population scenarios

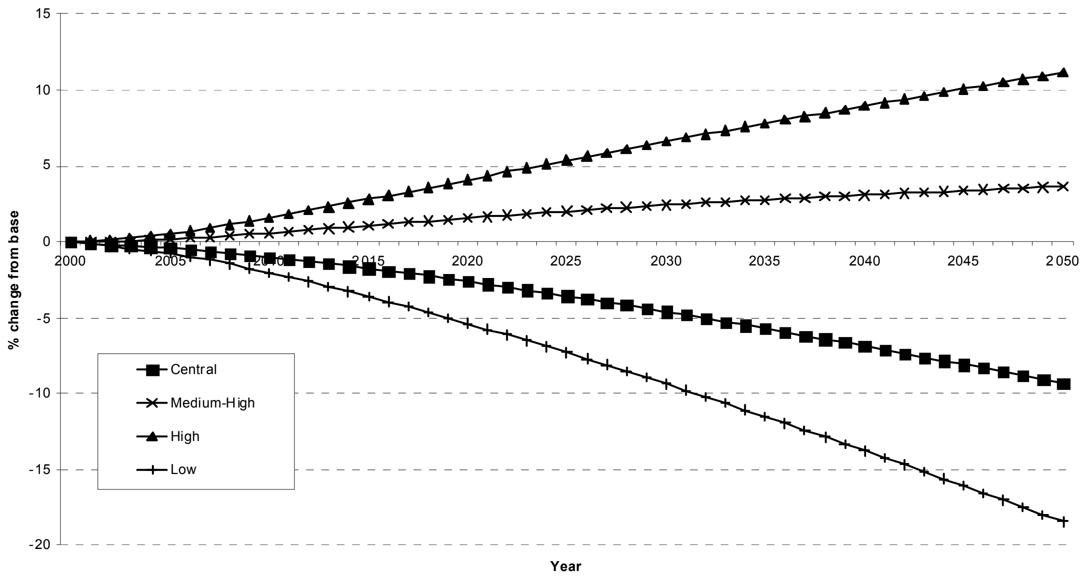


Figure A3.8: Trends of employment for "Central", "Medium-High", "High" and "Low" population scenarios

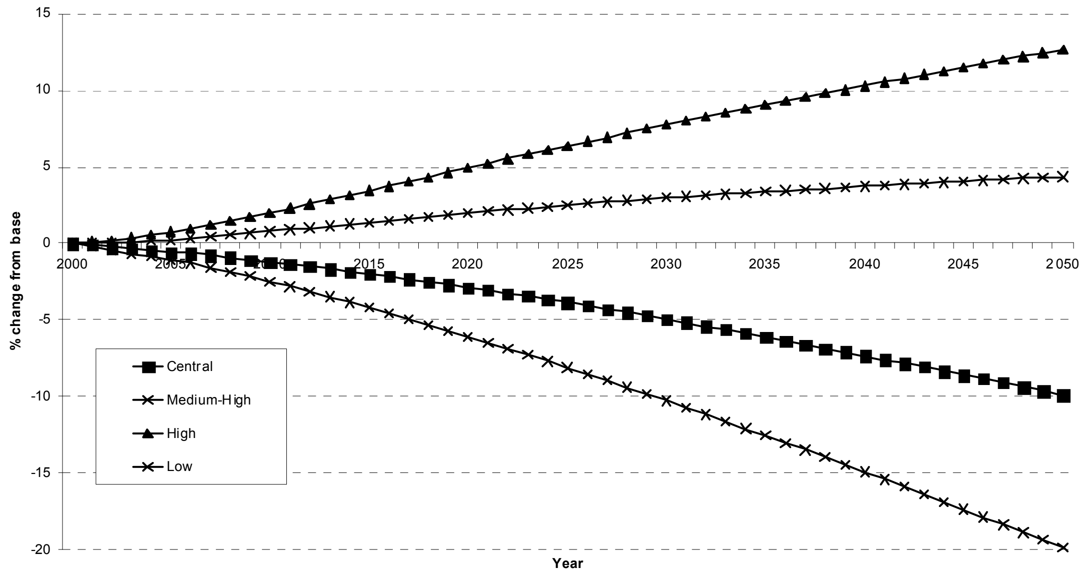
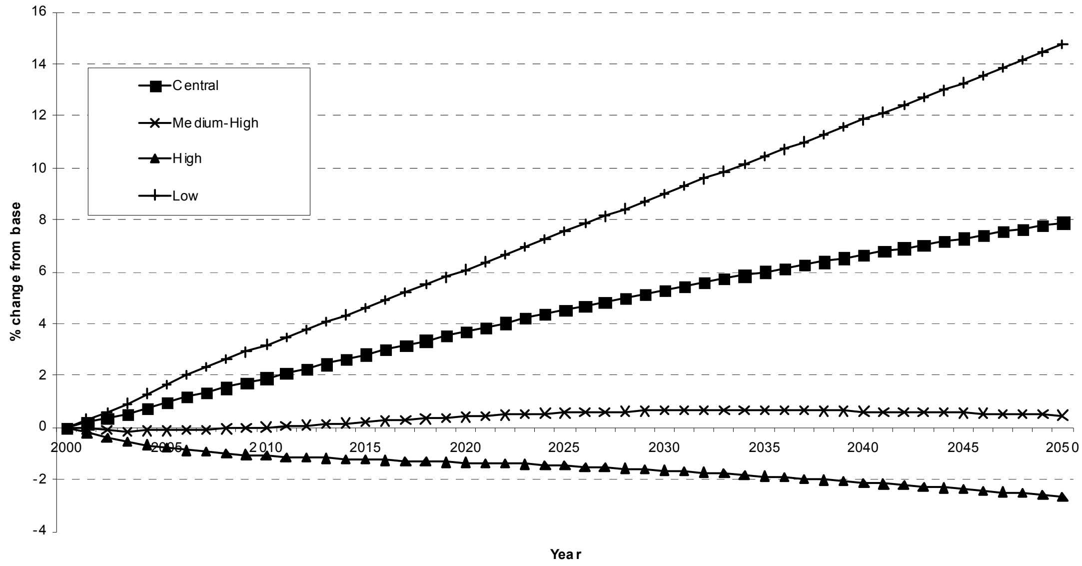


Figure A3.9 shows the changes in the real wage under the three population growth scenarios. It is the tightening in the regional labour market in response to the changes to working age population which drives changes in the real wages and the competitiveness of production, leading to the falls in output discussed above and shown in earlier figures. In the "High" scenario, where working age population and total population in 2050 are significantly higher than in 2000, these pressures are not seen. Conversely, in the "Low" scenario, the wage increase is much greater than the "Central" scenario.

Figure A3.9: Trends of real wages for "Central", "Medium-High", "High" and "Low" population scenarios



The impact of the alternative population scenarios on Scottish (private) consumption are shown in Figure A3.10. Under the "High" scenario, the change in total consumption in 2050 is positive, rising by 10 per cent. Consumption is also greater under the "Medium-High" scenario, but is lower in both the "Central" and "Low" scenarios. As in Lisenkova et al. (2008), the variation in consumption is less than the variation in GDP.

Figure A3.10: Trends in (private) consumption under "Central", "Medium-High", "High" and "Low" population scenarios

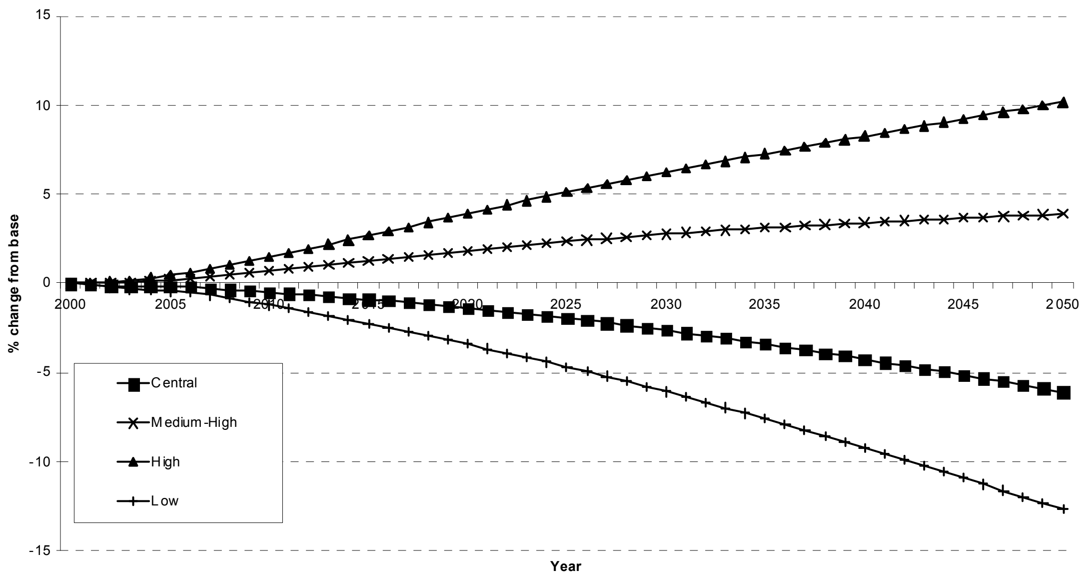
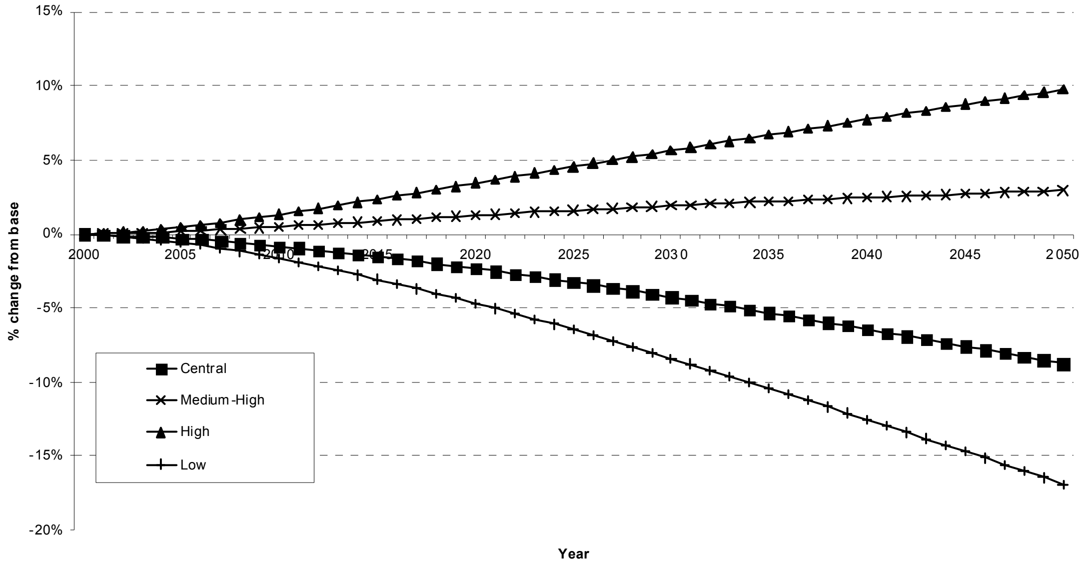


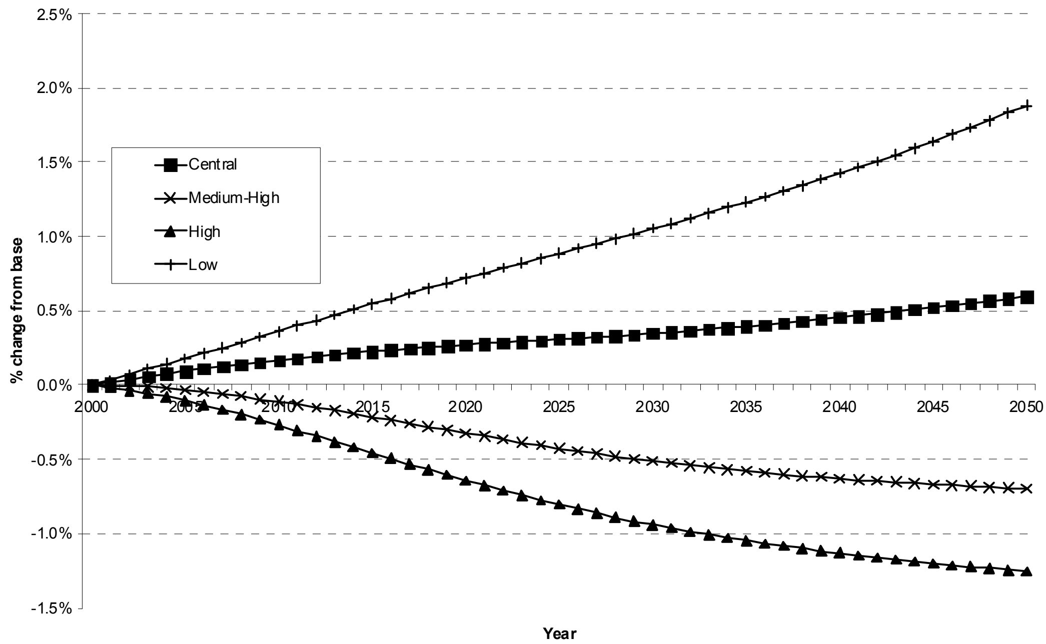
Figure A3.11 shows the impact of the alternative population scenarios on Scottish CO2 emissions. Under the "High" population scenario emissions of CO2 increase by 9.76 per cent, compared to an 8.76 per cent reduction observed under the "Central" scenario. With the "Low" population scenario, CO2 emissions fall further (down by 16.9%) due to the greater fall in economic activity.

Figure A3.11: Trends in CO_2 generation under "Central", "Medium-High", "High" and "Low" population scenarios



The movements in the "CO2 intensity of production" indicator are shown in Figure A3.12. As we have a greater increase in GDP than CO2 emissions for both the "High" and "Medium-High" scenarios (see Figure A3.7 and Figure A3.11), here this indicator moves in a downward direction, consistent with increasing sustainability of economic activity. Although the decrease in the CO2 intensity of production is small in both cases – 0.7 per cent and 1.4 per cent in the "Medium-High" and "High" scenarios respectively – this is an important finding. Recall however, that *total* CO2 emissions are 2.9 and 9.8 per cent higher in these scenarios.

Figure A3.12: Trends in CO_2 intensity of production indicator under "Central", "Medium-High", "High" and "Low" population scenarios



Roughly proportional falls are observed in electrical energy and non-electrical energy, as seen in Figures A3.13 and A3.14.

Figure A3.13: Trends in electrical energy demand under "Central", "Medium-High", "High" and "Low" population scenarios

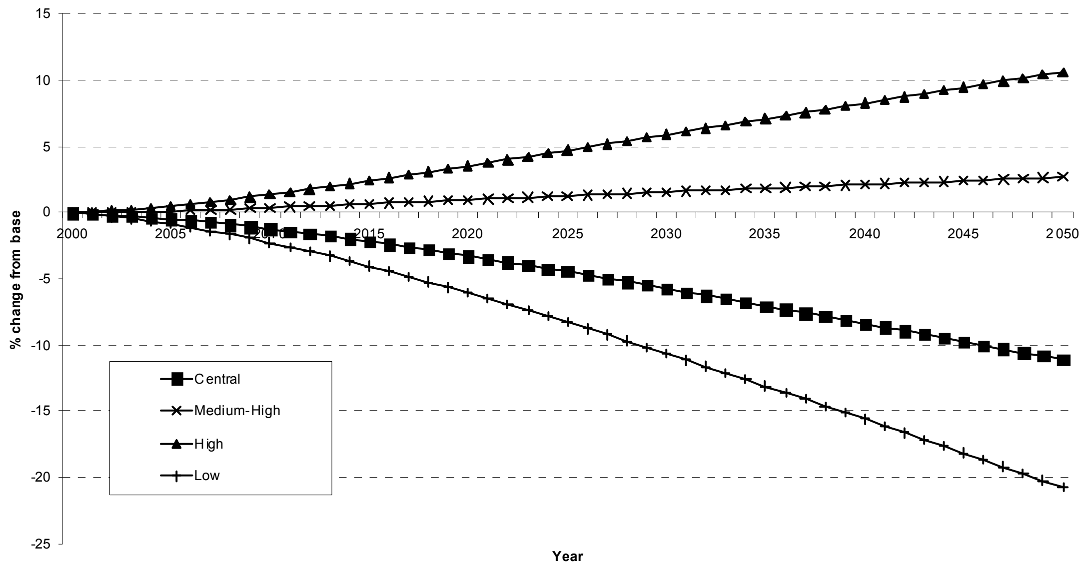
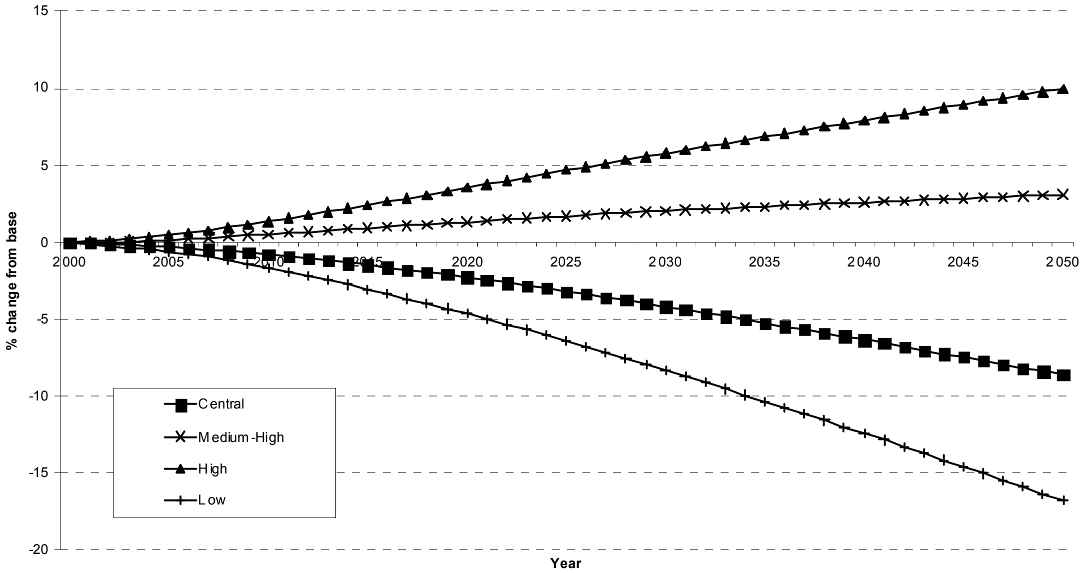


Figure A3.14: Trends in non-electrical energy (tonnes oil equivalent) demand under "Central", "Medium-High", "High" and "Low" population scenarios



Alternative labour market structures

In order to test how sensitivity the results are to variation in assumptions about the nature of the labour market, we conducted simulations for the same population changes, but under two limiting case. Firstly, we assumed within-period fixed labour supply. This means that labour supply is a given proportion of the labour force, where the labour force is adjusted period-by-period through demographic changes. There is therefore assumed to be no adjustments in unemployment, or the participation rate, as the labour market tightens. This implies a wage curve that is infinitely elastic. In any individual time period therefore, this is represented by a vertical labour supply curve.

The second alternative assumption is that the labour market is characterised by excess capacity, such that any changes in labour demand can be met by a corresponding change in the level of employment, but with no upward pressure on the real wage. In this case, in each time period the labour supply curve would be horizontal, and employment adjusts in labour demand through changes in the unemployment and participation rates. We saw the largest declines in GDP above in those scenarios in which real wages increased as a result of anticipated demographic change.

In the fixed labour supply case, we expect the employment reduction and the increase in the real wage to be larger than under the bargaining scenario. In the fixed real wage scenario, the opposite results should hold: we expect employment to fall and the wage increase to be less than in the bargaining scenario. However, when we run the model with a fixed real wage, the model fails to solve for a long-run equilibrium, and stops when unemployment rate falls to zero – although the dynamics of the model are wanting the unemployment rate to continue to fall. As noted in Lisenkova *et al*. (2008), the population constraints implied by the "Central" projections, combined with fixed *per capita* government expenditure, must cause real wages to rise. The fixed real wage scenario is therefore not feasible.

When labour supply is completely inelastic on the other hand, the whole adjustment to the labour force contraction comes through higher wages. Employment and output falls by more under this closure than under the bargaining closure as participation and unemployment rates remain fixed – i.e. firms are not able to substitute capital for now more expensive labour. In Table A3.2 we present the percentage changes in the main aggregate indicators under the fixed labour supply and fixed real wage labour market closures. When the model fails to solve under the fixed real wage labour market closure, we mark these cells with an asterisk.

TableA3.2: Percentage changes of aggregate economic and demographic variables under the "Central" population projection, for Exogenous Labour Supply and Fixed Real Wage labour market specifications

Exogenous Labour Supply	**2000**	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
Gross Domestic Product (GDP)	0.00	-1.12	-2.49	-5.43	-8.41	-11.34	-14.22
Real wage	0.00	2.34	4.10	6.98	9.36	11.29	13.06
Consumption	0.00	2.34	4.10	6.98	9.36	-5.57	-7.55
Working age population	0.00	1.29	2.91	-0.45	-5.85	-10.48	-14.91
Total population	0.00	0.63	1.66	3.16	3.16	1.28	-1.68
Total employment	0.00	0.00	-2.98	-5.96	-8.95	-11.93	-14.91
Competitiveness Index	0.00	0.58	1.36	2.98	4.49	5.75	6.87
Consumer Price Index	0.00	0.46	1.04	2.25	3.33	4.19	4.93
CO_2 generation	0.00	-0.76	-1.90	-4.60	-7.48	-10.34	-13.10
CO_2 intensity of output	0.00	0.36	0.60	0.88	1.01	1.13	1.31
Electrical energy demand	0.00	-1.15	-2.74	-6.39	-10.12	-13.65	-16.97
Non-electrical energy demand	0.00	-0.75	-1.86	4.50	-7.31	-10.11	-12.84
GDP/electrical energy demand	0.00	0.03	0.26	1.03	1.90	2.67	3.32
GDP/non-electrical energy demand	0.00	-0.37	-0.64	-0.98	-1.19	-1.37	-1.58
Fixed Real Wage	**2000**	**2005**	**2010**	**2020**	**2030**	**2040**	**2050**
Gross Domestic Product (GDP)	0.00	0.08	0.25	0.50	0.46	*	*
Real wage	0.00	0.00	0.00	0.00	0.00	*	*
Consumption	0.00	-0.18	-0.29	-0.60	-1.20	*	*
Working age population	0.00	1.29	2.91	-0.45	-5.85	*	*
Total population	0.00	0.63	1.66	3.16	3.16	*	*
Total employment	0.00	0.11	0.33	0.63	0.54	*	*
Competitiveness Index	0.00	0.00	0.02	0.01	-0.05	*	*
Consumer Price Index	0.00	0.00	0.01	0.00	-0.08	*	*
CO_2 generation	0.00	-0.01	0.04	0.08	-0.10	*	*
CO_2 intensity of output	0.00	-0.09	-0.21	-0.42	-0.55	*	*

Electrical energy demand	0.00	-0.01	0.04	0.09	-0.03	*	*
Non-electrical energy demand	0.00	-0.01	0.04	0.07	-0.12	*	*
GDP/electrical energy demand	0.00	0.09	0.21	0.41	0.49	*	*
GDP/non-electrical energy demand	0.00	0.09	0.21	0.43	0.58	*	*

With a fixed labour supply, employment is predicted to fall by 14.91 per cent, identical to the assumed reduction in the labour force and working age population. Under the bargaining closure, employment only reduces by 9.89 per cent (see Table A3.1). GDP is lower by 14.22 per cent (9.30 per cent in the bargaining case) and a real wages are 13.06 per cent higher (7.89 per cent higher in the bargaining case).

By 2050, under the fixed labour supply specification, the fall in economic activity and employment is manifested through a greater fall in CO2 generation than under the Bargaining case for the "Central" scenario. CO2 generation falls by 13.10%, however the greater fall in GDP (14.22%) means that the CO_2 intensity of output increases. CO2 emissions do not fall by as much as Gross Domestic Product is predicted to fall, and so the environmental impacts of economic activity worsen.

Energy demands, on the other hand, show a varied response under the exogenous labour supply case. Reductions in electrical and non-electrical energy demands are observed, and these are larger than the reductions in these variables under the bargaining scenario, as would be expected given the greater increase in the real wage and reduction in employment and activity. By 2050, electrical energy demands are 16.97% lower than the base year, while non-electrical energy demands are down by 12.24%. Electrical energy demands have fallen by more than GDP, so the GDP/energy demand indicator with electrical energy demands in the denominator shows a positive movement – consistent with increasing sustainability. Non-electrical energy demands, however, have fallen by less than GDP so the GDP/non-electrical energy demand indicator decreases, indicating negative movements in sustainability.

Alternative parameter values

Sensitivity to elasticity of substitution between labour and capital

One key parameter is likely to be the substitution elasticity between labour and capital in the production of value added at the sectoral level. In previous simulations, this parameter was constant for every sector in each simulation, at 0.3. There is a wealth of recent empirical work concerned with estimating the appropriate value for this parameter. In this subsection, we impose alternative values of 0.8, 0.999999 (approximately assuming a Cobb-Douglas function) and 1.2. We expect that as we make substitution between labour and capital easier (i.e. impose higher values of this elasticity), employment will fall more rapidly compared to our previous simulations.

Table A3.3: 2050 results for sensitivity analysis for elasticity of substitution between labour and capital, bargaining labour market specification under "Central" population scenario

	0.3	0.8	Cobb-Douglas	1.2
Gross Domestic Product (GDP)	-9.30	-9.17	-9.01	-8.85
Real Wage	7.89	6.65	6.40	6.19
Consumption	-6.08	-6.55	-6.60	-6.64
Working Age Population	-14.91	-14.91	-14.91	-14.91
Total Population	-1.68	-1.68	-1.68	-1.68
Total Employment	-9.89	-10.46	-10.58	-10.69
Competitiveness Index	4.00	3.87	3.79	3.45
Consumer Price Index	2.93	2.90	2.85	2.79
CO_2 generation	-8.76	-9.10	-9.03	-8.94
CO_2 intensity of output	0.60	0.08	-0.02	-0.10
Electrical energy demand	-11.10	-11.45	-11.35	-11.22
Non-electrical energy demand	-8.63	-8.96	-8.89	-8.81
GDP/Electrical energy demand	2.02	2.58	2.63	2.67
GDP/Non-electrical energy demand	-0.73	-0.23	-0.13	-0.05

The main aggregate economic, energy and environmental results for these three alternative values of this parameter are shown in Table A3.3. As expected, when there are higher values of the elasticity of substitution between labour and capital, employment falls by more (down by 10.69% in 2050 for an elasticity of 1.2). To the contrary, the greater ease of substitution between labour and capital means that the wage rate does not increase by as much (up 6.19% in 2050 for the elasticity of 1.2). The fall in GDP seen in the previous "Central" simulation, (9.30% by 2050) is less under higher values of this elasticity, down 9.17%, 9.01% and 8.85% for elasticities of 0.8, 0.999999 and 1.2 respectively. Thus, even large changes in the value of this elasticity have small impacts upon the aggregate economic indicators.

CO2 generation is lower for all three sensitivity simulations carried out compared to the simulation with an elasticity of 0.3. CO_2 generation falls by more than the decline in GDP for values of this elasticity greater than 1, meaning that the CO_2 intensity of production falls. This is, however, again associated with a lower level of economic activity and employment. Energy demands on the other hand, show a mixed result. As the elasticity of substitution between labour and capital is increased to 0.8, there are lower electrical and non-electrical energy demands. For values of 1 and 1.2, electrical and non-electrical energy demands still fall, but not by as much as where the elasticity of substitution is 0.8. The non-linear relationship between the elasticity of substitution and energy (electrical and non-electrical) demands suggests that this could be an interesting area for future research.

Sensitivity to elasticity of substitution between value added and intermediate inputs

Another key parameter is likely to be the substitution elasticity between value added and intermediate inputs, for the production of gross output of each sector. In the previous simulations, this parameter was held constant at 0.3 in each sector. In this subsection, we change this parameter across values of 0.1 to 1.2. We would expect that increasing the elasticity of substitution from 0.3 to higher values would lead to greater substitution away from more expensive value added (given higher real wages) and towards intermediate inputs. Employment will likely be lower for higher values of this elasticity, which is also likely to produce larger falls in GDP than simulations with lower elasticities. The converse is likely to be produced by simulations where this elasticity is lower than 0.3.

Table A3.4: 2050 results for elasticity of substitution between value added and intermediate inputs sensitivity analysis, bargaining labour market specification under "Central" population scenario

	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**0.999999**	**1.1**	**1.2**
Gross Domestic Product (GDP)	-9.08	-9.26	-9.30	-9.34	-9.37	-9.41	-9.44	-9.47	-9.50	-9.53	-9.56	-9.59
Real Wage	8.57	8.00	7.89	7.79	7.69	7.60	7.50	7.41	7.33	7.24	7.16	7.08
Consumption	-5.56	-6.00	-6.08	-6.16	-6.24	-6.32	-6.39	-6.46	-6.53	-6.60	-6.66	-6.73
Working Age Population	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91	-14.91
Total Population	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68	-1.68
Total Employment	-9.61	-9.84	-9.89	-9.93	-9.98	-10.02	-10.06	-10.10	-10.14	-10.18	-10.22	-10.26
Competitiveness Index	4.33	4.08	4.00	3.93	3.87	3.80	3.74	3.67	3.62	3.56	3.50	3.45
Consumer Price Index	3.21	2.98	2.93	2.88	2.84	2.79	2.75	2.71	2.67	2.63	2.59	2.55
CO_2 generation	-8.96	-8.94	-8.76	-8.58	-8.42	-8.25	-8.10	-7.94	-7.79	-7.65	-7.51	-7.37
CO_2 intensity of output	0.13	0.36	0.60	0.83	1.05	1.27	1.48	1.69	1.89	2.08	2.27	2.46
Electrical energy demand	-11.52	-11.32	-11.10	-10.88	-10.67	-10.47	-10.27	-10.08	-9.89	-9.71	-9.53	-9.36
Non-electrical energy demand	-8.82	-8.81	-8.63	-8.46	-8.30	-8.14	-7.98	-7.83	-7.69	-7.55	-7.41	-7.27
GDP/Electrical energy demand	2.76	2.32	2.02	1.73	1.46	1.19	0.93	0.68	0.44	0.20	-0.03	-0.25
GDP/Non-electrical energy demand	-0.29	-0.50	-0.73	-0.95	-1.17	-1.38	-1.58	-1.77	-1.96	-2.15	-2.33	-2.50

The results from varying this parameter are shown in Table A3.4. The results change in line with our prior expectations, with higher elasticity of substitution generating larger falls in employment, and so smaller increases in the real wage than under simulations where this parameter takes a lower value. With this elasticity at 0.9, employment falls by 10.14% (compared to a 9.89% for this scenario previously) and the GDP impact is greater with a decline of 9.50%. CO2 generation falls across all sensitivity simulations, but across all simulations falls by less than GDP declines, thus the CO2 intensity of Scottish production (CO2/GDP) increases, showing a declining sustainability of output.

Electrical energy and non-electrical energy demands fall by 9.89% and 7.69% respectively, smaller declines than under the scenario for lower elasticities of substitution. The GDP/energy indicators are lower than where the values of this parameter are lower. Positive values of these indicators suggest that economic activity is becoming more sustainable. For our previous results, the GDP/electrical energy indicator showed a positive movement, while the GDP/non-electrical energy indicator moved in a negative direction. As we increase the elasticity of substitution, both indicators move towards and become further negative respectively. For values of the elasticity greater than 1, both GDP/energy indicators show an absolute decline in sustainability.

Technical Appendix A4 Simulation results: Costly Requirements on Households to Reduce Energy Use

A4.1 Introduction

In this section we attempt to model the impacts of policies directed at household energy use. Currently, it is not possible to directly simulate issues relating to household energy use using the AMOSENVI framework.[18] Instead, here we attempt to model the knock on effects of such a policy (resulting from the impact on household income). In this Appendix, we describe the background and simulation strategy we use to model such a scenario using the AMOSENVI model and present the results from our simulations. Some sensitivity analysis is conducted over key parameters, including the assumed structure of the Scottish labour market in order to highlight the importance of these variables for our central results. As with other policies modelled, these simulations assume that the policy is directly introduced in Scotland, but not the rest of the UK. As such, these simulations can be considered as showing the impact of a differential policy introduced in Scotland, which goes beyond that of any policies introduced at the level of the UK as a whole. The impacts of such policies are those over and above the impacts of any UK-wide policies introduced.

This appendix is structured as follows. In Section A4.2 we set out our simulation strategy, and then in Section A4.3 we report the economic, environmental and energy results for the range of shocks to household income considered. In sensitivity analysis in Section A4.4, we vary the size of the decrease in household income, the migration closure and the labour market specification of the AMOSENVI model.

A4.2 Simulation strategy

In AMOSENVI we can model the labour market and system-wide consequences of the introduction of policies that serve to reduce household income. Such an approach is consistent with a mandatory requirement for households to purchase costly technologies that may reduce their energy use. There will be system-wide labour market consequences of the implied reduction in household income. The reduction in household income will lead to workers bargaining for an increased nominal wage, which will in turn reduce the competitiveness of Scottish economic activity. We would also expect there to be migration effects as, in AMOSENVI, net migration to Scotland is driven by real wage and unemployment rate differentials between Scotland and the rest of the UK. A lower real (take-home) wage may induce migration from Scotland.

The labour market impact of such a reduction would operate in a similar way to the imposition of an appropriately calibrated increase in income tax with no recycling of the additional revenue back into the economy[19]. This is the way that we model the impact in the simulations presented here. We model the impact of a 1% decline in household income. This is achieved through raising the overall share of wages paid to income tax by 1%. This requires a 6.3% increase in the rate of income tax in the base year data[20].

A4.3 Central scenario results

Central aggregate and sectoral results

As with previous simulations, results should be interpreted as being variations away from what would have happened to economic activity and environmental impacts but for the policy that reduced household income. Table A4.1 shows the aggregate results for economic, energy and environmental from such a policy in the long-run. The long-run here is a conceptual time period over which labour and capital stocks have fully adjusted to new equilibrium levels. In AMOSENVI with migration possible, this is consistent with a time period over which the real wage and

[18] This is one of the objectives of the current First Grant Project on modelling the impacts of improved energy efficiency.

[19] In previous work on energy efficiency improvements (Allan et al., 2007) we modelled the impact of recycling increased government revenues back to the economy increasing government expenditure or lowering taxes. In these simulations however, this loop back to the economy is not closed, with increased government revenues retained through increased savings.

[20] Income tax is modelled as a percentage share of total wage income and equals 16.1% in the base year data. A 6.3% increase in the rate of income tax increases the rate of total income tax to 17.1% of total wage income.

unemployment rate have been restored to their initial equilibrium values, and the capital rental rate is equalised across all sectors in the economy.

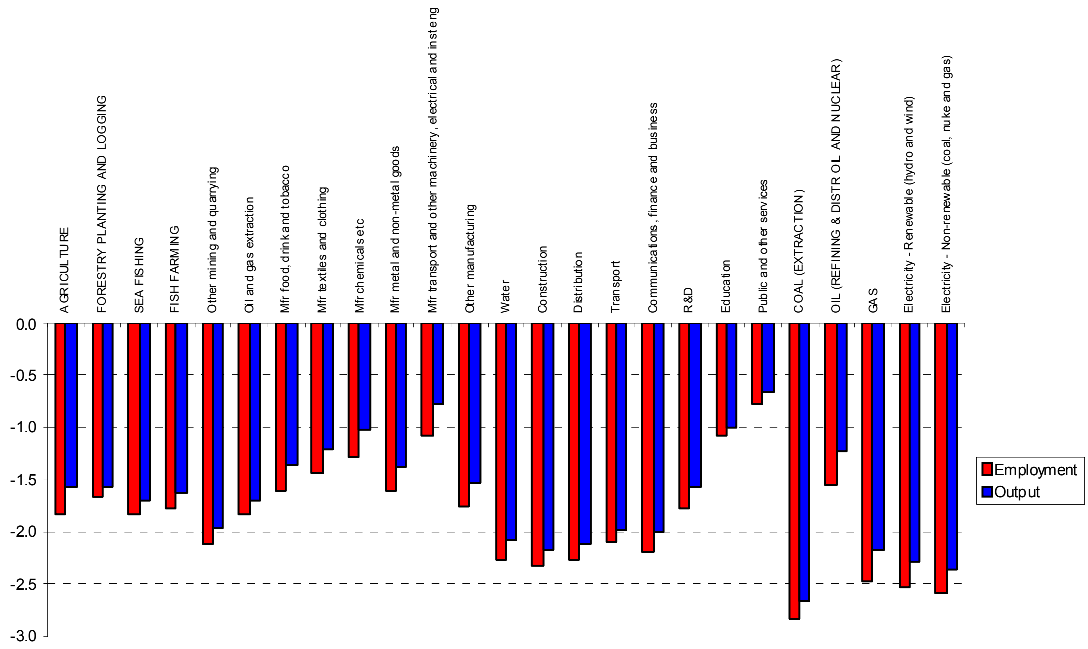
Table A4.1: Short- and long-run impacts on aggregate economic, energy and environmental indicators under a 1% decrease in household income, bargaining labour market, % changes from base year

	Short-run	**Long run**
Gross Domestic Product (GDP)	-0.23	-1.63
Consumption	-0.80	-1.80
Investment	-0.53	-1.67
Exports	-0.03	-1.14
Imports	-0.48	-0.73
Nominal (before tax) wages	0.43	1.33
Real (take home) wages	-0.35	0.00
Total Population	0.00	-1.66
Total Employment	-0.37	-1.66
Unemployment Rate	3.15	0.00
Consumer Price Index (CPI)	-0.10	0.44
CO_2 generation	-0.33	-1.81
CO_2 intensity of output	-0.11	-0.19
Electrical energy demand	-0.29	-2.20
Non-electrical energy demand	-0.35	-1.80
GDP/Electrical energy demand	0.06	0.58
GDP/Non-electrical energy demand	0.12	0.18

In line with our expectations, we observe that the initial decrease in household income leads to a 0.35% fall in the real wage in the short run (i.e. while capital and labour stocks are fixed). (Private) consumption is down by 0.80%, and overall GDP is lower by 0.23%. Under a bargaining labour market specification with migration from and to Scotland possible, as is used here, we would expect that this would lead to outmigration. While population is fixed in the short-run, over the long run outmigration should act to restore the real wage differential between Scotland and the rest of the UK.

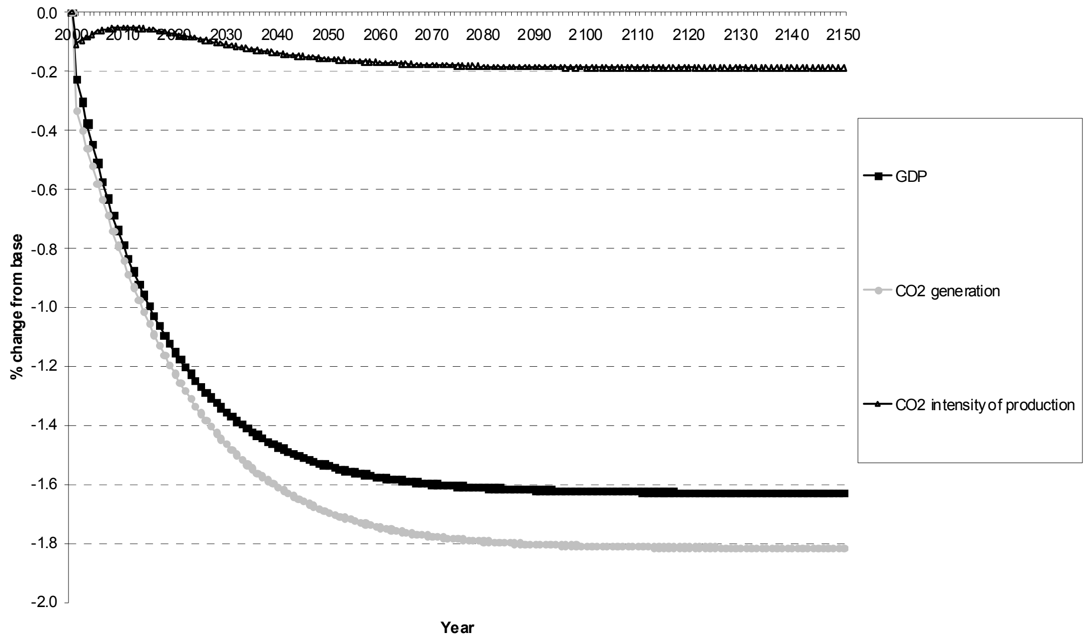
By the long-run, GDP is 1.63% lower, and while real wages have risen back to their pre-shock levels, nominal wages are 1.33% A4.1 higher and the CPI is higher. This has a damaging impact on employment and exports. The sectoral pattern of changes in output and employment is shown in Figure A4.1. Sectors that are labour intensive and export intensive suffer particularly badly, as (before tax) wages are higher and higher prices damage the competitiveness of output.

Figure A4.1: Long-run impact on sectoral output and employment, % changes from baseyear



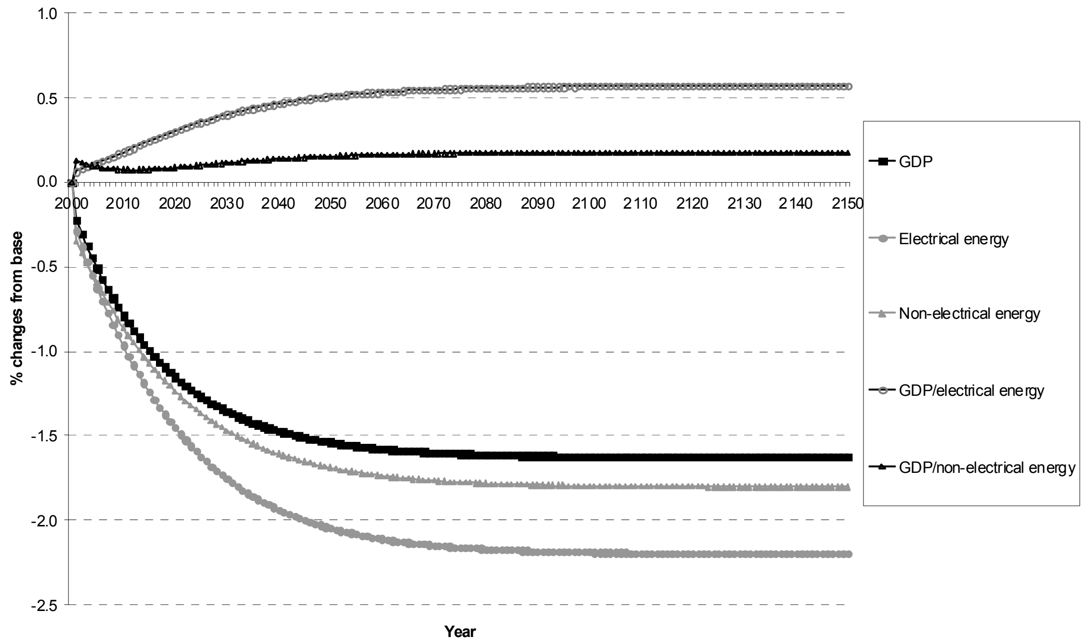
The environmental consequences of this policy are lower emissions in both the short and long-run, and the decreases in CO2 emissions are greater than the falls in GDP. The CO2 intensity of production thus decreases. The time path of the changes in GDP, CO2 emissions and the sustainable prosperity measure are shown in Figure A4.2. The simulation is run over 150 periods in order that a long-run equilibrium is reached, although most of the adjustment to the long-run has occurred by period 120. The CO2 intensity of production falls immediately and is lower again in the long-run, but does not decrease monotonically before reaching its long-run equilibrium.

Figure A4.2: GDP, CO_2 emissions and CO_2 intensity of production following a 1% decrease in household income, bargaining labour market, % changes from base



Energy demand (both electrical and non-electrical energy demands) is lower in the short- and long-run compared to the base year, with greater reductions in the long-run. The GDP/energy indicators show positive movements in sustainability, i.e. increasing GDP per unit of energy. Positive changes in this variable show greater economic output per unit of energy, and, despite total GDP being lower – both electrical and non-electrical energy use shows a greater decline. The profile of adjustment between the short-run and long-run equilibrium path for electrical and non-electrical energy demands – along with GDP and the GDP/energy indicators - is shown in Figure A4.3.

Figure A4.3: GDP, electrical energy and non-electrical energy demands following a 1% decrease in household income, bargaining labour market, % changes from base



A4.4 Sensitivity analysis

Sensitivity to size of the decrease in household income

Table A4.2 shows the aggregate long-run economic, energy and environmental results for alternative decreases in household income, under a regional bargaining labour market specification. As can be seen, when the decrease in household income is changed, the results across all variables respond in an approximately proportional way – i.e. a 0.5% reduction in household income has results roughly approximate to one quarter the effect of a 2% reduction in household income, and one half those of a 1% reduction in household income. Across all values of the shocks, the positive movements in the CO_2 intensity of output and the GDP/energy indicators remain, although GDP continues to be lower than the base year under all scenarios.

Table A4.2: Percentage changes in long-run for aggregate economic, energy and environmental indicators under variations in the decrease in household income, bargaining labour market

	0.5%	1%	1.5%	2%
Gross Domestic Product (GDP)	-0.82	-1.63	-2.42	-3.20
Consumption	-0.91	-1.80	-2.68	-3.55
Investment	-0.84	-1.67	-2.48	-3.28
Exports	-0.57	-1.14	-1.70	-2.25
Imports	-0.37	-0.73	-1.10	-1.45
Nominal (before tax) wages	0.66	1.33	1.99	2.66
Real (take home) wages	0.00	0.00	0.00	0.00
Total Population	-0.84	-1.66	-2.47	-3.27
Total Employment	-0.84	-1.66	-2.47	-3.27
Unemployment Rate	0.00	0.00	0.00	0.00
Consumer Price Index (CPI)	0.22	0.44	0.66	0.88
CO_2 generation	-0.91	-1.81	-2.70	-3.57
CO_2 intensity of output	-0.10	-0.19	-0.29	-0.38
Electrical energy demand	-1.11	-2.20	-3.27	-4.32
Non-electrical energy demand	-0.91	-1.80	-2.68	-3.55
GDP/Electrical energy demand	0.29	0.58	0.87	1.17
GDP/Non-electrical energy demand	0.09	0.18	0.27	0.36

Sensitivity to migration configuration of model

As mentioned above in the discussion of the 1% reduction in household income, an decrease in household income has the effect of lowering real (take-home) wages. In AMOSENVI, net migration to Scotland is a function of the real wage and unemployment differential between Scotland and the rest of the UK. Lower real wages in our simulations reported to date, will cause outmigration to occur as workers seek higher wages in the rest of the UK. This migration will reduce the size of the labour force in Scotland, and would be expected to exacerbate any decline in economic activity in Scotland that comes directly as a result of the lowering of household incomes. To that extent, it would be useful to consider a case in which such economic migration between Scotland and the rest of the UK is not permitted. Table A4.3 shows the aggregate results for a 1% decrease in household income in the cases where migration is and is not permitted.

Table A4.3: Percentage changes in long-run for aggregate economic, energy and environmental indicators under 1% decrease in household income with and without migration, bargaining labour market, % change from base

	1% with migration	1% without migration
Gross Domestic Product (GDP)	-1.63	-0.66
Consumption	-1.80	-1.12
Investment	-1.67	-0.69
Exports	-1.14	-0.33
Imports	-0.73	-0.50
Nominal (before tax) wages	1.33	0.38
Real (take home) wages	0.00	-0.62
Total Population	-1.66	0.00
Total Employment	-1.66	-0.67
Unemployment Rate	0.00	5.67
Consumer Price Index (CPI)	0.44	0.13
CO_2 generation	-1.81	-0.82
CO_2 intensity of output	-0.19	-0.17
Electrical energy demand	-2.20	-0.94
Non-electrical energy demand	-1.80	-0.83
GDP/Electrical energy demand	0.58	0.28
GDP/Non-electrical energy demand	0.18	0.18

As expected, there are significant differences between the results with and without migration for a 1% decrease in household income. The primary cause of this is the lack of any substantial decrease in population and employment in the long-run. No migration means that real wages are lower in the long-run, with a smaller increase in nominal wages, and so a less dampened impact on economic activity. While, relative to the base year, employment is still lower in the long-run under the no-migration case, the reduction (-0.67%) is significantly less than that seen where migration is permitted (-1.66%). There is a much less pronounced decrease in exports and investment as well, supporting a relatively higher level of economic activity. The CO2 intensity of output improves, as in the central results presented earlier, as CO2 generation falls by more than the decline in GDP. Electrical and non-electrical energy demands again decrease, but the increases in activity per unit of energy are smaller than where migration is permitted.

Sensitivity to labour market specification of the model

All of the simulations reported above assume that the regional labour market can be characterised by wage bargaining specification, where regional wages are related to the tightness of the regional labour market. In this subsection, we present some results from alternative treatments of regional wage setting. Two extremes of the regional labour market are explored: exogenous (fixed) labour supply, which would be consistent with a perfectly inelastic labour supply curve; and a fixed real wage specification, implying a perfectly elastic labour supply curve, as might be associated with an Input-Output specification in which there are no labour supply constraints in the regional economy. As in the previous sub-section, we also explore the implications under each of these specifications when migration is and is not permitted.

Table A4.4 shows the aggregate economic, energy and environmental impacts by the long-run under the three labour market scenarios, and for two migration scenarios considered in this section for each labour market scenario.

Table A4.4: Percentage changes in long-run for aggregate economic, energy and environmental indicators under 1% decrease in household income with and without migration possibilities for bargaining, exogenous labour supply case and fixed real wage specification of the regional labour market, % changes from base year

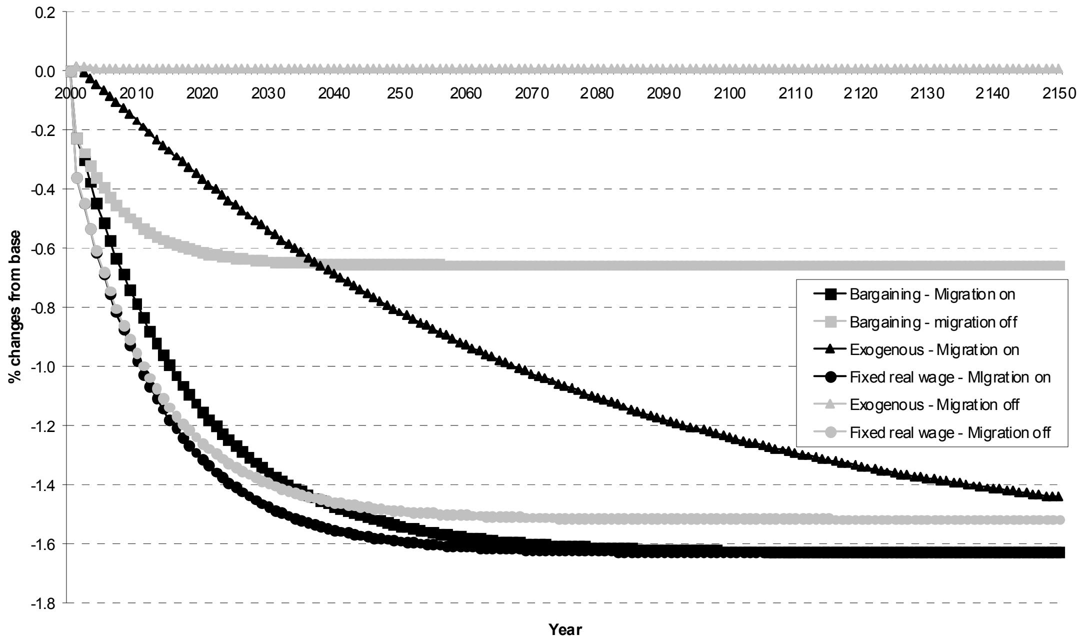
	Bargaining		Exogenous labour supply		Fixed real wage	
	Migration on	**Migration off**	**Migration on**	**Migration off**	**Migration on**	**Migration off**
Gross Domestic Product (GDP)	-1.63	-0.66	-1.44	0.01	-1.63	-1.52
Consumption	-1.80	-1.12	-1.69	-0.88	-1.80	-1.43
Investment	-1.67	-0.69	-1.49	-0.04	-1.67	-1.54
Exports	-1.14	-0.33	-0.97	0.29	-1.14	-1.14
Imports	-0.73	-0.50	-0.70	-0.45	-0.73	-0.56
Nominal (before tax) wages	1.33	0.38	1.16	-0.34	1.33	1.33
Real (take home) wages	0.00	-0.62	-0.11	-1.09	0.00	0.00
Total Population	-1.66	0.00	-1.48	0.00	-1.66	0.00
Total Employment	-1.66	-0.67	-1.48	0.00	-1.66	-1.55
Unemployment Rate (%)	0.00	5.67	0.00	0.00	0.00	13.03
Consumer Price Index (CPI)	0.44	0.13	0.38	-0.11	0.44	0.44
CO_2 generation	-1.81	-0.82	-1.62	-0.19	-1.82	-1.63
CO_2 intensity of output	-0.19	-0.17	-0.18	-0.20	-0.19	-0.12
Electrical energy demand	-2.20	-0.94	-1.95	-0.10	-2.20	-2.01
Non-electrical energy demand	-1.80	-0.83	-1.62	-0.22	-1.80	-1.61
GDP/Electrical energy demand	0.58	0.28	0.52	0.11	0.58	0.51
GDP/Non-electrical energy demand	0.18	0.18	0.18	0.23	0.18	0.10

Looking first at the Bargaining labour market specification, but comparing the case with Migration on, against the Migration off case, we see there are substantial differences in the long-run results. With Migration off, the long-run is found when capital rental rates are equalised across sectors, but we no longer assume that migration acts to restore real wages to their initial equilibrium levels. Real wages are lower under the Migration off case in the long-run and there is a smaller reduction in employment than the Migration on case. We also observe an increase in the unemployment rate in the long-run when Migration is not permitted. GDP falls by less in the Migration off case than in the Migration on case, protected by the decline in the real wage rate (and smaller increase in nominal wages) acting to partially offset the decline in employment and economic activity.

In both Bargaining Migration on and Migration off scenarios, the reduction in CO_2 generation is greater than the reduction in GDP, improving the CO_2 intensity of output indicator. Energy demand falls in both cases, less in the Migration off case, as would be expected by the relatively greater economic activity in this scenario. Both of the GDP per unit of energy indicators increase, indicating an improvement in the sustainability of energy use.

With a fixed real wage and with migration on, the long-run changes in economic activity, energy use and environmental impact will be the same as that under a bargaining labour market in which migration is also possible. In the long-run of the Bargaining case with Migration, the imposition of the 1% decrease in household income results in out-migration and a recovery of the real wage to initial equilibrium level. In the fixed real wage, the wage rate is fixed over all time periods. The results may be identical in the long-run, but the time path adjustments are quite different. Figure A4.4 shows the changes in GDP under all six of these labour market and migration specifications.

Figure A4.4: GDP changes over time under bargaining, exogenous labour market and fixed real wage labour market specifications, with migration on and off, % changes from base



Technical Appendix A5. Simulation results: Renewable Energy Supply 1 – Input-Output Analysis
(Sub-title: The economic and environmental impacts of alternative electricity generation technologies in Scotland: An Input-Output analysis)

A5.1 Introduction

Concerns about energy security and meeting environmental targets in Scotland are in the spotlight of academic, policy and public debate. As of 2000, fossil fuel (coal and gas) and nuclear technologies provided 34%, 22% and 34% respectively of the total electricity generated in Scotland. Scotland also has a history of developing electricity generation from renewable sources. A significant amount of electricity, around 9.5%, was generated by hydroelectric facilities in 2000, which were largely built in the post-WW2 years. At the same time, the last ten years have seen the development of a significant number of electricity generating facilities from other renewable sources, as well as some extension of the hydroelectric capacity. The geographical position of Scotland offers it significant renewable energy resources, including on- and off-shore wind, wave and tidal energy. A recent study for the Scottish Executive (Boehme et al, 2006) quantifies the potential scale of renewable energy resources available and extractable around Scotland. We do not seek to quantify the potential here, but to gauge the possible economic impacts of changes to the Scottish electricity generation mix.

There are likely to be significant changes to the electricity generation mix in Scotland in the coming decades. The two nuclear power stations at Hunterston B and Torness currently have lifetime licences until 2016 and 2023 respectively[21], while current large-scale coal facilities at Longannet and Cockenzie will come under the Large Combustion Plant Directive (LCPD) after 2015[22]. In the case of nuclear, the Scottish Government has stated that it does not want any new nuclear facilities constructed in Scotland. The Scottish Government has also recently set out ambitious targets for renewable electricity generation. These are that by 2020, 50% of electricity generated in Scotland will come from renewable sources, with an interim target of 31% by 2011[23]. No specific targets for any particular technology have been set for either time period, although it has been suggested that much of the renewable electricity will come from significant increases in the amount of onshore wind generation. On the other hand, recent consultations by the Scottish Government on reforms to the support for renewable energy projects have recognised the potential for Scotland to develop an indigenous marine electricity industry, and have sought to provide additional incentives through the "banding" of existing support mechanisms to the production of electricity from marine (i.e. wave and tidal) energy devices. Total electricity generated in Scotland from all renewable sources (hydro, wind, biomass, wave and landfill gas) has grown by 40 per cent between 2000 and 2006 (BERR). The installed capacity of renewable energy (hydro, wind/wave, landfill gas and biomass) facilities increased over the same period from 1.4 GW to 2.4 GW. Some 0.9 GW of this increase has come from the development of wind energy projects, with an installed capacity in 2006 of 946MW, generating 2,022 GWh in 2006. Figures on the generation of electricity from different technologies in Scotland, and the capacity of renewable energy technologies, between 2000 and 2006 are given in Tables A5.1 and A5.2 below.

[21] Hunterston B obtained a five-year lifetime extension to allow it to operate up to 2016, while Torness has yet to apply for a lifetime extension, but could extend its lifetime by up to ten years (i.e. to 2033).
[22] Scottish Power announced in 2006 that Longannet (capacity 2304MWe) will be opted-in to the EU's LCPD, but operation at Cockenzie (capacity 1152 MWe) has opted-out of the LCPD and so is allowed to run for 20,000 hours of operation from 2008, or until the end of 2015, whichever comes sooner.
[23] The measurement of this target will be total electricity generated from renewable sources divided by the sum of total electricity generated *minus* electricity exports plus electricity imports, multiplied by 100, or equivalently, total renewables generation as a percentage of generation required to support domestic consumption.

Table A5.1: Current (2000) shares of electricity generation by technology and four scenarios considered, %

	Base year (2000)	*Scenario A*	*Scenario B*	*Scenario C*	*Scenario D*
Nuclear	33.6	0.0	0.0	0.0	0.0
Coal	33.9	25.0	25.0	50.0	0.0
Hydro	9.4	15.0	15.0	15.0	15.0
Gas	22.4	25.0	25.0	0.0	50.0
Biomass	0.1	3.0	3.0	0.0	0.0
Wind	0.4	20.0	25.0	30.0	30.0
Landfill Gas	0.1	2.0	2.0	0.0	0.0
Marine	0.0	10.0	5.0	5.0	5.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Note: Shares may not sum 100% due to rounding.

Table A5.2: Aggregate results on GDP, employment and CO_2 emissions

		Scenario A	Scenario B	Scenario C	Scenario D
Type 1	Change in GDP (£millions)	263.24	153.69	202.43	109.42
	Change in employment (000s, FTE jobs)	24,984	13,172	13,173	11,375
	Change in CO_2 emissions, % from base year	-3.52	-3.59	0.82	-8.13
	% change in GDP	0.40	0.23	0.31	0.17
	% change in CO_2/GDP	-3.90	-3.82	0.51	-8.28
Type 2	Change in GDP (£millions)	416.41	247.78	287.91	180.11
	Change in employment (000s, FTE jobs)	29,572	15,957	15,738	13,502
	Change in CO_2 emissions, % from base year	-5.69	-5.89	-3.08	-8.86
	% change in GDP	0.63	0.38	0.44	0.27
	% change in CO_2/GDP	-6.28	-6.24	-3.50	-9.11

This section of the report uses Input-Output (IO) techniques to examine the economic and environmental consequences of significant changes in the electricity generation mix in Scotland. The motivation in using IO rather than CGE analysis in this section is because of the availability of an IO model with a greater disaggregation of the electricity sector than is currently incorporate in AMOSENVI. However, at such a time as which we are able to incorporate such a breakdown to AMOSENVI model, it would be desirable to repeat the analysis in a more flexible CGE framework.

In the present analysis, we use the IO modelling framework to develop four scenarios for the Scottish electricity generation mix. In each of the scenarios we have developed, we assume that the total electricity generated in Scotland is the same as in 2000, and we vary the generation mix. In each of the scenarios, the Scottish Government's target of 50% of electricity from renewable sources is met, and we assume that there is no generation from nuclear generation technologies. The types of renewable technologies that contribute to the renewables target are different in each case, but the common modal renewable technology is wind generation. We set out details of the IO model used for this analysis and the method used in Section A5.2. We provide details on each of the four scenarios in Section A5.3. In Section A5.4 we report the results for these simulations, where we focus on the aggregate and sectoral changes in economic activity, employment and emissions of CO2. Further, in Section A5.4, we carry out some sensitivity analysis regarding our assumptions about CO2 emissions factors, particularly with reference to those assumed for coal generation.

A5.2 Method and data

A5.2.1 Basic IO system[24]

IO is a standard method for examining the interrelationships between sectors of the economy and final demand (Miller and Blair, 1985). If certain assumptions are imposed, it provides a powerful tool for examining how changes in the final demand for products can affect the outputs of other sectors within the economy. Although IO has traditionally been used for economic impact analysis (McGregor and McNicholl, 1992), it has been subsequently extended to energy and environmental areas. In the case of Scotland, recent IO work has covered the generation and treatment of waste (Allan et al, 2007b) and CO2 (McGregor et al, 2004, 2008).

For IO analysis, the output of each sector of the economy in question is given by an equation relating total output to the demands for that sector's goods from both intermediate demand (i.e. other industrial sectors) and final demand. Final demands include, for example, consumption, government expenditure, and exports. Imposing constant returns to scale, a passive supply side, and unchanging technology allows specification of a set of linear equations of the sort

$$\begin{aligned}
X_1 &= a_{11}X_1 + a_{12}X_2 + a_{13}X_3 + a_{14}X_4 \ldots + a_{1n}X_n + Y_1 \\
X_2 &= a_{21}X_1 + a_{22}X_2 + a_{23}X_3 + a_{24}X_4 \ldots + a_{2n}X_n + Y_2 \\
\vdots \quad & \quad \vdots \qquad \vdots \qquad \vdots \qquad \qquad \ddots \quad \vdots \qquad \vdots \\
X_n &= a_{n1}X_1 + a_{n2}X_2 + a_{n3}X_3 + a_{n4}X_4 \ldots + a_{nn}X_n + Y_n
\end{aligned}$$

where X_i represents the output of sector *i* and a_{ij} represents the output of sector *i* that is required to produce one unit of output of sector *j* and Y_i. The a_{ij} coefficients are calibrated by dividing the value of the relevant intermediate purchases by the value of industry *j*'s output. In matrix notation, the IO system can be expressed as

$$X = AX + Y$$

This says that gross output (X) is the sum of all intermediate sales (AX) (used in the production of all other industries' outputs) and sales to final demand (Y), which are taken to be exogenous, determined wholly outwith the system. Solving for gross output (X) yields

$$X = (I - A)^{-1} Y$$

where I is an identity matrix and the term ($(1-A)^{-1}$) is known as the Leontief inverse matrix. The Leontief inverse matrix can be used to examine the extent of interrelationships among sectors within an economy, showing, as it does, the degree to which one sector relies upon the other sectors within an economic space for its inputs.

The system described above is the 'open' Leontief system in which all elements of final demand are considered to be exogenous and therefore are determined entirely outwith the system. The Leontief system can be 'closed' with respect to households, where the values of the Leontief inverse include not only the direct and indirect purchases necessary to meet changes in final demand, but where induced impacts, arising from endogenous consumption demands being linked to disposable incomes, are also included. (The income from employment row and consumer expenditure column from the IO table are, in this case, incorporated into the A matrix. The induced consumption effects are thereby incorporated in the multipliers.) A key feature of this system is that consumer expenditures are linked directly to households' disposable income, rather than being treated as exogenous as in the 'open' system. As income rises, this induces households to

[24] Sections A5.2.1, A5.2.2 and A5.2.5 draw liberally from material published in Allan *et al* (2007a).

consume more. These induced impacts reveal the wider effect of the increased incomes of workers in sectors that have experienced increased demand for their outputs. We now turn to using the features of the Leontief inverse to examine interrelationships among sectors in the Scottish economy, specifically examining the degree to which the electricity-generating sectors are embedded into the regional economy.

A5.2.2 IO multipliers

Rasmussen (1958) proposes to use the open (Type 1) Leontief inverse to estimate the direct and indirect backward linkages. These are more commonly referred to as output multipliers in that they show the additional gross output generated across an economy from an additional unit of final demand for an individual sector. They are calculated as the column sums of the Leontief inverse matrix, thus

$$O_j = \sum_{i=1}^{n} \alpha_{ij}$$

where α_{ij} identifies the element located at row *i* and column *j* in the Leontief inverse matrix. The output multiplier is defined as 'the total value of production in all sectors of the economy that is necessary to satisfy a pound's worth of final demand for sector *j*'s output' [12]. This Type 1 output multiplier incorporates both the direct and indirect impacts of the increased demand for sector *j*'s output while taking household consumption to be exogenous. Closing the model with respect to households implies that the induced consumption effect of extra household income associated with increasing the aggregate output of a sector is included in the Type 2 output multiplier.

Although gross output is of interest, as a measure of turnover, it says nothing about how the changes in output affect gross-value added (GVA or GDP) and employment. These can be calculated by multiplying the Type 1 and Type 2 Leontief inverses by the GVA-output and employment-output coefficients. Thus, the open GVA multiplier, M_j^G , is

$$M_j^G = \sum_{i=1}^{n} v_i \alpha_{ij}$$

where v_i is the value added to gross output ratio in sector *i*. The value-added multiplier gives the increase in total value-added (GDP) resulting from a pound's worth of final demand for sector *j*'s output.

Employment multipliers can be found in a similar way, using physical employment/output coefficients, e_i. Thus, we use a vector of employment-output coefficients (e_i) and multiply this by the open (for Type 1) or closed (for Type 2) Leontief inverse. CO_2 multipliers can also be derived in a similar way, using CO_2 emissions/output coefficients (m_i). Again, we can use these multipliers to quantify the increase in total CO_2 emissions resulting from a pounds worth of additional final demand for sector *j*'s output.

A5.2.3 Modelling economic impacts of alternative electricity generation mixes

In this section we set out how we use the disaggregated IO table to model the economic and environmental effects of changes in the Scottish electricity generation mix. We have seen that significant changes are expected over the next two decades, and this might be expected to have impacts on aggregate and sectoral output and employment levels where the replacement electricity generation has different linkages to the regional economy than the generation that it displaces.

Our method is to revise the A matrix of input coefficients to reflect a new pattern of purchases by the electricity supply (i.e. non-generation) sector from the eight electricity generation technologies. The pattern of purchases by this sector is altered in line with exogenously specified scenarios for the amount of generation coming from each different technology in Scotland. We set out and detail the four scenarios that we model in Section A.5.3.

We assume that the amount of electricity produced by the generation sector in Scotland, and purchased by the electricity supply sector, remains constant at 2000 levels (i.e. at 49.5 TWh). Boehme et al. (2006) consider that Scottish domestic demand for electricity will rise from 32.4 TWh in 2003 to 41 TWh in 2020. This would imply that the level of Scottish exports of electricity may be lower in 2020 than it is currently. However, for simplicity we assume that total final demands for electricity remains constant at levels from the year 2000[25]. Keeping the same final demand values ($\bar{Y}$), we can then examine the impacts on output across all sectors in the Scottish economy using the equation below:

$$X^{*} = (I - A^{*})^{-1}\bar{Y}$$

where the A^{*} matrix is constructed by adjusting the coefficients for the purchases from electricity generation by the non-generation sectors. All other coefficients remain unchanged. In this case, the new sectoral output level can be used to calculate the change in sectoral employment, GDP and CO_2 emissions driven by the change in the pattern of electricity generation in Scotland.

A5.2.4 Data and multiplier results for Scotland

The Input-Output table used in this chapter is that which is presented in Allan et al (2007a).[26] This is a thirty-one sector table for Scotland, with a base year of 2000 in which particular care has been taken to disaggregate the electricity sector between generation and non-generation activities, and then to break down generation by the technology used. This disaggregation is important as it is understood that different electricity generation technologies have different linkages with the regional economy. Further, different generation technologies will also have significant differences in their environmental impact, for instance through direct (and indirect and induced) CO_2 emissions. Standard disaggregations of the electricity sector in IO accounts would not account for the non-generation portion of the electricity sector, instead disaggregating the whole "Electricity" by various generation technologies employed within the economy. This however, has the effect of assuming that each generation type sells directly to the end consumer of the electricity, with each generation type paying for its own transmission, distribution and supply activities. Our disaggregation allows for a more realistic treatment, albeit illustrative, of the linkages between electricity generation technologies and the consumption of electricity by industrial and final demand categories.

The IO tables for Scotland, produced annually by the Scottish Government, are the starting point for this disaggregated table. However, survey work was carried out for electricity generation facilities so as to allow the separate identification of activities within this sector. This process is necessary as in the original IO tables (as published by the Scottish Government) there is a single sector identified as "Electricity" which covers all activities carried out by firms under SIC 2003 code 85, which includes not only generation of electricity, but also intermediate stages between generation and consumption of transmission, distribution and supply. To the extent that there are activities within this sector which are not related to generation of electricity, such a disaggregation of this sector is necessary. Full details of the identification of the generation technologies within an IO framework for Scotland are given in Allan et al (2007a). The sectoral breakdown for the thirty-one sectors are given in Table A5.3 below.

[25] It would be possible to incorporate the impacts of changes in Y, however this is not carried out in the current analysis.
[26] That is, it is not the same IO database as used in the current AMOSENVI framework.

Table A5.3 Sectoral breakdown of 31 sector IO table and CO2-output coefficients for 2000

	Sectors in original IO table for Scotland
Agriculture	*1*
Forestry planting and logging	*2.1, 2.2*
Fishing	*3.1, 3.2*
Other mining and quarrying	*6, 7*
Oil and gas extraction	*5*
Mfr food, drink and tobacco	*8 to 20*
Mfr textiles and clothing	*21 to 30*
Mfr chemicals etc	*36 to 45*
Mfr metals and non-metal goods	*46 to 61*
Mfr transport and other machinery, electrical and inst eng	*62 to 80*
Other manufacturing	*31 to 34, 81 to 84*
Water	*87*
Construction	*88*
Distribution	*89 to 92*
Transport	*93 to 97*
Communications, finance and business	*98 to 107, 109 to 114*
R&D	*108*
Education	*116*
Public and other services	*115, 117 to 123*
Coal (Extraction)	*4*
Oil and processing of nuclear fuel	*35*
Gas	*86*
Electricity non-generation	*85 (part of)*
Nuclear	*85 (part of)*
Coal generation	*85 (part of)*
Hydro	*85 (part of)*
Gas	*85 (part of)*
Biomass	*85 (part of)*
Wind	*85 (part of)*
Landfill gas	*85 (part of)*
Marine	*85 (part of)*

To allow us to generate a set of environmental results for this IO table, we required Scottish CO2-output coefficients for the same level of sectoral aggregation.[27] These were primarily obtained from the appendix of sectoral CO2-output coefficients reported in Ferguson et al (2004), but additional information was needed for the direct CO2 emissions coefficients for the eight electricity generation sectors and the non-generation portion of the electricity sector. For renewable electricity generation technologies, we make the simplifying assumption that direct emissions of CO2 are zero. This is not the same as assuming that they have zero emissions indirectly, or over their life cycle. Indeed, these sectors will have positive indirect and induced CO2-output multipliers driven by the extent to which their backward linkages support activity elsewhere in Scotland which is itself CO_2 emitting. The remaining non-renewable technologies are nuclear, coal and gas. For nuclear generation, we again assume that there are zero direct CO2 emissions in Scotland. For coal and gas electricity generating sources we use emissions factors from the Scottish Energy Study Volume 1 (AEA Technology, 2006). For coal, this study reports emissions factors of 0.3 $kgCO_2$/kWh for Scottish coal and 0.19 kgCo2/kWh for Scottish gas generating plants. We use these factors, and the output of coal and gas electricity generating plants in Scotland in 2000 to estimate base year emissions for these electricity generating technologies. In our thirty-one sector IO model, and including the direct emissions by households, total net CO_2 emissions from Scotland in the year 2000 are 45.2

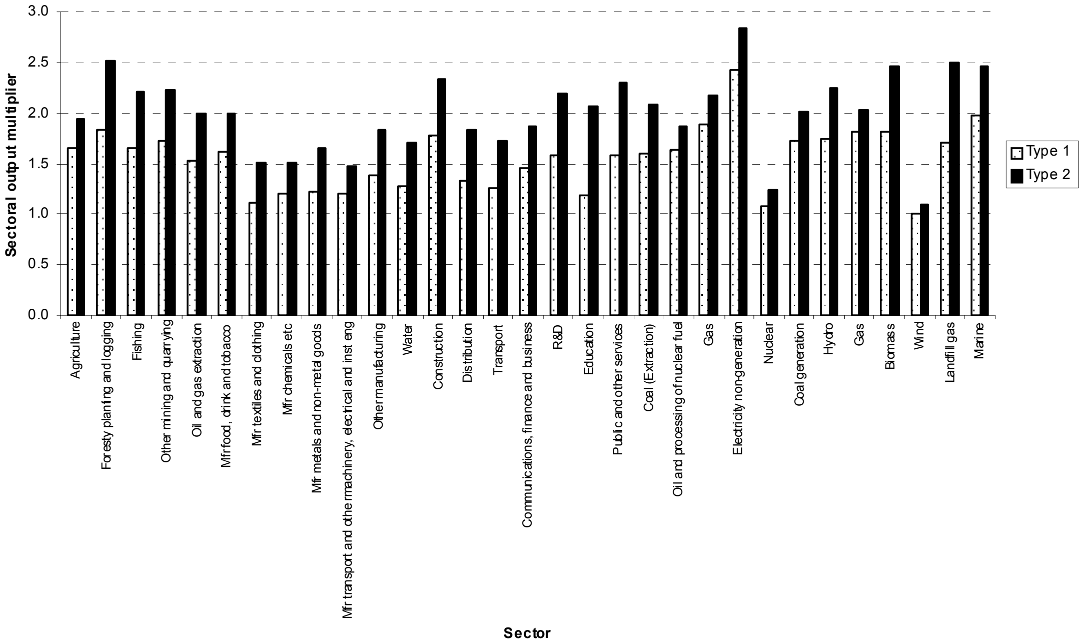
[27] In the CGE analyses elsewhere in the report, we relate emissions to input use, rather than output production (see sections 1.2 and A1.4). However, in an IO modelling framework, where there is a fixed proportional relationship between inputs and outputs, it is more common, and makes no numerical difference, to use output-pollution coefficients. However, as explained in Section A1.4, this limits the range of pollution effects modelled.

Mt of CO_2. This is slightly lower than published estimates for net emissions of CO_2 in Scotland for the year 2000 (AEA Technology, 2008) which details net emissions of 49.7 Mt of CO_2. This might suggest that our sectoral direct CO_2-output coefficients which we have carried over from 1999 data are, on average, lower than estimated sectoral coefficients for the year 2000. When we present changes from this base year level of CO_2 emissions, we might therefore expect that changes in CO_2 generation are slightly underestimated for this reason. We now set out some of the multiplier results, focusing on the extent to which electricity generation technologies differ in their backward linkages to the regional economy.

A5.2.5 Multiplier results for electricity sectors

Sectoral multiplier results from our thirty-one sector IO table have been derived. Beginning with output multipliers, these are shown, for Type 1 and Type 2 cases, in Figure A5.9 below.

Figure A5.1: Sectoral output multipliers, Type 1 and Type 2, from thirty-one sector IO table for Scotland in 2000



The calculated output multipliers for the eight electricity generation technologies are reported at the right-hand end of Figure A5.1. Allan et al (2007a) show how the pattern of intermediate purchases by the electricity generation technologies differ, and explain the differences in the output multipliers for the electricity generation sectors. These results shows that there is considerable heterogeneity among the output multipliers for the electricity generation sector, which effectively amount to a separation of the individual generating components of the overall electricity multiplier. Without disaggregation of the table, the economic impact of changes in electricity generation would be constrained to the multiplier value for the original electricity sector (2.43 and 2.84 for Type 1 and Type 2, respectively), thereby masking the striking differences between generating technologies.

Furthermore, some of the most marked differences in output multipliers are those within the fossil-fuel-based generating technologies and within renewables, so that even aggregation over either sub-sector may be highly misleading. These are clearly quite different, with a £10million reduction in coal generation resulting in a £20.5million loss of aggregate Scottish output, whereas a comparable contraction in nuclear would generate only a £12.5million reduction in aggregate output (on the basis of Type 2 multipliers). This largely reflects their differential degrees of embeddedness in the Scottish economy, with nuclear having one of smallest “knock-on” (indirect) effects.

Similarly, it would matter a great deal, on our admittedly provisional estimates, whether this loss was to be compensated for by comparable increases in the output of onshore wind (which would generate a beneficial output effect of £12.2million) or marine generation technologies (associated with an output stimulus of £24.2million). Indeed, in terms of output effects, wind is an even more limiting case than nuclear, with a negligible indirect impact on the Scottish economy. Solely from the perspective of impact effects on output, reducing nuclear and replacing the output with marine, would appear to maximize the net benefit to Scotland if these data are indicative. Of course, care needs to be taken over such a comparison. These estimates relate to variations in output at the margin assuming variable capacity: they do not take account of the costs of providing new capacity to stimulate renewables, for example, or the costs of decommissioning nuclear or coal-based generating facilities. Furthermore, they make no allowance for the qualitative difference between nuclear and marine outputs, specifically the variability of the latter.

Figures A5.2 and A5.3 give the Type 1 and Type 2 GDP-output and employment-output multipliers respectively. As mentioned above, the sectoral GDP-output multipliers can be interpreted as the additional impact on aggregate GDP of an additional £1 million of final demand for the output of each sector. An estimated (Type 2) GDP-output multiplier for the coal generation sector of 0.88 means that a £1 million increase in final demand of the coal generation sector would increase aggregate Scottish GDP by £0.88million. Sectoral employment-output multipliers can be interpreted as the additional aggregate employment generated in the Scottish economy by an additional £1 million final demand for the output of each sector. The sectoral employment-output multiplier (Type 2) for hydro generation is 23.1, implying that for an additional £1 million of final demand for the hydro generation sector, aggregate employment across Scotland is raised by 23.1 FTE jobs.

Figure A5.2: Sectoral GDP-output multipliers, Type 1 and Type 2, from thirty-one sector IO table for Scotland in 2000

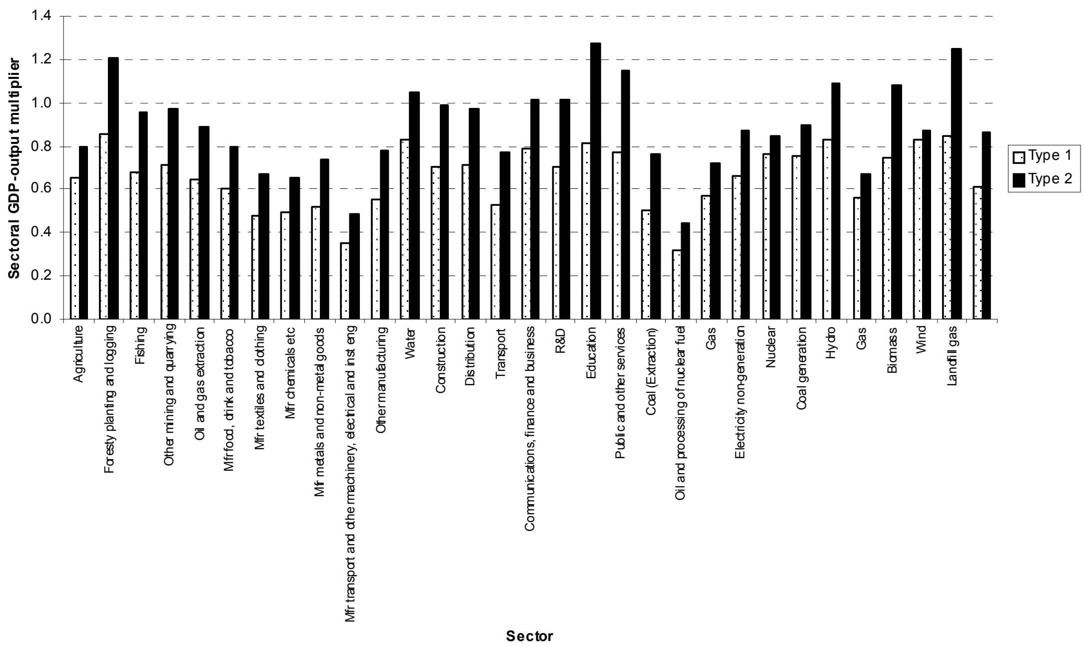
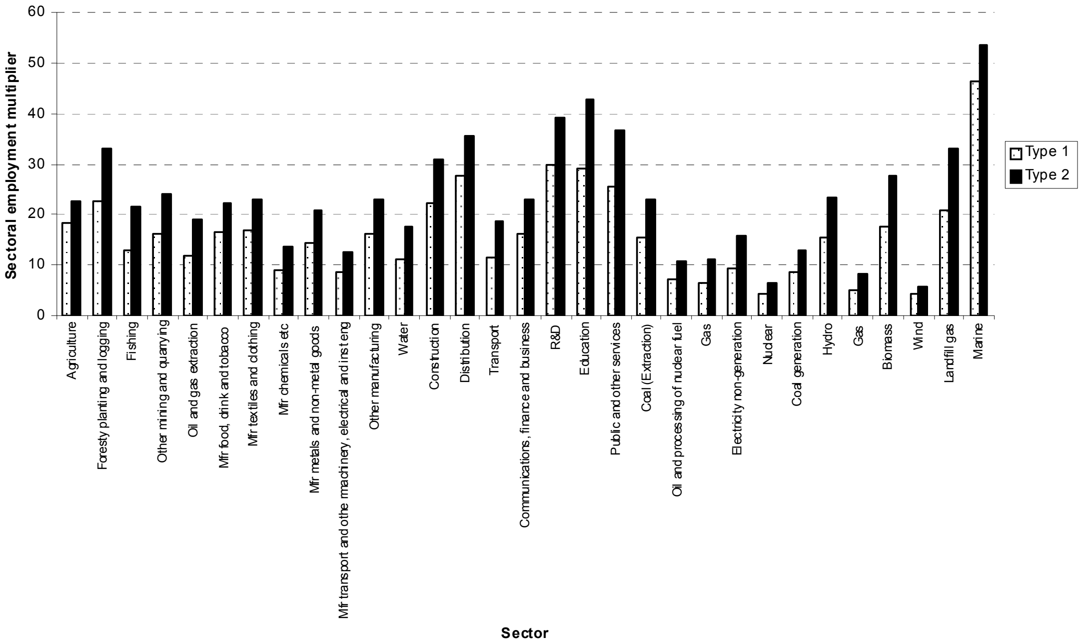


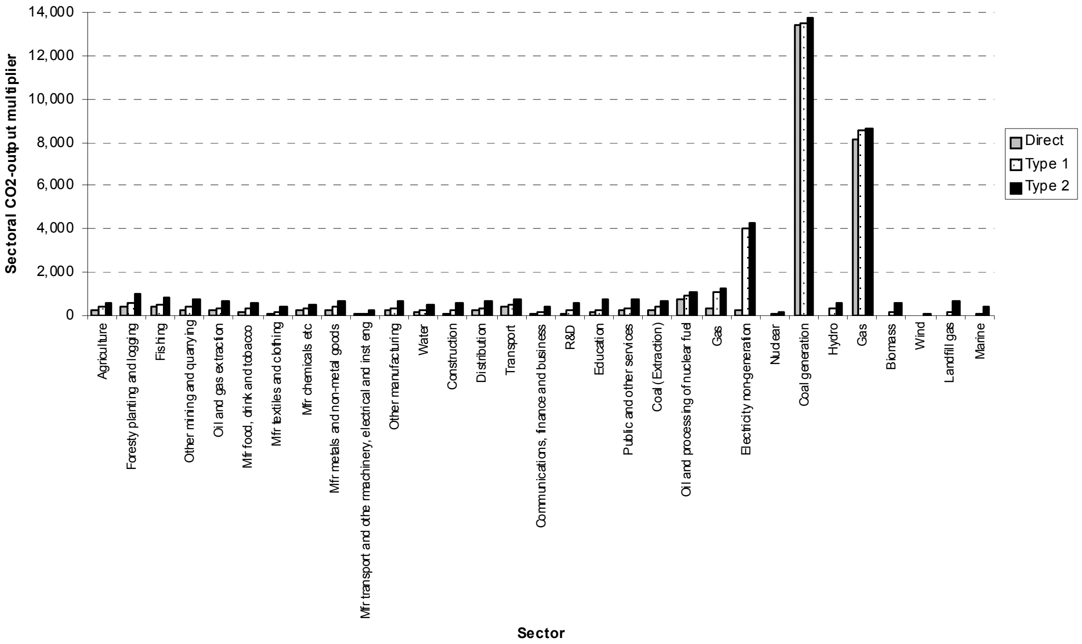
Figure A5.3: Sectoral employment-output multipliers, Type 1 and Type 2, from thirty-one sector IO table for Scotland in 2000



Sectors which have high value-added to output ratios exhibit relatively high GDP-output multipliers, with nuclear and wind consequently improving their overall rankings. The top-ranked electricity generation sector in terms of GDP-multiplier values is landfill gas, which reflects a combination of high output multipliers and moderate value-added intensity. Sectors with high employment to output ratios experience a bigger employment boost, explaining the major rise in the ranking of marine and the decline in nuclear and wind when compared with the GDP-output multiplier values. Looking at the GDP-output and employment output effects, replacing nuclear and coal with hydro, landfill gas, or wind, would suggest an economic boost to GDP, whereas the employment effects would be greatest from marine, landfill gas, and hydroelectric generation. Again, the caveat that these differences relate solely to the operational stages of electricity generation applies (Proops et al, 1996; Hondo, 2005).

We report the direct CO2-output coefficient (tonnes of CO2 per £1million of sectoral output) and the Type 1 and Type 2 CO_2-output multipliers in Figure A5.4. While the first column reports how much is generated by £1million of output, the second and third columns here relate the amount (tonnes) of CO_2 generated across the Scottish economy following a £1 million increase in the final demand for each sector with and without households endogenised. In the case of the electricity sectors, these results are especially heterogeneous, as may be expected. Recall firstly that renewable sectors, and the nuclear sector, were assumed to have emissions factors (CO_2 emissions/output) of zero. There are positive Type 1 CO_2-output multipliers for these sectors however, as an increase in the final demand for these sectors will generate additional demand through the backward intermediate linkages between this sector and other industrial sectors in the Scottish economy. Type 1 CO_2-output multipliers for the electricity generation sectors with zero direct emissions, vary from 0 for the wind sector, to 271 for the hydro generation sector. Type 2 CO_2-output multipliers for these electricity generation sectors will be higher than Type 1, given that we now also capture the additional CO_2 emissions generated by the spending of increased levels of wages in these sectors being spent by Scottish households. Type 2 results for these non-directly emitting sectors are shown in the third column in each case in Figure A5.4.

Figure A5.4: Direct CO_2-output coefficients and sectoral CO_2-output multipliers, Type 1 and Type 2, from thirty-one sector IO table for Scotland in 2000



CO2-output multipliers for coal and gas electricity generation are the highest and second-highest values seen in Figure A5.12. These sectors direct, indirect and induced effects on CO2 emissions across Scotland are massively greater than for any other sector included in this analysis[28]. This represents these sectors high direct CO2-output coefficients in our base year data. An additional £1 million of final demand for the output of the coal and gas generation sectors, increases Scottish CO2 emissions (using Type 2 results) by 13,728 and 8,663 tonnes of CO2 respectively. The CO2-output (Type 1 and Type 2) multiplier for the non-generation sector is significantly higher than its direct emissions factor due to the nature of the disaggregation of the electricity sector. Each additional £1 million of final demand for the non-generation electricity sector will increase in turn the demand for each generation technology, in proportion to that technology's share in base year generation.

A5.3 Scenarios

We model the impacts of four alternative scenarios for the electricity generation mix in Scotland (see Table A5.4 below). As stated in Section A5.1, in each of these scenarios 50% of electricity comes from renewable energy sources, the majority of which comes from onshore wind. Further, in none of these scenarios is there any generation from nuclear sources in Scotland. None of these scenarios are referenced against expected or predicted changes in the pattern of electricity generation mix in Scotland, or make any assumptions about the costs or viability of any of the scenarios considered here – such as, for instance, whether each scenario provides sufficient generation to meet expected future demand or to provide appropriate margins between peak demands and supply capacity[29]. We use these scenarios purely to illustrate the usefulness of the IO method for estimating the economic impact of large changes in the pattern of electricity generation. We begin by briefly sketching the features of each of the scenarios considered.

[28] Note, however, that there may be other sectors with greater CO2-output coefficients and multipliers, and such sectors would be revealed by a full industrial analysis of the CO2 intensity of output across all sectors of the Scottish economy.
[29] We assume that total electricity output remains at its current levels. It would be possible, of course, to explore alternative assumptions about future consumption and production, so the present analysis should be regarded as indicative.

Table A5.4: Current (2000) shares of electricity generation by technology and four scenarios considered, %

	Base year (2000)	*Scenario A*	*Scenario B*	*Scenario C*	*Scenario D*
Nuclear	33.6	0.0	0.0	0.0	0.0
Coal	33.9	25.0	25.0	50.0	0.0
Hydro	9.4	15.0	15.0	15.0	15.0
Gas	22.4	25.0	25.0	0.0	50.0
Biomass	0.1	3.0	3.0	0.0	0.0
Wind	0.4	20.0	25.0	30.0	30.0
Landfill Gas	0.1	2.0	2.0	0.0	0.0
Marine	0.0	10.0	5.0	5.0	5.0
Total	**100.0**	**100.0**	**100.0**	**100.0**	**100.0**

Note: Shares may not sum 100% due to rounding.

Scenario A: Technology mix – high marine
Under this scenario, generation from coal falls slightly compared to its base year levels, while generation from gas technologies rises slightly. Together, these technologies provide 50% of electricity generated in Scotland under this scenario. Generation from hydroelectric facilities increases by fifty per cent, up to providing 15% of electricity generated. Biomass and landfill gas increase their contribution to the Scottish electricity generation mix, rising to provide 3% and 2% of total generation in this scenario. Marine provides 10% of electricity generation capacity, with wind providing the remaining 20%.

Scenario B: Technology mix – low marine
All technologies are assumed to provide the same share of electricity generated in Scotland under this scenario, with the exception of marine and wind. Under this scenario, the proportion of electricity generation from wind is 25%, and the proportion generated from marine sources is assumed to be 5%. Such a change from Scenario A could be consistent with a less successful outcome for marine-specific support mechanisms, in terms of bring forward marine electricity generation, with wind generation dominating.

Scenario C: No Gas
Under this scenario, 50% of electricity generated in Scotland comes from renewable sources – with wind providing 30%, and hydro and marine providing 15% and 5% of total electricity generated in Scotland respectively. The remaining 50% of electricity generation is met through coal generation, with gas generation providing 0%. Output of biomass and landfill gas falls from current levels to zero.

Scenario D: No Coal
In this final scenario, renewable technologies provide the same specific and aggregate proportions of Scottish electricity generation, but rather than coal providing the remaining 50%, this is met through gas generation. By comparing Scenario C with Scenario D, we can examine the economic and environmental impacts from coal, or gas, generation providing the non-renewable portion of future Scottish electricity generation.

A5.4 Results

Table A5.5 presents the main aggregate results on GDP, employment and CO_2 emissions for each of the four scenarios outlined above.

Table A5.5: Aggregate results on GDP, employment and CO_2 emissions

		Scenario A	Scenario B	Scenario C	Scenario D
Type 1	Change in GDP (£millions)	263.24	153.69	202.43	109.42
	Change in employment (000s, FTE jobs)	24,984	13,172	13,173	11,375
	Change in CO_2 emissions, % from base year	-3.52	-3.59	0.82	-8.13
	% change in GDP	0.40	0.23	0.31	0.17
	% change in CO_2/GDP	-3.90	-3.82	0.51	-8.28
Type 2	Change in GDP (£millions)	416.41	247.78	287.91	180.11
	Change in employment (000s, FTE jobs)	29,572	15,957	15,738	13,502
	Change in CO_2 emissions, % from base year	-5.69	-5.89	-3.08	-8.86
	% change in GDP	0.63	0.38	0.44	0.27
	% change in CO_2/GDP	-6.28	-6.24	-3.50	-9.11

Recall that the only difference in Scenario A compared to Scenario B is that there are higher amounts of wind and lower amounts of marine electricity generated. In Scenario B there is 25% of electricity generation from wind and 5% from marine, while in Scenario A there is 20% of electricity from wind and 10% of electricity from marine sources. The higher amount of marine generation, combined with that sector's output multiplier being significantly higher than that for wind generation, result in a greater economic boost to Scotland than in the lower wind case. The impact of an additional 5% of electricity from marine sources, rather than from wind generation, is to increase GDP by £109.55 million, and increase employment by 11813 FTE jobs with Type 1 analysis, and, under the Type 2 IO model, to raise GDP by £168.64 million and employment by 13615 FTE jobs.

The increased economic impact, and activity, generated in Scenario A compared to Scenario B, comes at the expense of a slightly smaller decline in CO2 emissions, as is reflected in the smaller reduction in the CO2 intensity of Scottish production indicator (CO2/GDP) in Table A5.2. Under Scenario A, emissions of CO2 are 3.52% lower under Type 1 analysis, and 5.69% lower with Type 2. Under Scenario B, CO_2 emissions are down by 3.59% and 5.89% under Type 1 and Type 2 respectively. This greater decline under Scenario B is to be expected since economic activity is greater under Scenario A (due to the additional stimulus offered by the marine generation sector) and so CO2 emissions are slightly higher – although reduced relative to the base year. This is reflected in the results for the CO2 intensity of Scottish Production, which declines by 3.9% with Type 1 and 6.28% for Type 2 under Scenario A, and by slightly less, 3.82% and 6.24% respectively under Scenario B. Under Scenario C, when it is assumed that the non-renewable 50% of electricity generation in Scotland comes solely from coal generation, the GDP and employment impact is not as large as Scenario A – an additional £287.91 million on GDP and 15.738 FTE jobs under Type 2 results. The CO2 impact however is different, with Type 1 CO2 emissions actually increased relative to the base year, and an increase in the CO2 intensity of Scottish production of 0.51%. This arises due to the assumed CO2 emitting nature of coal generation technologies. The Type 2 change in CO_2 emissions shows a decline relative to the base year of 3.08% - a smaller fall in emissions than either Scenarios A or B – and a much smaller, 3.5%, decrease in the CO2 intensity of Scottish production. Under Scenario D, the smallest increased in GDP is observed (0.17% with Type 1 and 0.27% with Type 2) but the biggest Type 2 reduction in CO2 emissions

(8.86%), which gives us the biggest Type 2 reduction in the CO2 intensity of Scottish production (9.11%). This is due largely to the absence of coal generation technologies.

These results suggest that the composition of the renewables technologies which contribute to meeting the 50% target is important. Technologies with strong backward linkages back to the Scottish economy provide the greatest possibilities for an economic gain to be realised. What is suggested by Scenarios C and Scenario D is that it matters what is assumed about the technologies which provide the other 50% of electricity generated in Scotland. Without nuclear generation, this would be likely to be met through either a combination of gas and coal technologies, or, as extreme cases, from each technology alone (e.g coal in Scenario C and gas in Scenario D). As with the wind/marine results in Scenarios A and B, the economic results for these scenarios can be explained with reference to the initial linkages of each sector. Coal generation sector has greater employment-output and GDP-output multipliers than the gas generation sector in our initial IO framework. The scenario that assumes coal technologies, rather than gas generation, provides the non-renewable element of future Scottish electricity generation sees higher economic benefits, although these are associated with smaller declines in CO2 emissions.

Sectoral results for Scenarios A and B

Recall that, in all four Scenarios, we assume that 50% of electricity generated comes from renewable sources and that there is no generation from nuclear technologies in Scotland. The demand for electricity is unchanged, so Scotland remains a net exporter of electricity to the rest of the UK. In Scenarios A and B, 30% of electricity is generated from wind and marine sources, but in Scenario A 10% comes from marine sources and 20% from wind, while in Scenario B 5% comes from marine sources and 25% from wind. All other generation technologies have the same share, so the difference in the results from Scenario A to B are solely driven by the switch from marine generation to wind generation. While the aggregate results are discussed above, we focus here on the sectoral differences in these results. Absolute sectoral changes in GDP (in £million) are shown for Scenarios A and B in Figures A5.5 and A5.6 respectively.

Figure A5.5: Absolute sectoral changes in GDP, £million, in Scenario A (high marine)

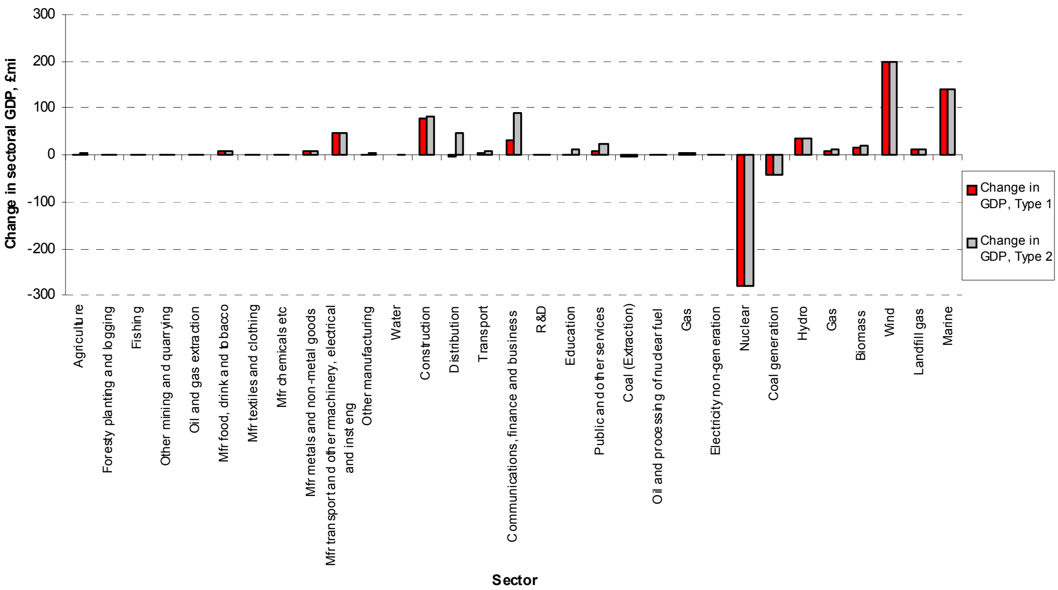
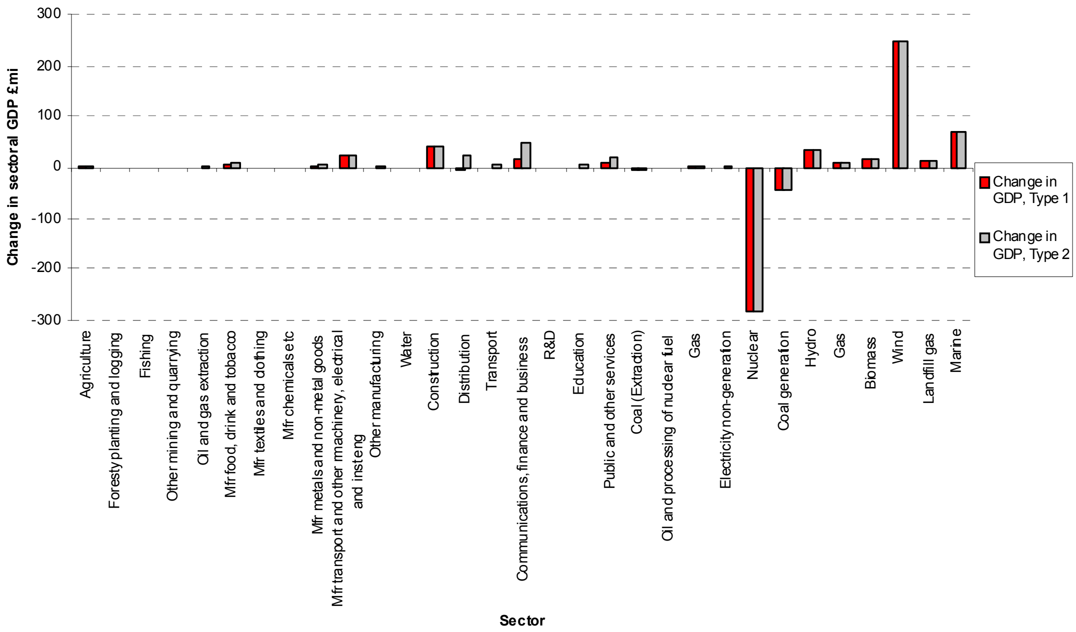


Figure A5.6: Absolute sectoral changes in GDP, £million, in Scenario B (low marine)



While the change in most sectors GDP is similar in Scenario A and B, it can clearly be seen that as well as significant changes in the wind and marine generation sectors, Scenario A sees significantly greater activity in the "Construction", "Communications, finance and business" and "Transport and other machinery". In both the Type 1 and Type 2 results, moving from Scenario A to Scenario B the change in GDP in these sectors decreases by almost fifty per cent. As seen in Section A5.2 above, these are sectors with which the marine generation sector has strong backward linkages.

The absolute change in sectoral employment in Scenarios A and B is shown in Figures A5.7 and A5.8. This shows the extent to which employment at the sectoral level is affected by the larger marine or wind generation in Scotland. The sectoral pattern of impacts may be different to that seen in Figures A5.5 and A5.6 since sectors that are GVA-intensive, are not necessarily employment intensive (as was seen in Section A5.2 above). As would be expected, in Figure A5.6, where the largest aggregate impact on employment is found, this is largely explained by the expansion of the marine sector, but also partly by the model, but significant, increase in employment in the "Construction" sector.

Figure A5.7: Absolute sectoral changes in employment, FTEs, in Scenario A (higher marine, lower wind)

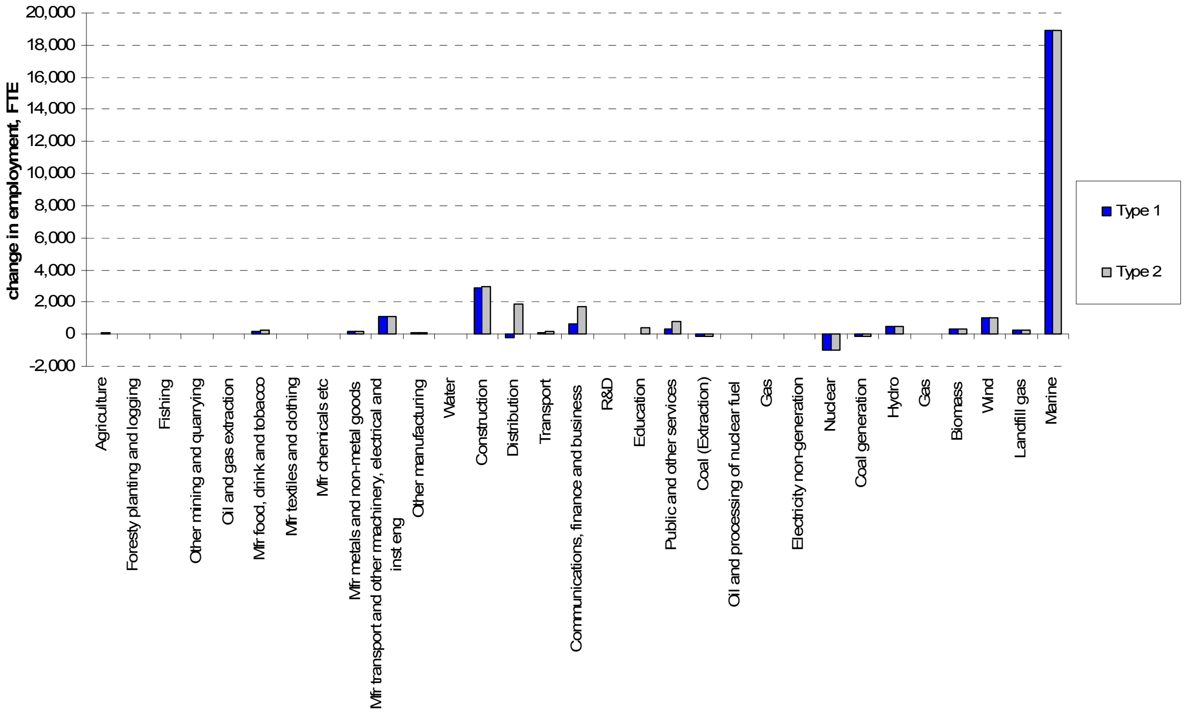
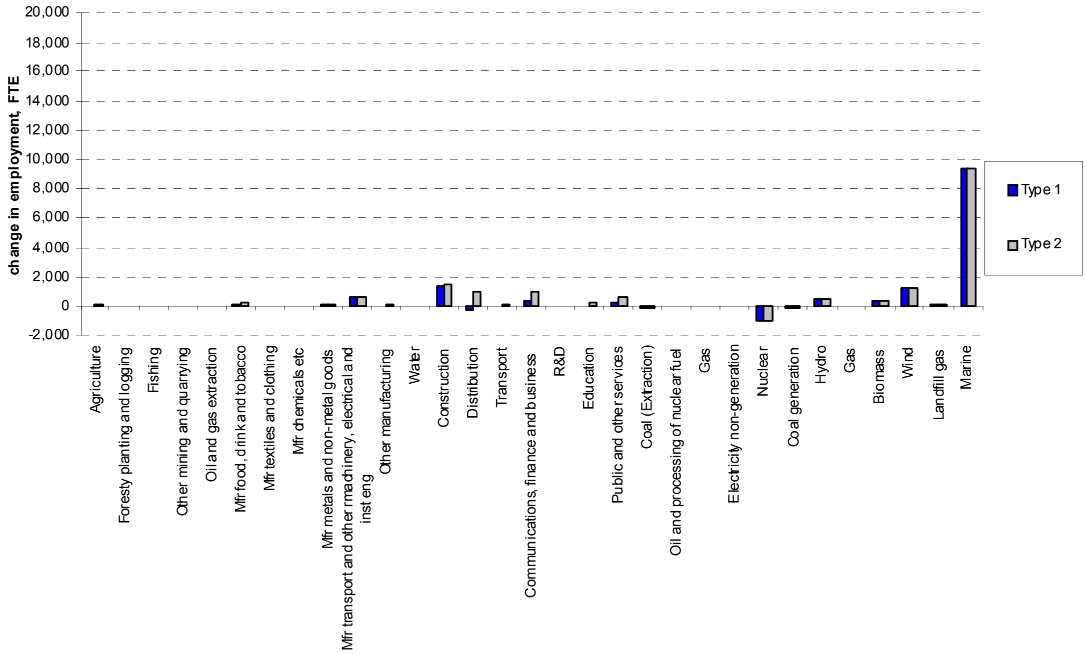


Figure A5.8: Absolute sectoral changes in employment, FTEs, in Scenario B (lower marine, higher wind)



Sectoral results for Scenarios C and D

In Scenarios C and D, we assume that the non-renewable element of future Scottish electricity generation comes from two extreme possibilities – purely coal generation, and then purely gas generation. Note again, that we assume that no electricity in Scotland is generated from nuclear sources, and that the total demand for electricity us unchanged, so Scotland remains a net exporter of electricity to the rest of the UK. The renewables' share of the future electricity generation mix in both Scenarios C and D remains the same in each scenario, with 30% from wind, 15% from hydro and 5% from marine technologies. The differences in results between Scenarios C and D therefore come solely from coal generation providing the whole of the remaining 50% of Scotland's electricity generation in Scenario C, while gas generation provides this 50% under Scenario D. While the aggregate economic and environmental results are discussed above, we focus here on the sectoral differences in these results. Absolute sectoral changes in GDP (in £million) are shown for Scenarios C and D in Figures A5.9 and A5.10 respectively.

Figure A5.9: Absolute sectoral changes in GDP, £million, in Scenario C

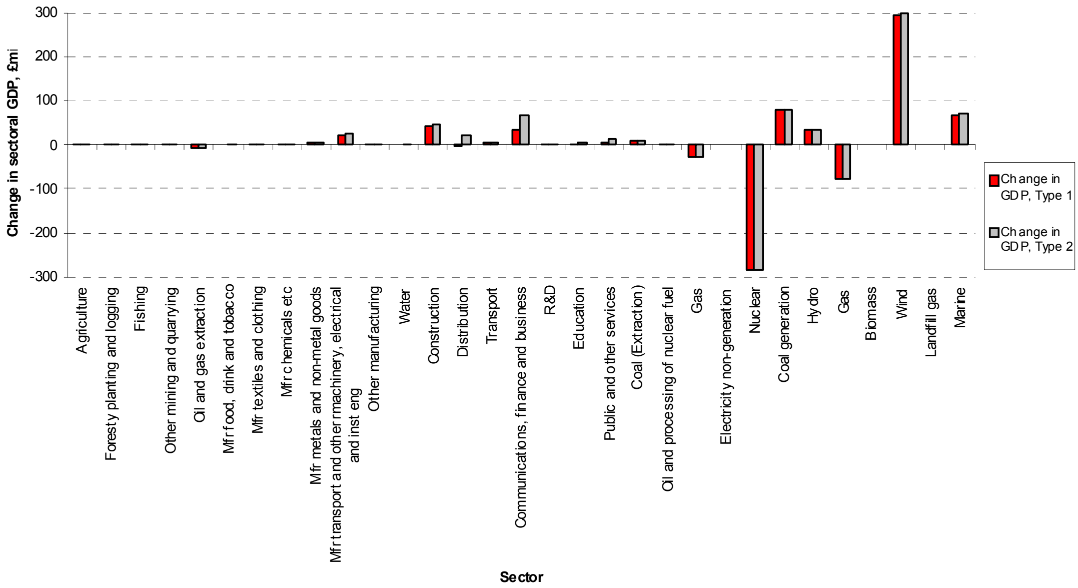
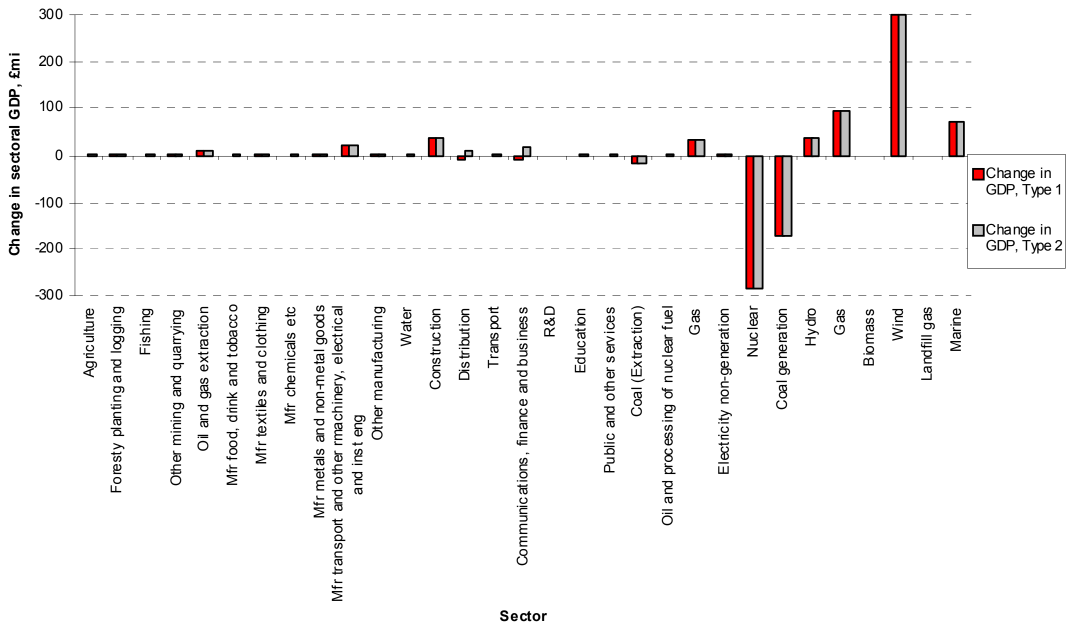


Figure A5.10: Absolute sectoral changes in GDP, £million, in Scenario D



While the results between Scenarios C and D are approximately the same for hydro, marine and wind generation sectors, there are considerable differences among the non-renewable sectors, and also in sectors that have strong links to the non-renewable sectors. The expansion of the "Coal generation" sector in Scenario B, with results in an increase not only in the "Coal generation" sector itself, but also sees an expansion in the "Coal extraction" sector (of almost 15%) and an expansion, large in absolute terms, in the "Communications finance and business" sector. Both these sectors have links to the “Coal generation” sector in the base year IO table. The “Gas refining” sector exhibits a contraction in Scenario C and an expansion in Scenario D, as would be expected. In Scenario D GDP in the “Gas refining” sector rises by over 21%, while it falls by almost 19% in Scenario C.

The absolute changes in sectoral employment in Scenarios C and D are shown in Figures A5.11 and A5.12. This indicates the extent to which employment at the sectoral level is affected by coal or gas generation providing the non-renewable portion of future Scottish electricity outputs. As with Scenarios A and B, the biggest employment impact is in additional jobs for the expanded marine generation sector. Employment in the construction sector is higher in both scenarios, while the same negative effect as found for GDP exists for employment in the “Coal extraction” sector in Scenario D and the “Gas refining” sector in Scenario C.

Figure A5.11: Absolute sectoral changes in employment, FTEs, in Scenario C

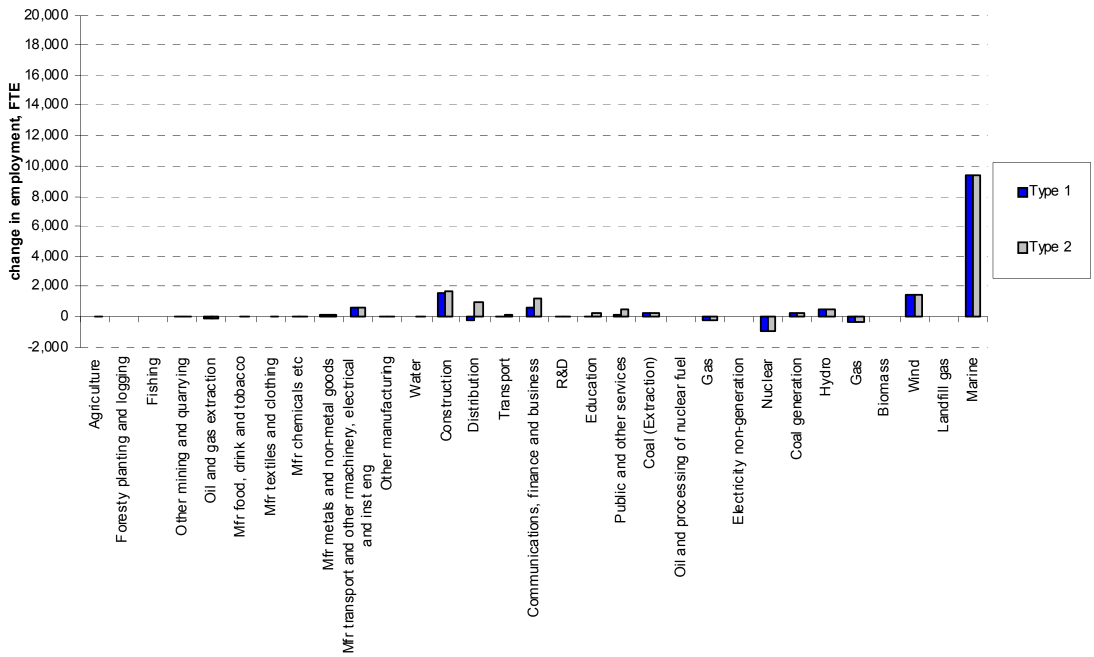
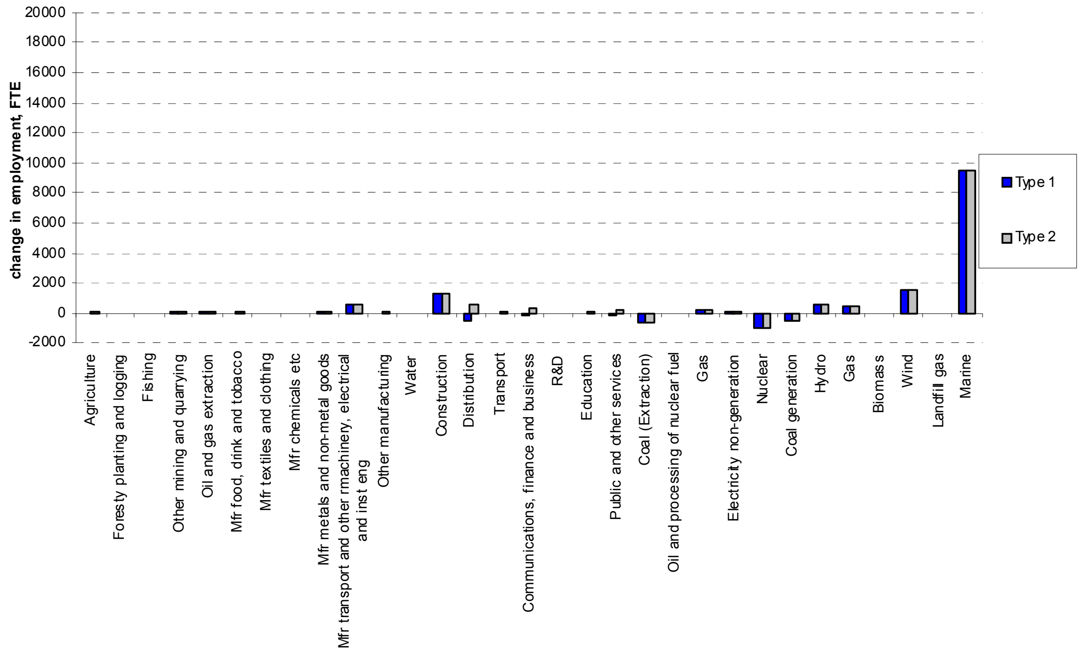


Figure A5.12: Absolute sectoral changes in employment, FTEs, in Scenario D



A5.4.1. Sensitivity analysis

Sensitivity to emissions factors for coal generation technologies

We used figures from the Scottish Energy Study (AEA Technology, 2006) as CO2 emissions factors (kg of CO2 produced per kWh generated). For electricity generation from gas and coal technologies respectively these were 0.19 and 0.3 kgCO2/kWh. Specifically for future coal technologies, legislation requiring "cleaner" generation makes it likely that there will be significant reductions in the quantities of CO2 produced per kWh generated from existing levels. Carbon Capture and Storage (CCS) technology, which involves extracting CO2 emissions directly at the point of production and storing these emissions, perhaps in underground "sinks", can reduce the emissions per kWh from coal by up to 90%[30]. We can examine the impact of this reduction, by reducing the CO2 emissions-output coefficient for the "Coal generation" sector by 90% - from 0.3 kg/kWh to 0.03 kg/kWh.

With this adjustment to the emissions factor for the "Coal generation" sector, emissions under each scenario are given in Table A5.6

Table A5.6: Change in CO_2 emissions, % from base year, under for scenarios with original emissions coefficients and 90% reduction in Coal generation emissions coefficients

		Scenario A	Scenario B	Scenario C	Scenario D
Type 1	Original coefficients	-3.52	-3.59	0.82	-8.13
	With 90% reduction in "Coal generation" emissions coefficients	-15.08	-15.12	-22.13	-8.13
Type 2	Original coefficients	-5.69	-5.89	-3.08	-8.86
	With 90% reduction in "Coal generation" emissions coefficients	-13.12	-13.31	-17.80	-8.86

In each of the scenarios in which coal plays a role (A-C), the reduction in the Coal CO_2 emissions factor has a significant impact upon the resulting CO2 emissions. In Scenarios A and B the share of electricity generated from Coal sources is constant at 25%. Reducing the CO2 emissions per unit of output in the Coal generation sector by 90% significantly lowers the emissions in both of

[30] See BERR (2008) for details of the UK Government's support for Carbon Capture and Storage.

these scenarios, with emissions down by 15% and 13% under Type 1 and 13% in Type 2 results respectively. The biggest change from the original and adjusted Coal emissions coefficient unsurprisingly is in Scenario C, where we assume that Coal generation produces 50% of the total electricity generated in Scotland. Emissions of CO_2, which rose under Type 1 analysis for the original coefficients, decline by 22% and almost 18% under Type 1 and Type 2 analysis respectively. Results for total CO_2 emissions in Scenario D are unchanged, as in this scenario there is no electricity generated in Scotland from coal sources.

Technical Appendix A6. Simulation results: Renewable Energy Supply 1 – CGE Analysis

A6.1 Introduction

Our final set of simulations involves modelling the economic and environmental impact of increases in the share of electricity generated in Scotland from renewable energy sources. This appendix sets out some illustrative results from running the AMOSENVI model to simulate such an outcome. A number of practical problems have been encountered during the simulating of this outcome and we set these out in this note as well, before discussing the simulation strategy employed and the results of such policies. We have sought to model the effects of increases in the amount (and share) of renewable electricity generation in Scotland from the base year levels in the AMOSENVI model (1999). In the base year of the model (1999), we begin with a situation where renewable electricity generation provides 10.4% of all electricity generated in Scotland. In total, 42,482 GWh of electricity was generated in the base year of the analysis. In the core simulation which we present below we have sought to increase the share of electricity coming from renewable technologies, while maintaining the total amount of electricity generated in Scotland at levels as close as possible to the original figures for 1999. It would be possible, of course, to explore alternative assumptions about future consumption and production, so the present analysis should be regarded as indicative.

We carry out and report sensitivity analysis where in order to increase the proportion of the renewables, we relax the assumption that generation levels remain close to base year levels. There are a number of issues about the simulations which we report. Firstly, we assume that the underlying technology used to create the output of the renewable electricity generation remains unchanged. There is an extensive literature on learning rates, and the reduction in the costs of electricity generation from increased development and deployment of renewable energy technologies (e.g. Winskell *et al*, 2007). These simulations do not incorporate such developments. Secondly, we seek to make changes to the sectoral output of the renewable and non-renewable electricity generation sectors, so that total output of the electricity sectors remains close to existing levels. Results for electricity consumption relate to total electricity consumption by industries and final demand categories in Scotland, and as such, include imports of electricity. Thirdly, the database used for these simulations is that using an experimental disaggregation of the Electricity sector in the original IO table for Scotland. In summary, features of the AMOSENVI model make the results presented no more than illustrative of the type of results which can be obtained from CGE analysis.

In Section A6.2, we set out some of the practical issues encountered in running the AMOSENVI model to capture the effects of increased penetration of renewable electricity generation in Scotland. In Section A6.3, we briefly describe the simulation strategy employed, while in Section A6.4 we report the economic, environmental and energy results from a "central" scenario in which we significantly increase the level and share of renewable electricity generation. In sensitivity analysis in Section A6.4, we further increase the share of renewables, but this can only be accommodated in the model with an associated further rise in the price of electricity. Therefore allowing total electricity generated in Scotland to be lower than the base year, we report the results from scenarios where the level and share of renewable electricity generation is significantly greater. These scenarios are also associated with a relative decrease in Scottish CO2 emissions, against the "core" scenario, but also larger declines in Scottish GDP.

A6.2 Practical issues in modelling increased penetration of renewable generation

Our initial plans to model the impact of renewable energy supply were to focus on the electricity sectors in the AMOSENVI model (sectors 24 – renewable electricity; and sector 25 – non-renewable electricity) and introduce shocks to the efficiency of production at various points on the sectors' production function. With the greater penetration of renewable energy supply, there would be a requirement for additional grid enhancement, requiring greater capital intensity, as well as additional capacity or capital-intensive electricity storage being required to accommodate the greater intermittency of electricity production. The CGE model could then be used to identify the substitution and output effects of the movement towards greater capital intensity of production in both the electricity renewables and non-renewable generation sector. The levels of negative shocks to capital efficiency which would be introduced into the model, would be calibrated on existing estimates of direct cost changes for greater levels of renewable electricity generation.

This simulation strategy ran into a number of problems, most notably that we were unable to calibrate the necessary shock and we were not able to enter the capital efficiency changes correctly. These problems appear to suggest that additional programming development work is necessary before the AMOSENVI model can accommodate simulations using this route. An alternative approach was necessary which we use for the "central" simulation and the sensitivity analysis that follows.

A6.3 Simulation strategy

Our alternative simulation strategy involves introducing subsidies to renewable electricity generation and taxes on non-renewable electricity generation. The intention is to choose the appropriate tax and subsidy rates such that the outputs of these two sectors adjust so that the combined "physical" electrical output of these two sectors remains approximately constant, but that the share of electricity produced by renewable electricity increases from its base year value. When we hold "physical" electricity output constant this is not equal to the combined real value of the output of the two electricity sectors being kept constant.

Ideally, the tax and subsidy raised should be revenue-neutral to the Government exchequer. We ensure this by allowing government expenditure to adjust so as to maintain the ratio of government deficit to GDP at its base year level. In all the simulations that follow, government expenditure is lower than in the base year, indicating that increased tax revenues in the non-renewable sector are not large enough to offset the subsidies required to stimulate the renewable electricity sector. The increases in tax necessary for the non-renewable sector to get the relative prices of renewable output to non-renewable output to shift, will have the effect of reducing the real wage, and in principle might increase government revenues. In the simulations which we report, however, the competitiveness effect of high prices is larger than the demand stimulus, and, in fact, government expenditure, and GDP, fall. The tax take is lower

Results in Section A6.4 consider the economic implications of a Government policy package designed to increase the share of renewable electricity generation as a proportion of total electricity production. This is intended to explore the potential system-wide consequences of the Scottish Government's stated objective for 31% of total energy generation to be sourced from renewable energy technologies by 2011. For reasons explained above, we analyse alternative subsidy and taxation combinations that are applied to the renewable/non-renewable electricity generation sectors, respectively. Various model constraints, however, are such that we are not able to replicate exactly the magnitude of renewable electricity generation penetration that is implied by the Scottish Government's objective. In total, we ran approximately 500 simulations, with different levels of taxes and subsidies such that we held total electrical output approximately constant, and increased the share of electricity from renewable sources.

As in our previous CGE modelling analyses, we examine the effects of the policy change subject to our benchmark equilibrium time period; that is, our results refer to percentage changes in variables compared to base. In this model framework, wages are determined according to our bargaining set-up, and we allow for migration of the labour supply to and from the rest of the UK. We report long-run results, where this represents a conceptual time period over which labour and capital stocks fully adjust to new equilibrium values. In the current model set-up, this corresponds to a timeframe whereby real wages and unemployment are restored to initial equilibrium values, and the capital rental rate is equalized across all sectors.

A6.5 Central results and sensitivity analysis

A6.4.1 Central aggregate and sectoral results

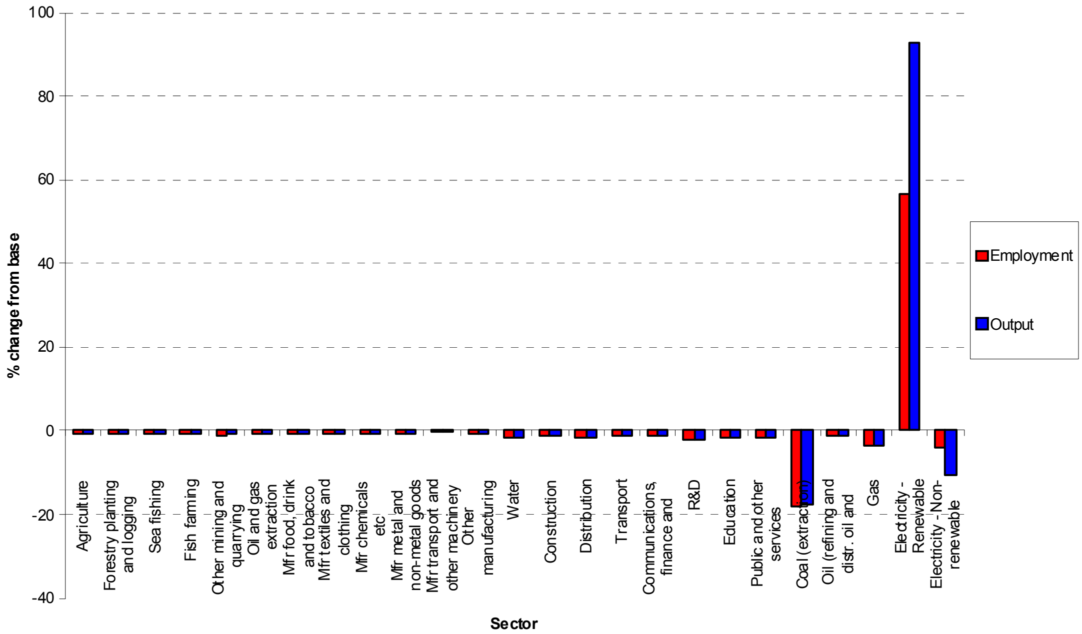
Our central scenario involves a subsidy package equivalent to 94.1% of value added for the renewable electricity generation sector, and a tax equivalent to 36.9% of value added to the non-renewable electricity generation sector. Table A6.1 reports the long-run impacts on key aggregate economic, energy and environmental variables. This policy change has the effect of reducing long-run GDP by 1.15%. The key factor underlying the negative impact on output are the price effects associated with the policy change. The extent of taxation in the non-renewable electricity sector is such that the price of output in this sector increases significantly (by 28.54%). This leads to a relative increase in the cost of the electricity composite, which combines with other energy inputs to form an overall energy composite. Increases in the price of the energy composite will serve to raise the cost of intermediate inputs, which will have negative implications for economic activity across the economy as a whole.

Table A6.1: Long-run aggregate economic, energy and environmental impact from "central" increase in renewable electricity generation in Scotland, bargaining labour market, % changes from base expect where indicated

	Long-run
% share of total electricity generation from renewable sources (base year = 10.4%	*20.06*
% change in total electricity generation from base year	*-0.04*
Gross Domestic Product (GDP)	-1.15
Consumption	-1.20
Government expenditure	-1.42
Investment	-0.90
Exports	-0.33
Imports	-0.24
Nominal (before tax) wages	0.51
Real (take-home) wages	0.00
Total population	-1.35
Total employment	-1.35
Unemployment rate (%)	0.00
Consumer Price Index	0.51
Renewable electricity generation	92.82
Non-renewable electricity generation	-10.82
CO_2 generation	-4.15
CO_2 intensity of output	-3.03
Electrical energy demand	1.96
Non-electrical energy demand	-3.18
GDP/Electrical energy demand	-3.05
GDP/Non-electrical energy demand	2.09

Figure A6.1 illustrates the long-run changes in output and employment across all sectors. It shows that those industries which are heavily dependent on the activity of the non-renewable electricity generation sectors (such as the coal extraction and gas sectors), are most negatively affected by the fall in output in that sector

Figure A6.1: Long-run impact on sectoral output and employment, % changes from base year



Significantly higher production costs mean that output contracts relative to base in the coal sector by 17.85% (higher even than the fall in output in the non-renewable electricity sector of 10.82%), and in the gas sector by 3.56%. The only sector to experience an increase in output is, as expected, the renewable electricity sector. In this sector the subsidy leads to a reduction in the price of outputs (by 49.79%), and is associated with an increase in sectoral output of 92.8%.

The effect of this reduction in the price of renewable electricity as an intermediate input, and the overall boost in activity in this sector is, however, insufficient to outweigh the negative effects in the non-renewable energy sector. The relative dominance of non-renewable electricity generation in the supply chain is such that all other sectors experience an overall increase in input prices. As noted above, we hold “physical” electricity output constant, but the real value of output of the electricity sectors decreases as the increases in the price of the electricity composite is greater than the increase in the value of output. This leads to an economy-wide increase in prices: CPI increases by 0.51% relative to base. In the long-run, real wages return to their pre-shock level, but there is a lasting effect on nominal wages. Nominal wages increase by 0.51%, reflecting the increase in CPI, and a reduction in external competitiveness means that exports fall by 0.33%. Government expenditure falls by 1.42% in total, as the subsidies required to bring forward renewable electricity generation are greater than the taxes raised from non-renewable electricity generation, requiring government expenditure to contract to maintain the ratio of Government deficit to GDP, as described above.

The implications for the labour market are clear. In line with changes in output, employment falls across all sectors, except for the non-renewable electricity sector, and the highest relative reductions occur in the most energy-dependent sectors. Across all sectors, the percentage change in employment is closely comparable with changes in output, with the exceptions of the renewable and non-renewable electricity sectors, which reflects the fact that the tax and subsidy are effected on capital, and so incentivise a substitution towards/from capital in the renewable and non-renewable electricity generation sectors respectively. The overall fall in aggregate employment leads to outward migration, and a fall in Scottish population relative to base.

The environmental consequences of this policy are lower CO_2 emissions. The fall in CO_2 emissions outweighs the reduction in GDP, partly due to the shift in the composition of electricity generation from non-renewable to renewable sources. In the long-run, the share of electricity generation sourced from renewable technologies is 20.06%, compared to a share of 10.4% before the policy shock. This means that the CO2 intensity of Scottish production falls, along with total CO2 generation.

A6.4.2 Sensitivity analysis

Table A6.2 shows the long-run impact on aggregate economic, energy and environmental indicators for alternative combinations of subsidy/taxation rates on the renewable and non-renewable sectors respectively. Our aim of this analysis was to analyse a subsidy/taxation mix that would lead to an increase in the penetration of renewable electricity generation in order to match the Scottish Government's objective of a 31% share of total electricity output, whilst at the same time keeping total "physical" (i.e. kWh) electricity output constant. However, modelling constraints mean that to achieve a 31% share would require significant alterations to the current model framework, which is outwith the scope of this study. Although we are able to determine subsidy/taxation ratios that achieve a higher market share than in our central scenario, this is at the expense of keeping total physical electricity output close to its initial level. As such, we carry out a number of simulations, which are feasible within our current model framework, for alternative subsidy/taxation mixes. These consider (i) a subsidy/taxation mix that is designed to achieve the highest possible penetration of renewable electricity outputs, whilst keeping total electricity output fixed at its base year value (the central case scenario), and (ii) subsidy/taxation packages that increase the percentage share of renewable electricity output to as close to 31% as possible, whilst allowing the total level of electricity generation to fluctuate away from the base year value (scenarios 1, 2 and 3).

The findings of these simulations are broadly as anticipated. In scenario 1, the higher subsidy/taxation rates have a corresponding impact on the wider economy. The same effects on input prices and export competitiveness are evident as in the central case, but to a greater extent. The magnitude of the effects on aggregate output and employment are therefore much increased compared to the central scenario: output and employment fall 4.24% and 4.51% respectively, relative to base, compared with falls of 1.51% and 1.35% in the central case. This translates to more significant improvements in the environmental indicators than in our central scenario: CO_2 generation falls by 10.05%, compared with a fall of 4.15% in the previous case. This is partly due to the fact that renewable electricity output as a share of total electricity is higher (24.21% in this scenario compared to 20.06% in the central case), but is also because total electricity output has fallen compared to base (by 13.38% in this scenario, compared with a fall of 0.04% in the central scenario).

For the higher subsidy/taxation mixes (scenarios 2 and 3), we find that we are able to achieve a higher penetration of renewables electricity (market shares of 25.46% and 26.08% respectively), though for each of these scenarios, total "physical" electrical output moves significantly away from the base year values. These two scenarios involve higher taxation of the non-renewable electricity sector compared to both the central case and scenario 1. As expected, this is associated with a higher increase in the price of non-renewable electricity inputs to production, and therefore a greater increase in CPI, and underlies significant reductions in export competitiveness and GDP. The fall in the competitiveness is greater than the demand stimulus from an increased government revenue; in fact in these scenarios the tax take is reduced with a consequent fall in government expenditure. The increase in the market share of renewable electricity, combined with reduction in total electricity output (of 12.13% and 12.98% respectively), leads to a notable improvement in environmental indicators, with CO_2 generation falling by almost 13% for scenario 3.

Overall, the results suggest that policy intervention to increase the market share of renewable electricity generation, in the form of a subsidy/taxation package such as those described above, could lead to a deterioration in overall economic performance in the long-run. The scenario analyses suggest that the higher subsidy/taxation rates outlined above are associated with greater downturns in economic activity. One important caveat is that we assume that the cost of the required net subsidy is decreased government expenditure. An alternative specification could be possible, where government budget remains in balance by changing the average tax rate. This could have important consequences for the scale of the aggregate economic impact, as the tax rate would affect the labour supply decisions facing households.

These results, however, are subject to there being no other policy measures or economic influences at work to offset or reinforce these effects. We do not consider, for example, the consequences of significant skilled labour shortages in the renewable electricity industry, and consequent wage increases. This may be a feasible outcome of an intense subsidisation policy, and such effects would exacerbate any economy-wide price pressures. Nor do we consider scenarios reflecting the growth in dominance of renewable electricity inputs in the supply chain over time, which could alleviate, to some degree, the increase in prices of non-renewable electricity inputs. These effects, and other policy measures designed to complement the subsidy/taxation mix, could have important implications for the overall outcome of increased penetration of renewable electricity generation.