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Assessing the Appropriate Methodology for Projecting Scottish CO_2 Emissions to 2030

A final report for the Committee on Climate Change

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Revision and Authorisation History

Version	Date	Authorised for release by	Description
1.1	27/11/2009	Sudhir Junankar	Added, as requested by client, a footnote and link to the DEMScot report and updated historical figures to most recent outturn (2007), where applicable
1.0	20/11/2009	Sudhir Junankar	Merged report incorporating Phase 1 and Phase 2 reports in line with client comments

Contents

Executive Summary

- The Committee on Climate Change (CCC) commissioned Cambridge Econometrics (CE) to assess the modelling approach used by the CCC to project CO_2 emissions in Scotland. An assessment of the CCC's then existing approach, which was applied in the preparation of the CCC's inaugural report of December 2008 and entitled *Building a low carbon economy – the UK's contribution to tackling climate change*, and recommendations for improvement was conducted in the first phase of the project[1]. The main section of this report presents the work undertaken in the second phase of the project and describes the development of the new modelling tool. A number of reference scenarios have been produced using the new tool, under different sets of input assumptions, and the results are also reported here.

- In Phase 1, we presented our assessment of the existing methodology against a number of criteria and proposed improvements to the method. The proposed changes included:
  - a Scotland-specific level of EU ETS coverage by sector, that proved markedly lower than the proportion estimated for the UK
  - a more detailed calculation of policy impacts in the domestic sector that considered the circumstances specific to Scotland
  - model-determined income and price responses for scenario analysis
  - the use of a dedicated transport model to project road and rail transport emissions, specifically, the Department for Transport's (DfT's) National Transport Model (NTM); a simpler treatment has been incorporated into the projections tool
  - methods to project emissions from sources not currently covered by the CCC; their complexity is constrained by the available data

- Our recommendations and the updated and new projection methods have been implemented in a spreadsheet-based modelling tool, accompanied by a User Guide. This tool, along with a number of reference scenario projections, with varying fossil-fuel price and economic-growth assumptions, are the key outputs from Phase 2 of the project and discussed in this report.

- Six reference scenarios were produced under varying assumptions about economic and population growth and fossil-fuel prices. The results of these are discussed more fully in the main report (Chapter 4) and the non-traded totals summarised in Table ES.1 below. In the central case, reductions in non-traded sector emissions of around 7.5% compared to the 2005 level are projected by 2020 with emissions increasing to just 0.4% below the 2005 level in 2030 as a result of continued economic growth. All scenarios indicate that emissions in 2020 will be below the 2005 level but the results for 2030 are more varied; emissions may be as much as 6.9% higher than the 2005 level in the 'worst' case and -7.1% below in the 'best'.

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[1] The findings from Phase 1 are summarised in Chapter 2 of this report. For further detail, the reader is referred to Appendix B.

TABLE ES.1: NON-TRADED SECTOR EMISSIONS PROJECTIONS, SCOTLAND

$ktCO_2$

Scenario	2005	2007	2010	2020	2030	% diff in 2020 on 2005 level	% diff in 2030 on 2005 level
Central fossil fuel price	27,033	26,528	24,858	25,000	26,912	-7.5	-0.4
High fossil fuel price	27,033	26,528	24,464	24,079	26,254	-10.9	-2.9
Low fossil fuel price	27,033	26,528	25,547	25,705	27,769	-4.9	2.7
High emissions	27,033	26,528	25,669	26,265	28,898	-2.8	6.9
Low economic growth	27,033	26,528	24,651	24,077	25,100	-10.9	-7.1
High economic growth	27,033	26,528	24,977	25,548	28,017	-5.5	3.6

Note(s): Figures exclude aviation emissions.

Source(s): NAEI, Cambridge Econometrics.

1 Introduction

1.1 Background and context

The UK Climate Change Act (2008) requires that, when advising on carbon budgets, the Committee on Climate Change (CCC) should take into account ‘differences in circumstances between England, Wales, Scotland and Northern Ireland’, amongst other things. Also, under section 38 of the UK Act, the CCC must provide advice, analysis, information or other assistance to any national authority[2] in connection with any greenhouse-gas emissions target, budget or similar requirement. In August 2009, the Climate Change (Scotland) Act received Royal Assent. The Act commits Scotland to reduce its emissions by at least 80% by 2050 compared to 1990 levels, with an interim target for 2020 of a 42% reduction (subject to advice from the Committee).

The CCC, under section 38 of the UK Act, has been asked to give advice on the appropriate level of annual targets and the highest achievable interim target in accordance with the Climate Change (Scotland) Act. In order to advise the Scottish Government, the CCC will undertake a number of pieces of analysis. The first of which is to establish reference emissions projections for Scotland’s non-traded source sectors (ie excluding emissions covered by the EU Emissions Trading Scheme), which will help determine the scale of the challenge in meeting emissions targets in Scotland.

To develop its advice for Scotland, the CCC commissioned Cambridge Econometrics (CE) to assess the existing methodology[3] for projecting Scotland’s CO2 emissions and to provide an extended methodology and tool to deliver projections to 2030.

1.2 Structure of the report

This report covers the method and results of the projections modelling tool for Scotland’s non-traded carbon emissions. The model we have developed is also accompanied by a User Guide.

This report is divided into seven chapters. Chapter 2 contains a summary of the work undertaken in Phase 1 and the reader is referred to Appendix B of this report for a more detailed description of these findings. Chapter 3 explains the underlying framework of the model and the method used to project emissions for each sector. This chapter is supported by a more technical Model User Guide provided to the CCC. Chapter 4 outlines the scenarios used in the analysis and explains why scenarios were developed to test the range of projections. In Chapter 5, we discuss the key results of the modelling projections tool under various scenarios and we test the user options for projecting emissions in different sectors. Concluding remarks are provided in Chapter 6 particularly drawing on the limitations of the modelling approach and the various uncertainties that are inherent to the projections modelling. In the final chapter we provide recommendations for further research in this area, that address the key

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[2] In the Climate Change Act, the term national authority relates to: the Secretary of State, Scottish Ministers, Welsh Ministers and the relevant department in Northern Ireland.

[3] That is, the method used in the preparation of the CCC’s inaugural report of December 2008, *Building a low carbon economy – the UK’s contribution to tackling climate change*. All references to the ‘current’ or ‘existing’ method should be taken to mean the method used for this inaugural report.

constraints to developing a better model driven by bottom-up Scottish data and energy analysis and build on the criticisms discussed in Chapter 6.

There are two appendices that accompany this report. Appendix A provides some commentary reconciling the projections from the tool described in this report with those from the DEMScot model[4]. Appendix B contains a more detailed report of the Phase 1 work.

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[4] DEMScot is a model of the Scottish housing stock designed to allow for the assessment of the potential to reduce CO_2 emissions from the domestic sector. More details can be found at: http://www.scotland.gov.uk/Publications/2009/10/08143041/0

2 Phase 1 Summary

The first phase of the project was composed of five main tasks:

1. to assess the existing method for projecting Industry, Commercial and Domestic emissions
2. to assess the coverage of the EU ETS traded and non-traded sectors for Scotland
3. to assess the method for including policy impacts specific to Scotland
4. to compare the Department for Transport's National Transport Model (NTM) against the Transport Model for Scotland (TMfS) and suggest a method for developing emissions projections from road transport
5. to propose a methodology for previously omitted sectors, including: rail, domestic and international aviation, domestic and international shipping, offshore oil and gas, and process emissions

We developed a number of criteria[5] (nine) that we consider should be met in a robust and credible forecasting or projections model, that were divided into four broad categories:

- inputs to the method
  - the consistency and suitability of the data used
  - the past performance of the method and its previous applications
  - the underlying assumptions and the application of intuition and theory
  - functional form and parameters
- outputs from the method
  - the scope/detail of the outputs
- forecasting performance
  - learning from history
  - forecast accuracy
  - transparency
- cost (relative to the detail provided)

These were used to assess the CCC's existing method and the key outcomes and recommendations are presented below:

- we proposed largely to retain the CCC's method for disaggregating Commercial, Industrial and Domestic emissions, having concluded that, on the basis of the criteria above, it was suitable for the CCC's purposes. Our main recommendation in this regard was to, where possible, make use of more detailed industry data such as SCPnet data
- we calculated that the percentage of emissions from industry that are covered by the EU ETS is much lower in Scotland than the coverage estimated by the CCC in its inaugural report for the UK[6]. We found a number of inconsistencies between the datasets used in calculating the coverage and believe further analysis may therefore be necessary in the future and suggest that more work be done on bringing the various data series into line
- the possible presence of Scotland-specific factors is a recognised weakness in the CCC's existing approach to applying policy impacts in a similar manner to the

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[5] Please refer to Chapter B.2 in Appendix B.

[6] http://www.theccc.org.uk/reports/building-a-low-carbon-economy

disaggregation method used. This is perhaps most notable in the case of domestic emissions, for which the differing characteristics of the Scottish and UK housing stocks, and the differing income profiles will have an impact on the effectiveness of CERT. This has been reflected in the application of more detailed estimates of the impact of CERT

- in evaluating the NTM and the TMfS road-transport models, we recommended that NTM be used, despite offering less detail than the Scotland-specific TMfS in some respects, on the grounds that the NTM covers Great Britain (this integrated structure being considered important) and offers greater scope to examine policy impacts, for example, through its endogenous representation of the vehicle stock. The NTM also offers broader coverage, including Public Service Vehicles. In the end, a simple emulation was developed based on NTM outputs that were allowed to vary according to differing income and price assumptions
- governed largely by the available data, our proposed methods for projecting CO_2 emissions from non-traded sources not currently projected by the CCC are similar to the disaggregation methods used previously, although we have also suggested a number of sources for which emissions are related directly to key drivers and solved dynamically

Having made these recommendations, we proposed to develop a relatively simple, but robust, spreadsheet projections tool to incorporate the revised and new methods.

The recommendations from Phase 1, and the extent to which they have been incorporated into the final modelling tool, are summarised in Table 2.1 along with a list of recommendations for future work.

TABLE 2.1: SUMMARY RECOMMENDATIONS AND MODEL DEVELOPMENTS

Sector	**Phase 1 recommendations**	**Phase 2 developments**	**Further recommendations**
Industry & commerce	Apply DECC price elasticities to the results of the central run to mimic the DECC model responses	Implemented	More disaggregated energy-consumption data required, covering more sub-sectors
	Preserve UK industry breakdown of energy demands	Implemented	Further efforts to reconcile regional consumption data with UK aggregates
	Use SCPnet data to differentiate energy demand by user (eg Iron & steel, mineral products etc) and by fuel	Not implemented; SCPnet data were found to be inconsistent with data from official sources	May wish to further investigate discrepancies when combining data sources
	Use Scotland-specific data on EU ETS installations, CCAs and Opt-outs to determine the coverage by broad sector	Implemented, although CCAs and Opt-outs are based on relevant emissions, not outturn data	Investigate discrepancies in datasets with greater sectoral detail (eg NAEI vs SCPnet) and incorporate outturn data (CCAs, Opt-outs) as they become available. Consider how the coverage may change over time as more data become available
Domestic	Apply DECC price elasticities to the results of the central run to mimic the DECC model responses	Implemented	Greater scrutiny is required of the DECC model equation parameters, specifically, the negative estimated income elasticity of demand, as it is counter-intuitive
	Use more detailed housing-stock data to inform more realistic trends in fuel switching and a more plausible set of policy impacts eg CERT	Policy impacts included; Scotland-specific likely future trends in energy mix not included	Investigate further the differences in the fuel mix between regions and how these might be projected under, say, different income assumptions
Road transport	Use the DfT NTM to project emissions, as opposed to TMfS; alternatively develop an emulation of the model's responses to income and prices, including the supply side	Implemented a simple treatment that applies DECC road-transport elasticities to a set of transport model results (NTM or TMfS)	Investigate further the reasons for differences between model projections to assess which is the more appropriate. Develop a hybrid which makes use of several bespoke transport model runs and therefore captures supply-side factors
Rail transport	Employ a dedicated transport model to project emissions	Included a central projection but no responses to alternative input assumptions	Investigate further the scope for using a dedicated transport model
Aviation	Link aviation fuel demand to (OECD) activity and oil-price assumptions; apply trends in domestic/international aviation split	Implemented	
Shipping	Link to an activity indicator	Implemented	More/better data are required. The CCC may wish to investigate empirical studies on price responses, if any
Industrial processes	Link to an activity indicator	Implemented	Investigate the possibility of a more detailed, technology-based treatment

Source(s) : Cambridge Econometrics.

3 Model Outline

3.1 Model overview

The model was developed based on the recommendations of the Phase 1 findings and the user requirements of the CCC. Among other important factors that guided our research were that the CCC were keen to ensure that the model met three broad criteria, of which the first two were considered of greater importance:

- robustness/accuracy
- transparency
- efficiency

The model is ‘accurate/robust’ in the sense that the historical emissions and energy demand are consistent with the data sources and the projections look plausible when compared to the last year of data. Of course, the projections of the model are intended to be counterfactual, because policy and technology impacts not captured as part of these reference scenarios will also reduce carbon emissions in Scotland. As such there will be no objective standard whereby the accuracy of these projections can be assessed, as is the case with more conventional forecasts which attempt to accurately predict the impact of future policy intervention.

The model has been developed in Excel and all the data sources are fully referenced. A model user guide (model documentation manual) has been provided to accompany the model. This ensures that the model is, in our judgment, very transparent. A non-technical individual would be able to understand the key drivers from this report and the model documentation, while a more technically-proficient user would be able to make use of the Excel formula to understand the precise mathematical solution. The model solves instantly due to its relative simplicity.

Of particular importance to the CCC from our suggested nine criteria were the additional criteria relating to:

- the underlying assumptions and the application of intuition and theory: the model’s assumptions are broadly consistent with the approach taken at the UK, both by government and forecasters (eg CE) and the applied theory is consistent with methods used in the past
- functional form and parameters: a number of the relationships that underpin the model projections are based on those estimated in the DECC model, the source of the central run incorporated into the model. This includes some of the estimated equation parameters. The properties of the projection methods that use this information are thus expected to be similar to those of the DECC model
- the scope/detail of the outputs: the model provides emissions projections for seven broad sectors:
  - domestic (ie households)
  - industry (energy), further disaggregated by type of industry
  - industry (process) further disaggregated by type of process
  - road transport: energy demand is further disaggregated by ‘Car’ and ‘Commercial Vehicle’
  - aviation, further disaggregated by domestic, international and military
  - shipping, further disaggregated by domestic, international and naval

– rail

In the case of the domestic, industry (energy) and road transport sectors, the model also projects energy demand, as an intermediate step in the emissions calculations.

3.2 Drivers in the model

The drivers for each sector in the model are summarised in Table 3.1. For some sectors, the projections are calculated based on results from a 'central run' from the DECC model, provided to us by the CCC. These are marked in the table. The other sectors, for various reasons, are not treated in this way. For these other sectors, the projections are based directly on the growth profiles of the relevant input assumptions.

TABLE 3.1: DRIVERS IN THE MODEL

Sector	Drivers
Domestic*	- household numbers - real disposable household income - energy prices
Industry (energy use)*	- output (by industry) - energy prices (own and competing)
Industry (process emissions)	- output (by industry)
Road transport*	- income (for cars) - pump prices (for cars) - output (for commercial vehicles)
Aviation	- OECD activity - oil prices - historical split of domestic/international emissions (to project the split forwards)
Shipping	- OECD activity or manufacturing GVA (depends on user option)
Rail*	- (constant)

Note(s): * indicates a sector for which projections are derived relative to a central projection that has been incorporated into the model. Road transport projections have been provided from NTM and TMfS; all other results are from a DECC-model run.
Sectors not marked with a * are solved dynamically based on the input assumptions.

3.3 Coverage

In 2007 total carbon emissions (including estimates of international aviation and shipping) in Scotland were 45.41 $MtCO_2$, of which power generation, refineries and oil and gas emissions (all assumed to be covered by the EU ETS and therefore excluded from this analysis) accounted for 18.15 $MtCO_2$, net LULUCF[7] is responsible for -4.45 $MtCO_2$ emissions and so this gives a total of 31.71 $MtCO_2$. Of this the model covers 31.69 $MtCO_2$[8]. The model can therefore be considered to be sufficiently comprehensive in its coverage to meet the objectives of this study.

3.4 Domestic

In Scotland, domestic emissions accounted for 15% of total CO_2 emissions (6.9 $MtCO_2$) in 2007. In the domestic sector, the combustion of fossil fuels, mainly natural gas (although petroleum- based products are also prominent in Scotland), for heat is the main source of carbon emissions. The main drivers are therefore the number of houses requiring heating, the price of fossil fuels, the heating technology employed (eg gas central heating) and the thermal (insulation) characteristics of the house. The DECC approach is to use both the number of households and household income, in turn, the CCC has, in its previous method[9], used the number of households to share out Scotland's domestic carbon emissions from the UK total.

We have not drastically changed the previous method mostly because the data were insufficient to build a preferred method. The number of households in Scotland relative to the UK is still used to share the UK central energy demand projections from the DECC model. However we now make use of DECC's income and price elasticities so that changes to fossil fuel prices and real household disposable income can be assessed in the Scotland modelling tool, without the need to run the DECC model under different fossil fuel price and income projections[10]. The DECC model holds household demand from solid fuels and petroleum products constant, but electricity demand and gas demand respond to changes to fossil fuel prices and income.

Projections for the other income (economic growth) and fossil fuel price scenarios are derived using the elasticities of demand in the DECC model, such that for each fuel:

$$de_t^v - de_t^b = \beta_1(p_t^v - p_t^b) + \beta_2(i_t^v - i_t^b)$$

where:

- β_1 is the price elasticity of demand
- β_2 is the income elasticity of demand
- de is domestic energy demand (differentiated by fuel)
- p is the price of fuel

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[7] Land Use, Land Use Change and Forestry.

[8] Only waste incineration is not covered. This sector accounted for 0.02 $MtCO_2$ in 2007.

[9] CCC's first report, see Chapter 14 and supporting research: http://www.theccc.org.uk/reports/building-a-low-carbon-economy

[10] The projections tool replicates the counterintuitive result from the DECC model that an increase in income leads to a reduction in energy demand, as opposed to the non-negative change that would normally be expected on a priori theoretical grounds. This negative income elasticity possibly reflects the uptake of efficiency measures that are not explicitly specified in the equations.

- i is income
- b denotes a baseline value (central run)
- v represents a household number, income and/or price variant
- t is time

Energy demand for each fuel is then calibrated to the DECC regional energy consumption statistics[11] for the domestic sector for the final year of data, 2006. Carbon emission coefficients are then applied to each type of fuel to derive estimates of emissions arising from each fuel which are then aggregated and calibrated to the emissions total for the domestic sector in Scotland.

With regard to policy impacts, and in particular that of CERT, we have also introduced an off-model adjustment to allow for differences in the current housing stock between Scotland and the UK and thus to allow for differences in the effectiveness of the policy, based on past data and the number of homes in Scotland qualifying for priority assistance, relative to the UK. The differing impact of this Scotland-specific policy adjustment, when compared to simply sharing the results of the UK, is discussed in Section 4.2. These Scotland-specific impacts do consider the rebound effect.

To summarise, the following factors affect domestic energy demand projections for Scotland in the model:

- Household projections: the share of households in Scotland relative to the UK is used to derive the first estimate of domestic energy demand for Scotland from estimates for the UK
- Fossil fuel prices (and associated electricity prices): affects the demand for electricity and natural gas based on the DECC elasticities for the UK
- Economic activity (real disposable income): affects the demand for and natural gas based on the DECC elasticities for the UK
- The choice between simply sharing out the impact of domestic policies based on the number of households or adjusting to take account, in a stylised manner, of factors specific to Scotland's housing stock and socio-economic characteristics

A brief comparison of the underlying method with that of the DEMScot model and their respective recommended uses is presented in Appendix A.

3.5 Industrial and commercial (energy)

In 2007, industrial and commercial emissions accounted for some 14% of total CO_2 emissions in Scotland. For the purposes of this report 'Industry and Commerce' includes all manufacturing, construction and services sectors, with the exception of transport services, power generation, refineries and offshore oil and gas.

The purpose of the modelling tool is to project CO_2 emissions from the non-traded sector in Scotland, ie those emissions not covered by the EU ETS. As such, it is also important to consider the extent to which the composite sector is covered by the EU ETS and how this might change in the future.

In Scotland we estimate that, using the same basis for comparison as the CCC, 37.6% of CO_2 emissions from the Energy Industry[12] are estimated to be traded and 42.3% of

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[11] http://www.decc.gov.uk/en/content/cms/statistics/regional/regional.aspx

[12] Industries that produce manufactured fuels.

Other Industry[13] emissions. The estimated proportion of traded emissions across all Scottish industrial sectors is 35.6%. This compares with 70% for the UK[14] based on figures for 2005. In the model, the traded splits are applied at the broad industry level, differentiating, for example, Other Industry from Services.

The levels of coverage estimated were, in some cases, based on data of 'relevant emissions' rather than outturn data. This was the case for emissions covered by CCAs and Opt-outs and the estimates would be improved once the outturn data for these years is released. These emissions are included in the estimate as future phases of the EU ETS will include installations which previously were allowed to opt out of the scheme.

Our proposed method to disaggregate a set of UK energy-demand projections closely follows the CCC's existing approach. The main difference in the production of projections under varying sets of assumptions is that the UK variants are estimated within the model and disaggregated to the Scotland level. This contrasts with the CCC's approach which disaggregated DECC model runs under the various assumptions.

The steps of the disaggregation method are listed below:

1 Output (GVA) projections by region and sector are used to share out the UK-level sectoral energy demands to form a first estimate of regional energy demand disaggregated by sector and fuel type (at this point the fuel mixes are identical across regions).

2 Each nation's implied energy demand from Step 1, by fuel, is compared in the last year that DECC regional energy consumption statistics are available to produce a set of adjustment factors (ie residuals). When these residual adjustments are applied to the first estimate calculated above, to the last year in which data are available, energy demand will necessarily match the outturn figures. The residual adjustment factors are applied over the projection period and held constant throughout. At the regional level, by fuel user, there is only one series per fuel for industrial and commercial users combined, so the sum of the estimates from Step 1 are used to calculate a common set of adjustments to each sector.

3 Standard emissions factors (as reported in DUKES, among others) are applied to the energy demand projections from Step 2 to produce a first estimate of CO_2 emissions for Scotland and by sector.

4 A further scaling adjustment is applied to the emissions projections such that, when summed across fuel types, the emissions by sector in the last year of available outturn data match official sources. At this stage, we have extended the method to keep a distinction between different sector sources for emissions. This is a similar procedure to that in Step 2 and the resulting adjustment is then applied to all years over the projection period for each industry feeding into one emissions source sector. The (IPCC) emissions source sectors are:

   – Other Energy Industries
   – Manufacturing Industry & Construction: I&S

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[13] Industries that engage in manufacturing activities that cannot be classed to Iron & Steel.

[14] This figure has been calculated based on the CCC methodology but offshore emissions have been excluded, leading to a smaller proportion of coverage calculated for the UK.

- Manufacturing Industry & Construction: Other
- Manufacturing Industry & Construction: Off-road
- Other Transportation
- Commercial/Institutional
- Agriculture/Forestry/Fishing: Stationary

So, rather than combine and sum energy demand to the Industry and Commerce totals in Step 2, we have scaled each sector to the Commerce and Industry energy totals, by fuel, and preserved the industry breakdown. While we recognise that these are broad-brush estimates and will not necessarily accurately reflect the fuel share for each sub-sector, it is useful to have this disaggregation to then apply the emissions coefficients, aggregate to NAEI source sectors and then apply the estimated coverage of the EU ETS. By preserving this level of disaggregation we can better account for the response to price of each industry and the coverage of the EU ETS. The largest drawback to this approach is that the implied fuel mix for each industry is almost entirely arbitrary, reflecting only the fuel mix for that industry at the UK level and the total fuel mix for Scotland's Industry and Commercial sector as included in DECCs regional energy data.

We have also added a price response based on the DECC parameters. Previously, the CCC estimated the price response for industrial emissions in Scotland by running the DECC model for the UK with differing fossil fuel price inputs and deriving Scotland's share of the consequent emissions. Instead, we have used of DECC's price elasticities so that changes to income and fossil fuel prices can be assessed directly in the Scotland modelling tool, without the need to run the DECC model under different fossil fuel price and activity growth scenarios.

To summarise, we have estimated the central run in the same way the CCC have done before by calculating emissions from regional energy demand based on industry growth in Scotland relative to the UK (as described above in Steps 1-4), but we have preserved the sector disaggregation and applied the EU ETS coverage at this disaggregated level. This happens between Steps 2- 3, and Steps 3-4 in the previous method.

The other reference scenarios are produced as deviations from the central run (the baseline) using the elasticities of demand in the DECC model, such that for each industry and each fuel:

$$ie_t^v - ie_t^b = \beta_1 (p_t^v - p_t^b)$$

where:

- β_1 is the price elasticity of demand
- *ie* is industry energy demand
- *p* is price
- *b* denotes a baseline value (central run)
- *v* represents a fossil fuel price variant
- *t* is time

In Phase 1 we had originally proposed to allow for changes in GVA. However, because the GVA projections are now calculated from growth rates relative to the UK and used to share out modified UK central-run figures, this feature is no longer necessary.

Clearly, it would be advantageous at this stage, instead of the suggested approach, to make use of the SCPnet data as an additional calibration for each sub-sector's fuel mix, rather than use crude estimates. We had proposed to calibrate the fuel mix for each industry, ahead of scaling to the DECC Industry and Commerce aggregates. This would allow for a more informed view of the fuel mix and fuel demand of each individual sector in Scotland its relative position compared to the UK, rather than simply infer that they are identical.

At first glance and as noted in Phase 1, the SCPnet data (the dataset includes consistent energy data and emissions data) have been compared to the NAEI emissions data for Scotland and are encouragingly quite similar. However, further investigation has revealed that, at the detailed level, the SCPnet data is inconsistent with all three of the other datasets (NAEI, DECC regional consumption statistics and EU ETS installation data). This means that we have reverted to using a method equivalent to that used in the CCC's approach, although preserving some break-down between industrial sectors.

3.6 Industrial and commercial (process)

Process emissions accounted for around 1% of Scotland's CO_2 emissions in 2007 at just 476.9 ktCO_2. Process emissions are emissions which arise from industrial activity but are not themselves related to energy use, for example, cement decarbonisation.

Ideally, projections of process emissions would be based on a bottom-up modelling approach which incorporated a comprehensive treatment of each industrial process, potential technological changes to each process and a clear treatment of how the process fits into the supply chain of final products.

This would require a combination of bespoke industry expertise and modelling experience that are outside the time and cost constraints of this project. A simpler, cruder, method is to link an activity indicator to each relevant industrial process, we have used industry gross value added as it is consistent with the energy activity indicators but we suggest that, if it were available at the regional level, gross output would be a more suitable driver. Gross output is a more suitable driver because, unlike GVA, it alters with inputs, whereas an increase in inputs might not necessarily lead to a change in GVA. As an example, a firm could increase its inputs by a greater amount than it is able to increase its outputs, becoming less efficient. GVA would fall, whereas gross output would increase and therefore better reflect the increase in inputs and process. If possible, the results of the projections could be further improved by validation from industry experts.

3.7 Road transport

In 2007, road transport accounted for the second-largest share of Scotland's CO_2 emissions at 22% (10.1 MtCO_2) and the largest share of non-traded sector emissions. Ideally, any projections model for the transport sector should be able to account for complex supply-side measures such as vehicle stock parameters, network availability, network speed, network safety, land use, alternative modes of transport available; and the demand-side factors, trip purpose, income, fossil fuel prices etc. In the Phase 1 assessment, we compared two bespoke transport models which capture all these variables: LATIS, a Transport Model for Scotland (TMfS) and the National Transport Model for Great Britain (NTM). The projections provided from these models were not annual and do not cover the entire period required so a simple interpolation and extrapolation was undertaken to fill the series.

The recommendation made in Phase 1 was that the CCC should make use of the NTM[15]. However, should a consistent run of the TMfS be commissioned, this can be incorporated into the modelling tool. We did emphasise in Phase 1 that further analysis and/or discussion may be necessary to assess how the inputs might be used and in explaining possible differences between the projections. At present the default option is to use the NTM projection.

It was felt that, if possible, the user should have the option to choose between the two. This option has been built into the tool. Because the nature of the inputs and outputs differ between the models, a simple treatment was employed to make the data provided to us from the TMfS compatible in format to the outputs from the NTM. The percentage differences between the filled NTM and TMfS series for vehicle km demand were calculated and applied to the NTM fuel demand series. The implicit assumption is that the TMfS projection differs only in the total travel demand; the split by fuel and vehicle type and the implicit coefficients linking vehicle km to fuel demand are the same in the two models. This relatively simple treatment is open to review should more detailed TMfS outputs and analysis be made available.

There are a number of other factors which affect energy demand from road transport in Scotland:

- real household disposable income impacts on fuel demand arising from passenger cars
- fossil fuel prices, through pump prices also impact on fuel demand arising from passenger cars
- gross value added in Scotland impacts on the fuel demand arising from commercial vehicles

Because the NTM is time consuming to run and the CCC has limited scope and resources to call on model runs as required rather than build a ready-reckoner based on several outputs of either the NTM model or the TMfS model, we have used DECC model parameters for road transport fuel demand income and price elasticities. However, as discussed in Chapter 5 this assumes that the other, mainly supply side, variables are constant. While this is slightly limiting assumption, in the sense that it only implicitly captures the supply side impact, it is not obvious that the supply side variables will alter greatly when compared with income growth and fossil fuel price which are the two key variants to be modelled in the reference projections.

In the NTM: $re_t^b = f_{NTM}(y^b, p^b, s^b)$

where

- f_{NTM} is the functional form of the NTM model
- re is road transport emissions
- y is income
- p is the fuel price
- s represents the supply-side variables
- b denotes a baseline value (central NTM run)
- t is time

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[15] A discussion of this can be found in the Appendix B.

The ready reckoner would take the form, where v represents an income and price variant. The parameters (β_1 and β_2 below) are taken from the DECC model.

$$re_t^v - re_t^b = \beta_1(y_t^v - y_t^{b)}) + \beta_2(p_t^v - p_t^b) + \varepsilon_t$$

3.8 Aviation

Importantly, all aviation emissions are likely to become part of the traded sector by 2012. For completeness however, we have included aviation emissions to 2030.

To provide a complete model for aviation emissions for Scotland, it would be necessary to have a global transport model which explained the motivation for air travel by the underlying economic factors, eg business travel might be driven by economic growth in a specific area (eg business services), tourism by income levels etc. However, this would be an enormous undertaking and probably require an entirely separate project if these issues are to be satisfactorily addressed.

As an alternative, to project UK emissions from international and domestic aviation, the DECC model links aviation to growth in OECD demand as a proxy indicator for demand for air travel. The OECD demand proxy is broad, but adequate, as recent history prior to the current global economic and financial turmoil has shown the rapid expansion of air travel as the income of OECD industrialised countries has increased. However, it does not account adequately for some of the other factors affecting air transport demand, such as the price of travel. We have followed the method used in the DECC model and, like the DECC model, we also include a response to energy prices.

However, we also implemented a treatment to split the share of emissions between domestic and international emissions. This is based on the changing trend in the data which shows a significant change in the share of international vis-à-vis domestic emissions in Scotland's aviation.

OECD demand is an assumption input in the DECC model, and we have taken the same assumption and we also use the DECC income (OECD demand) and price elasticities.

The emissions arising from military aviation are assumed, for simplicity, to remain constant over the projection period.

3.9 Shipping

Estimates of emissions from shipping, both domestic and international, at the regional level are available from the National Air Emissions Inventory (NAEI). There are significant data constraints for this sector and there is not currently an agreed international protocol that defines how the sub-UK split should be calculated or how international emissions might be allocated to the regions[16]. The absence of detailed data on shipping movements means that fuel use for shipping by region has been proxied by the mass of port traffic in the historical period.

We have considered and given the option to select one of two alternative activity indicators to project shipping emissions:

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[16] http://www.airquality.co.uk/archive/reports/cat07/0811180855_International_aviation_and_shipping1990-2006_final_v5.xls.

(i) Projections of OECD activity (as will be used to project aviation emissions) and,

(ii) Projections of Scotland trade activity (proxied by manufacturing GVA, on the basis that shipping activities relate predominantly to cargo rather than tourism etc).

The latter seems more preferable, as these projections will to some extent capture the projected trends in global activity and are obviously more Scotland orientated. Manufacturing GVA would also be more preferable determinant because it captures tangible physical goods, whereas OECD activity may also be driven, as it is in the UK, by growth in value added from services. As manufacturing GVA is available for Scotland the proxy indicator is also more reflective of Scottish economic activity. However, the proxy does not contain explicit information on the impact of higher incomes on the imports of manufactured items, or a shift towards imports caused by changes in exchange rates, although this might to some extent be offset by a change in the opposite direction of exports. As such we identify manufacturing GVA as a suitable, but imperfect, indicator of the growth in shipping emissions in Scotland, such that shipping emissions projections are calculated as follows:

$$\log(se_t) - \log(se_{t-1}) = \alpha(\log(y_t) - \log(y_{t-1}))$$

where:

- α is the response to activity
- se is shipping energy demand
- y is activity (either OECD GDP or Scotland manufacturing GVA)
- t is time

We are not aware of any evidence for deriving a suitable price elasticity term in the literature and so we have not included a price response in the shipping emissions equation. We also consider that there is not enough data to estimate a robust parameter. We have compared the projections of both cases in Chapter 4.

Naval emissions are held constant across the projection period.

3.10 Rail transport

Rail emissions in 2007 were just 232 ktCO$_2$, a very small proportion (0.5%) of Scotland’s CO$_2$ emissions in that year. During Phase 1 we recommended making use of the bespoke transport models to give either a central set of estimates for rail or at the least assumptions on electrification of the rail network in Scotland, to compare to that of the UK. The purpose of this was to capture the important supply side factor which impacts heavily on the use of electricity in rail travel rather than petroleum. However, it was not possible to get estimates as appropriate model outputs were not available from either NTM or TMfS. Currently then the treatment assumes that energy demand from rail in Scotland is proportional to the UK, and so therefore are emissions. This proportion is fixed for the last year of data and used to project emissions based on the UK projections arising from the DECC model. Rail emissions do not respond to fossil fuel prices, or economic growth.

3.11 Using the model for abatement scenario analysis

The modelling tool is designed to produce reference emissions projections, which can act as the baseline for analysis of emissions reduction scenarios in Scotland. When considering these projections as baseline emissions forecasts, the effect of any policies captured (implicitly or explicitly) in the projections must be considered to avoid any double counting of emissions reductions.

If the policy has yet to be enacted ie it will occur after the last year of data, then the calculated effect can be applied relatively simply. An issue arises when a policy has already been running and its effects will already, to some extent, be reflected in the raw data. The impacts to date will be carried through into the projection period by the calibration treatment. Moreover, it is likely that the behavioural effects will be reflected in the parameter estimates, eg uptake of energy efficiency measures in homes.

The DECC model equations and, by extension, the parameters in the modelling tool are estimated on past data using standard statistical techniques[17]. In the case of households, increases in income and prices may make it more attractive to undertake measures to improve energy efficiency. However, no attempt is made to identify precisely what measures were taken (eg cavity wall insulation or new boilers), only that some were. The effect captured is, in essence, an average effect. The result is that changing incomes[18] over the projection period will include some improvement in energy efficiency, based on the uptake of measures in the historical period. More specifically, the relationships estimated on historical data (1971-2003) are assumed to hold over the projection period.

To illustrate the implications of using such behavioural relationships, consider the take-up of loft insulation and, furthermore, assume that it is the only energy-efficiency measure available to households. Also assume, for simplicity, that energy prices (the other driver in the model) have not changed over the historical period. Under such, purely stylised, conditions, the relationship between income and the uptake of loft insulation can be estimated and is isolated[19]. The use of this relationship implies that, in the projection period, a one-unit increase in income would lead to a similar amount of additional loft insulation and thus a similar reduction in energy demand, based on the negative DECC income elasticity. The assumption of income growth, other inputs remaining unchanged, means that there will be continual improvements in the levels of energy efficiency, with no limit imposed.

This contrasts with the treatment in DEMScot, which is not intended to be behavioural. DEMScot models the effect of different energy-efficiency measures explicitly and is designed to estimate changes in domestic energy demand contingent on different measures being adopted; there is no mechanism to explain how they are taken up, it is simply assumed that they are. The differences in approach also means that applying an emissions-reduction estimate derived from DEMScot may not be appropriate because some increase in energy efficiency will already be accounted for in the projection from the modelling tool. It seems likely that there would be less of a

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[17] At the time of writing, using annual data for the period 1971-2003.

[18] Owing to the negative elasticity used.

[19] The assumption that other factors are unchanged is not of course a requirement for a relationship to be estimated, it is a presentational device for bringing out the key messages of this example.

problem carrying out such an exercise if trends in energy efficiency could be distinguished from changes in income. It is not clear that this is possible in the current specification of the DECC model equations.

Such considerations should be taken into account when analysing emissions reduction scenarios using the projections and the necessary care taken in interpreting the results.

3.12 The structure of the model and updating the inputs

All the input data, parameters and assumptions are stored in worksheets within the model and in this sense the model is self-contained and should be relatively easy to update with, for example, a new central DECC-model projection. The sheets that contain calculations also contain summary documentation describing the underlying logic.

For more details of the structure of the model, and a guide to how it is intended to be used, the reader should consult the User Guide that accompanies the model.

All the behavioural parameters in the model are stored in a sheet in the model and these can be easily changed. For consistency with the DECC model, the elasticities in this sheet would normally be updated in line with the parameters that underpin the central projection that serves as the baseline. While the relationships captured in the projections tool are informed by the economic theory and econometric results that underpin the DECC model, there is no software-related reason why the elasticities cannot be changed to be different from those in the DECC model.

From an econometric standpoint, changing the value of a particular parameter (eg output or price) alters its importance in predicting the dependent variable; in turn one or more of the other parameters in the equation should change to reflect this alteration. This would be revealed if the complete equation were to be re-estimated. This also alters the ability of the equation to explain trends in the historical data. The projection properties of the implied equation are also altered but a smooth transition between the historical and projection periods remains because of the calibration in the last year of available data.

Because only the most important responses (in our view) have been included in the model, the changes in the other parameters and the associated issues of interpretation are in some sense overcome by the assumption that these variables either remain constant over the projection period or do not change between assumption variants[20].

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[20] This is implied by their exclusion from the model.

4 Scenarios

4.1 Introduction

The purpose of modelling scenarios (and sensitivities) is to get estimates of the projections for CO_2 emissions for Scotland under different internally-consistent ‘states of the world’. Fossil fuel prices, economic growth and household growth projections will not be predicted with perfect foresight: scenarios enable us to get an understanding of the range of internally-consistent projections under different world conditions. That is not to say that emissions will fall inside the projected range, simply that under a given set of assumptions a range of plausible projections can be provided. Moreover in this case where the tool is designed to provide a set of counterfactual projections against which to measure policy impacts and the development of new technologies, the range of projections provided shows what the level of emissions might have been and not necessarily will turn out to be.

We have modelled five scenarios in addition to the central scenario (see Table 4.1). The central scenario uses central fossil fuel prices, central economic growth assumptions and central household growth assumptions (as discussed in the next section).

The scenarios are not designed to represent actual outcomes but provide an idea of the range of outcomes and also the sensitivity of the projections to changes in key variables[21].

TABLE 4.1: SCENARIO OUTLINE

Scenario Name	Fossil Fuel Prices	Economic Growth	Household Projections
Central	Central	Central	Central
High fossil fuel prices	High	Central	Central
Low fossil fuel prices	Low	Central	Central
High emissions	Low	High	High
High growth	Central	High	High
Low growth	Central	Low	Low

Source(s): CCC.

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[21] The CCC is aware that the Scottish Government has set a number of strategic targets in its Government Economic Strategy (GES). Although the scenarios have not been designed to represent these targets, the high scenario most closely matches the growth and population targets. It is important to bear in mind that it is not true representation of the targets having been met because the GES targets are relative to a range of different countries’ trends and it is difficult to define a scenario which accounts for this.

4.2 Key assumptions

The central economic growth scenarios for the UK are provided from HMT sources and are consistent with those used by DECC and the CCC for the central economic growth reference scenarios. These projections are used to inform the central economic projections of the DECC model for the CCC and have been used to calculate Scottish GVA projections by sector.

Growth differentials from previous CCC analysis were used to inform economic assumptions for Scotland in-line with UK HMT economic projections

To determine the central Scottish GVA variant, the 2008 economic estimates provided to the CCC for the UK and for Scotland were used to calculate growth differentials. The growth differentials between Scotland and the UK are then applied to the latest UK central projections to give Scottish central projections of GVA by sector. This assumes that the impact of the recession will affect Scottish industry in the same way as the UK aggregate. This is a simplified assumption but was necessary in the absence of an official or revised CCC GVA forecast for Scotland.

The central scenario assumes that Scotland's GVA grows by approximately 1.8% pa over 2007-30; the UK grows at 2.2% pa over the same period. The scenarios defined by the CCC were in terms of relative GVA growth of Scotland to the rest of the UK. A change in the economic assumptions, therefore, feeds into the model by altering the growth rate for each sector upwards by 0.25 pp in the high variant and downwards by 0.5 pp in the low economic growth variant. This is done for each year of the projection period. A stylised assumption is made that the impact is evenly attributed to each sector.

The income and OECD assumptions also reflect the aforementioned growth variants. For the central case, the OECD growth forecast has been provided by the CCC to be consistent with the inputs to the central reference scenarios. Real household disposable income in Scotland is assumed to grow in line with the central real household income projection for the UK; it is varied on the same basis as the growth variants already discussed of 0.25 pp and -0.5 pp changes to forward looking growth rates.

Different economic variables affect different emission source sectors

The sector GVA projections affect:

- industry emissions (energy)
- industry emissions (process)
- shipping emissions (under the relevant user option)
- road transport emissions (through commercial vehicle fuel demand)

The income projections, that can be found in the worksheets 'Economic assumptions central', 'Economic assumptions low' and 'Economic assumptions high' and, affect:

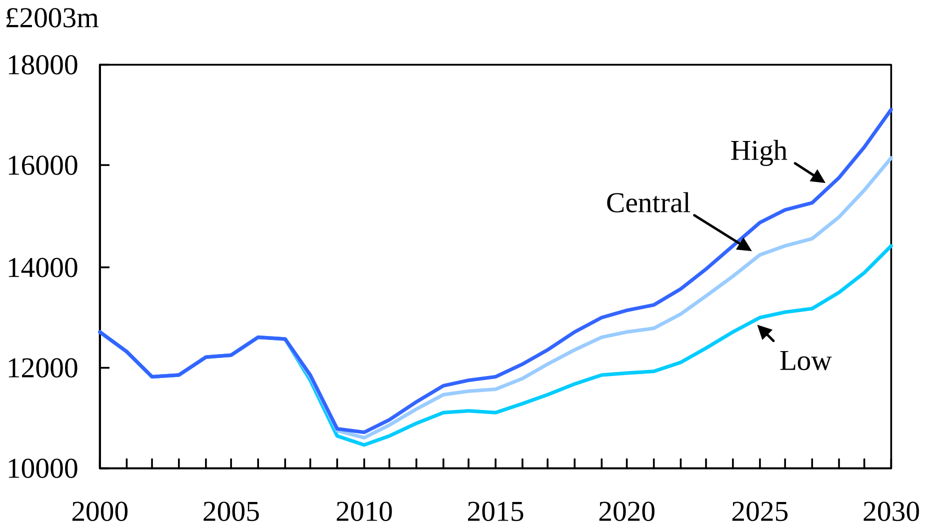
- domestic emissions (in Scotland only, not UK total)
- road transport emissions (through passenger-vehicle fuel demand)

OECD projections can be found in the worksheet 'OECD demand growth', and have an impact on:

- aviation emissions
- shipping emissions (under the relevant user option)

Chart 4.1 shows the variation in manufacturing GVA across each of the three economic variants.

CHART 4.1: MANUFACTURING GVA ASSUMPTIONS



Source(s) : DECC, Cambridge Econometrics.

The fossil fuel prices are provided for four different variants as defined by the Department of Energy and Climate Change (DECC):

- Low: Low Global Energy Demand
- Central: Timely Investment, Moderate Demand
- High: High Demand, Producers' Market Power
- High high: High Demand, Significant Supply Constraints

This report provides results for the first three of these (low, central and high). Chart 4.2 shows the variation in Crude Brent oil prices, measured in real terms, across these variants. Chart 4.3 shows the variations in household growth projections over the period to 2030.

Petrol and diesel pump prices and electricity prices have been provided from the DECC model for each fossil fuel price variant

Alongside these fossil fuel prices, the CCC has also provided petrol and diesel pump prices and electricity prices which are determined in the DECC model for energy demand.

We assume that the pass-through of wholesale energy price changes to end users remains constant between varying fossil fuel prices and so changes in fuel prices are simply taken as being equivalent to changes between the wholesale prices. The exception would be pump prices for diesel and petrol: due to the large tax proportion in pump prices, they do not change by as much as the crude oil price. Pump price variants have therefore been provided for each fossil fuel price scenario. Changes in pump prices feed through to the changes in road transport fuel demand.

Three different variants of household/population growth projections can be selected which impact on household demand for energy. The variants are provided by GRO Scotland[22]. The three sets of projections for household numbers for Scotland are

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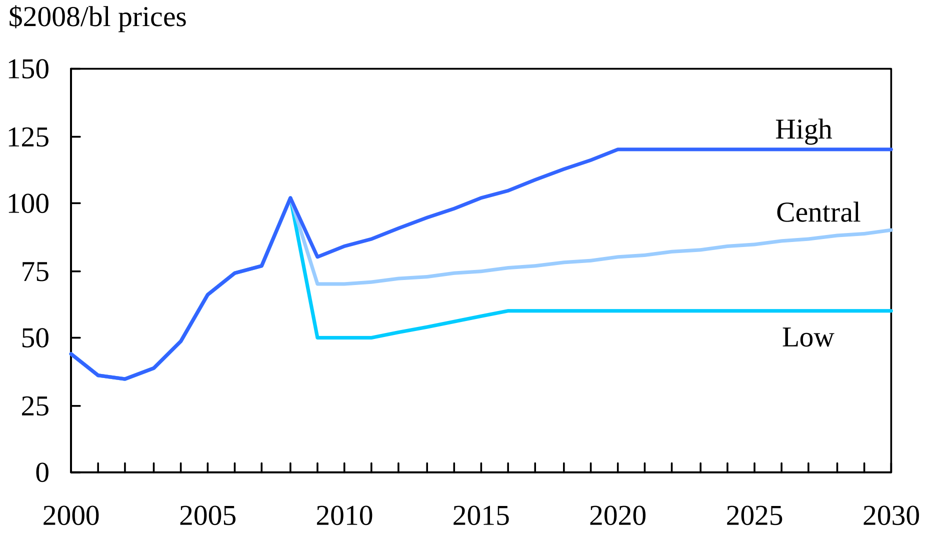
[22] The GRO low migration variant household projections represent an indicative estimate at the aggregated Scotland level and do not represent the same degree of statistical accuracy as the other household projections.

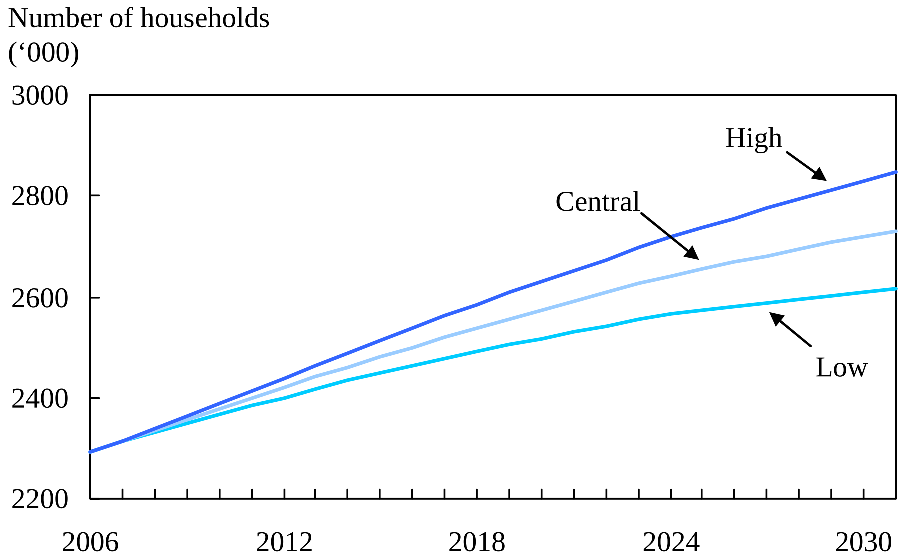
shown in Chart 4.3. The alternative specification makes use of the change in the proportion of households in Scotland compared to the UK to determine the share of energy demand before calibration. As the share changes, as a result of changing the input assumptions for Scotland, so do the energy demand projections. All policy impacts except CERT are disaggregated using the household share. The impact of CERT is applied exogenously using a set of off-model calculations that have been entered into a worksheet in the model.

CHART 4.2: OIL PRICE ASSUMPTIONS



Source(s) : DECC.

CHART 4.3: HOUSEHOLD GROWTH ASSUMPTIONS



Source(s) : GRO Scotland.

4.3 Model options selected

There are a number of options in the modelling tool that give an alternative set of projections for various emissions sectors, they are:

- Use Aviation Trend of Share: Yes/**No**
    - the user has the option of applying a trend limit to domestic and international aviation emissions to reflect how the shares between these two sources of aviations emissions have changed over the recent historical period (1990-2006). This does not affect the total amount of emissions arising from aviation in total, simply the split between domestic and international.
- Shipping driver: OECD/**Manufacturing GVA**
    - the user can choose between two separate drivers of shipping emissions: manufacturing GVA and OECD demand
- Domestic Policy Impact: **Yes**/No
    - by default ('Yes'), a specific policy calculation is made to reflect the specific characteristics of the Scottish housing stock and the proportion of Scottish households qualifying as Priority groups under CERT. Alternatively, the policy impact of EEC1, EEC2 and CERT can be based on the number of households
- Road Transport: **NTM**/TMfS
    - in Phase 1 we suggested that the NTM model would be better suited than the TMfS model to use for the central energy demand estimates for Scotland arising from the road transport sector. However, it was felt that if possible the user should have the option to choose between the two. There are a number of differences between the central model outputs between the two models; vehicle efficiency, vehicle km demand, types of vehicle, output years. The input assumptions on economic growth and fossil fuel prices are also different: the TMfS model inputs are different to the rest of this modelling tool. A very simple treatment has therefore been employed which takes travel demand, in vehicle km, and the fuel demand based on NTM implied fuel coefficients.

The default options are highlighted in bold text above to reflect the recommended method of solution and the use of central assumptions. The recommended solution methods reflect the findings from Phase 1, and the subsequent model development, and are discussed in the relevant sections of this report. The impact of each of these options is discussed in the results chapter.

5 Results

5.1 The central scenario

In the history, emissions of CO_2 from non-transport sources have generally fallen since 1990 as a result, for example, of the closure of Scotland's iron and steel industry and the likely fuel switching towards gas in the case of domestic users. In the central scenario, after the last year of available data (2007), total CO_2 emissions are projected to fall sharply, by 2% in 2008 (the result of high fossil fuel prices and the slowing economy) and a further 3.1% in 2009 (capturing the reduction in economic activity in the recession). Emissions are then projected to fall in 2010, by less than 2% and the period 2011-13 will see smaller reductions. Emissions are projected to grow modestly from 2015 onwards. Total emissions in 2007 are 11.7% lower than in 1990 and this reduction increases to 16% in 2020. The subsequent growth is projected to reduce the gap in 2030 to 8.7%; emissions in 2030 are 3.4% higher than 2007 in this central run. As will be become evident, all the reference scenarios are characterised by growth in emissions in the later part of the projection period.

The projections for the non-traded sector are reported in Table 5.1. For consistency, emissions results for aviation are not included in these projections (EU ETS coverage of this sector is due to change over the projection period). The projections from the six main scenarios indicate that non-traded emissions are lower in 2020 than in 2005: -7.5% in the central case to as much as -10.9% in the low economic growth and high fossil-fuel price cases and as little as -2.8% in the high emissions scenario. The results are more varied by 2030; emissions are projected to be just 0.4% below the 2005 level in the central case. Under the low economic growth assumptions, non-traded CO_2 emissions also remain below the 2005 level, by 7.1%, but in the high emissions scenario, projected non-traded CO_2 emissions are 6.9% higher.

TABLE 5.1: NON-TRADED SECTOR EMISSIONS PROJECTIONS, SCOTLAND

$ktCO_2$

Scenario	2005	2007	2010	2020	2030	% diff in 2020 on 2005 level	% diff in 2030 on 2005 level
Central fossil fuel price	27,033	26,528	24,858	25,000	26,912	-7.5	-0.4
High fossil fuel price	27,033	26,528	24,464	24,079	26,254	-10.9	-2.9
Low fossil fuel price	27,033	26,528	25,547	25,705	27,769	-4.9	2.7
High emissions	27,033	26,528	25,669	26,265	28,898	-2.8	6.9
Low economic growth	27,033	26,528	24,651	24,077	25,100	-10.9	-7.1
High economic growth	27,033	26,528	24,977	25,548	28,017	-5.5	3.6

Note(s): Figures exclude aviation emissions.

Source(s): NAEI, Cambridge Econometrics.

Growth in emissions in the central run is driven by transport, notably road transport. The emissions profiles from other sources are generally quite flat. The inclusion of other transport and the different economic growth assumptions used are likely to account for the principal differences between the projections outlined in the CCC's inaugural report and the central scenario reported here.

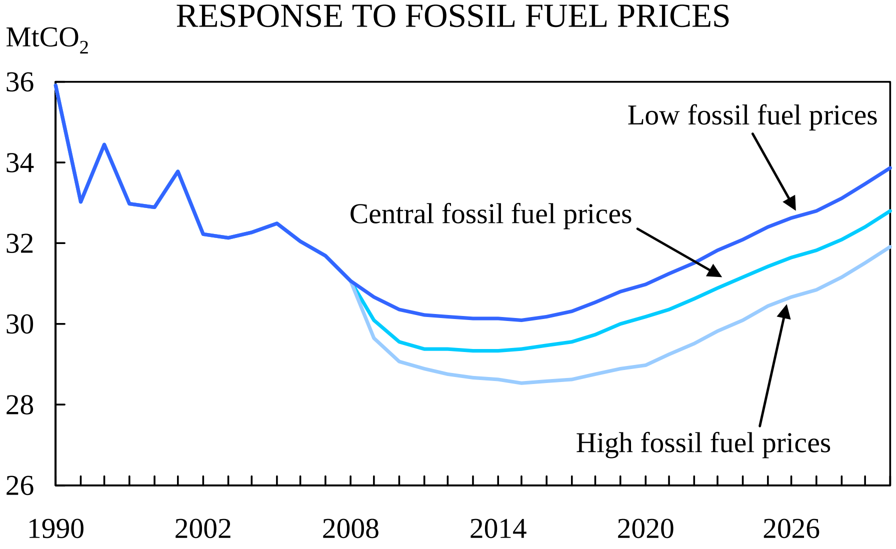
5.2 Summary results

Total CO_2 emissions in 2030, in the scenarios modelled, range from 7.6% below the central run (under the 'Low growth' assumptions) to 8% above the central case ('High emissions' assumptions). These totals include all emissions covered by the model ie they include international aviation and shipping and do not subtract the emissions that we have estimated to be covered by the EU ETS and are thus traded. Total projected CO_2 emissions are shown in Charts 5.1 and 5.2.

Chart 5.1 shows the sensitivity to a change in the fossil-fuel prices assumed, around the central scenario. Under the high fossil-fuel price assumptions, total emissions in 2009 are 1.6% below the central scenario, with the gap widening to 2020 (3.9%, or 1.2 $MtCO_2$, below the central run in this year). Thereafter, the gap begins to close again, to -2.6% (0.9 $MtCO_2$) by 2030. In the Low fossil fuel price scenario, emissions rise almost continuously above the central case, to 2.7% (0.8 $MtCO_2$) higher in 2020 and 3.3% (1.1 $MtCO_2$) by 2030. Emissions in 2030 in the low fossil fuel price run total 33.9 $MtCO_2$ and in the high case total 31.9 $MtCO_2$.

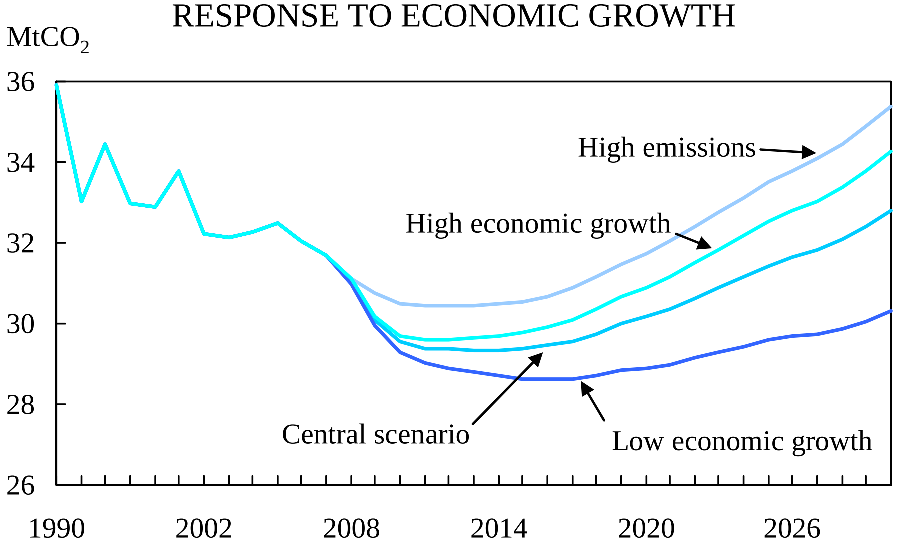
Chart 5.2 shows the economic growth scenarios and also the high emissions scenario, which effectively shows the worst-case scenario for emissions under the various sets of assumptions available in the model. In the High emissions case, 2020 emissions are 11.6% below the 1990 level (compared to 16% in the central run) and a 1.4% below the 1990 level in 2030 (compared to -8.7% in the central run). In the High emissions run, total emissions stand at 31.7 $MtCO_2$ in 2020 and 35.4 $MtCO_2$ in 2030.

CHART 5.1: TOTAL CO_2 EMISSIONS, RESPONSE TO FOSSIL FUEL PRICES



Note(s) : Total emissions covered by the model.
Source(s) : NAEI, Cambridge Econometrics.

CHART 5.2: TOTAL CO_2 EMISSIONS RESPONSE TO ECONOMIC GROWTH



Note(s) : Total emissions covered by the model.
Source(s) : NAEI, Cambridge Econometrics.

At the other end of the range of economic-growth assumptions, in the Low economic growth run, total emissions stand at 28.9 $MtCO_2$ in 2020 (4.2% below the central run and 19.5% below the 1990 level) and 30.3 $MtCO_2$ in 2030 (7.6% below the central run and 15.7% below the 1990 level).

5.3 Domestic emissions

Unlike the other projections, domestic emissions are affected by all three of the general assumptions: fossil fuel prices, economic growth and household growth. Table 5.2 shows the results for emissions for each scenario in 2007, 2010, 2020 and 2030 and the percentage difference from selected base years.

The results show that in all scenarios, by 2020, we project a reduction in emissions on the 1990 baseline of between 14.5% (in the High emissions case) and 26.7% (the High fossil fuel price case). The results also show that economic growth and household projections scenarios have a relatively small impact. This is unsurprising when the (low) elasticity of demand for gas in response to changing income and the small variance around the projections for household growth are considered. By contrast, the fossil fuel price assumptions have a modest impact on energy demand from households.

TABLE 5.2: DOMESTIC EMISSIONS PROJECTIONS, SCOTLAND

ktCO$_2$

Scenario	1990	2007	2010	2020	2030	% diff in 2020 on 1990 level	% diff in 2020 on 2007 level
Central fossil fuel price	7,525	6,876	6,759	5,893	5,962	-21.7	-14.3
High fossil fuel price	7,525	6,876	6,574	5,519	5,704	-26.7	-19.7
Low fossil fuel price	7,525	6,876	7,145	6,305	6,400	-16.2	-8.3
High emissions	7,525	6,876	7,176	6,437	6,648	-14.5	-6.4
Low economic growth	7,525	6,876	6,731	5,778	5,742	-23.2	-16.0
High economic growth	7,525	6,876	6,789	6,016	6,193	-20.1	-12.5
Central, shared policy	7,525	6,876	6,722	5,793	5,899	-23.0	-15.8

Source(s): NAEI, Cambridge Econometrics.

The final row in Table 5.2 shows the projected domestic emissions in the central case from using the (non-default) shared policy calculation rather than the Scotland-specific off-model figures. The emissions reduction is shown to be somewhat greater than the Scotland-specific impact. The higher emissions in the central, specific-policy run can be explained by the fact that, while total domestic energy demand is slightly lower due to a higher proportion of CERT Priority Group households in Scotland, the impact of the policies on gas demand is reduced because the higher proportion of flats in Scotland reduces the scope to install cavity-wall and loft insulation.

5.4 Industry and commerce emissions

Table 5.3 shows industry emissions projections for Scotland under the six scenarios, the results suggest substantial cuts against the 1990 level under all scenarios, although most of the cuts have already occurred before 2007. This happens because of the closure of all major iron and steel production in Scotland. Moreover, the impact of the recession shows a considerable fall in emissions arising from industry in the period between 2007 and 2010.

TABLE 5.3: INDUSTRY EMISSIONS PROJECTIONS, SCOTLAND

$ktCO_2$

Scenario	1990	2007	2010	2020	2030	% diff in 2020 on 1990 level	% diff in 2020 on 2007 level
Central fossil fuel price	14,036	9,839	8,538	8,273	8,300	-41.1	-15.9
High fossil fuel price	14,036	9,839	8,438	8,039	8,144	-42.7	-18.3
Low fossil fuel price	14,036	9,839	8,690	8,423	8,489	-40.0	-14.4
High emissions	14,036	9,839	8,758	8,700	8,986	-38.0	-11.6
Low economic growth	14,036	9,839	8,406	7,752	7,404	-44.8	-21.2
High economic growth	14,036	9,839	8,605	8,545	8,786	-39.1	-13.2
	2005	2007	2010	2020	2030	% diff in 2020 on 2005 level	% diff in 2020 on 2007 level
Central, non-traded	7,322	6,646	5,891	5,723	5,735	-21.8	-13.9

Source(s): NAEI, Cambridge Econometrics.

The results are reasonably responsive to economic activity, ranging from -10.8% below the central run in 2030 in the Low growth case to 8.3% above in the High emissions scenario. By contrast the range of the impact of fossil fuel prices is much smaller in 2030: 1.9% lower under High fossil fuel prices and 2.3% higher under Low fossil fuel prices.

The final row in Table 5.3 shows the impact on non-traded emissions and suggests a decline, by 2020, of 21.8% compared to the 2005 baseline. However, once again this is largely the result on the short-term impact on energy demand, and therefore emissions, of the current economic recession.

Process emissions vary only in response to economic growth assumptions. In the High economic growth scenario, process emissions are 575 $ktCO_2$ by 2030, compared to 543 $ktCO_2$ in the central assumption and 484 $ktCO_2$ in the Low economic growth scenarios. The results reflect the range of the economic growth assumptions, only.

5.5 Road transport emissions

Road transport emissions are presented in Table 5.4. The results show that, although road-transport emissions fall slightly over 2007-10, as a result of the economic recession, overall there is likely to be an increase in emissions on the 1990 level under all of the scenario variations. The results show a moderately stronger response to price than to income. However, as discussed in Chapter 2 these results do not take into account the effect of income, potentially, on supply-side measures. This is cited as an area for improvement in the next chapters of the report.

By 2030 emissions vary, relative to the central run, by ±2.7% depending on the fossil-fuel prices assumed and are driven by emissions from cars, fuel demand for which is

TABLE 5.4: ROAD TRANSPORT EMISSIONS PROJECTIONS, SCOTLAND

ktCO$_2$

Scenario	1990	2007	2010	2020	2030	% diff in 2020 on 1990 level	% diff in 2020 on 2007 level
Central fossil fuel price	9,092	10,135	9,948	10,552	11,217	16.0	4.1
High fossil fuel price	9,092	10,135	9.799	10,144	10,910	11.6	0.1
Low fossil fuel price	9,092	10,135	10,161	10,756	11,525	18.3	6.1
High emissions	9,092	10,135	10,179	10,857	11,722	19.4	7.1
Low economic growth	9,092	10,135	9,913	10,357	10,853	13.9	2.2
High economic growth	9,092	10,135	9,966	10,653	11,414	17.2	5.1
Central, TMfS (adapted)	9,092	10,135	10,278	11,753	10,628	29.3	16.0

Source(s): NAEI, Cambridge Econometrics.

affected by prices. Fuel demand from both cars and commercial vehicles has been modelled to respond to changes in economic growth (income and GVA, respectively) and the range of percentage difference from the central case is larger: -3.2 to 1.8%. In the high emissions case, the 2030 increase on the baseline is larger: 4.5%.

The final row in the table shows the calibrated TMfS model run which has a greater demand for road transport as measured by vehicle km. However, the TMfS model also has lower emissions per vehicle; this element of the run has not been captured as the data were not available in a sufficiently detailed form. The TMfS model run could in principle be expanded in detail within this model framework to deliver a much more consistent central projection. The TMfS model run was also commissioned with different input assumptions to the rest of the model. As noted in Section 3.7, outputs of travel demand from the TMfS, expressed in vehicle km, were converted to fuel demand based on conversion factors implied by the NTM results.

The results show that by 2020 emissions from road transport are substantially higher under the adjusted TMfS estimates for vehicle km demand but fall to below the NTM central results by 2030. To some extent this reflects the assumptions required in extrapolating model outputs beyond the last years provided from each of the transport models.

5.6 Aviation emissions

Table 5.5 shows the changes to aviation emissions under the different economic and fossil fuel price scenarios. Aviation emissions are expected to grow substantially more than doubling in all scenarios between 1990 and 2020.

TABLE 5.5: AVIATION EMISSIONS PROJECTIONS, SCOTLAND

$ktCO_2$

Scenario	1990	2007	2010	2020	2030	% diff in 2020 on 1990 level	% diff in 2020 on 2007 level
Central fossil fuel price	1,052	1,977	2,032	2,621	3,315	149.2	32.6
High fossil fuel price	1,052	1,977	1,984	2,461	3,171	133.9	24.4
Low fossil fuel price	1,052	1,977	2,096	2,683	3,464	155.0	35.7
High emissions	1,052	1,977	2,102	2,776	3,704	163.9	40.4
Low economic growth	1,052	1,977	2,020	2,448	2,902	132.7	23.8
High economic growth	1,052	1,977	2,038	2,713	3,544	157.9	37.2
Central, Domestic	658	840	859	1,066	1,309	61.9	26.9
Central, International	394	1,138	1,173	1,556	2,006	295.1	36.8
Share, Domestic	658	840	830	906	961	37.6	7.8
Share, International	394	1,138	1,202	1,716	2,354	335.8	50.8

Note(s): ‘Share’ uses the central assumptions but the relative trends between the domestic and international emissions have been maintained.

Source(s): NAEI, Cambridge Econometrics.

Most interestingly, the bottom four rows show the split between emissions before and after the share trend was applied. After the share trend, international emissions growth looks even stronger over the projection period and this is probably more in line with what might be expected *a priori*: international emissions actually grow more than fourfold from the 1990 level to 2020, and by 2030 international emissions are projected to exceed 2.3 $MtCO_2$, nearly six times that of the level of emissions in 1990.

5.7 Shipping emissions

Carbon emissions arising from shipping are assumed to not vary with the price of fossil fuel. To be more precise, there are insufficient data to estimate what the relation might be and so a stylised assumption is made. The results show that by 2020 emissions from shipping could have fallen by between 13% and 26.3% depending on the economic assumptions. About half of this decline occurs in the historical period to 2007 and the additional fall is as a result of the economic downturn which has affected emissions output in the period to 2010.

The final row shows the difference for the central run of applying the OECD driver, rather than using manufacturing GVA as a proxy for trade, and therefore demand for shipping. Under this assumptions emissions do not fall in the short term period between 2007 and 2010 in fact emissions increase slightly, this seems perhaps less intuitive than the result using manufacturing GVA.

TABLE 5.6: SHIPPING EMISSIONS PROJECTIONS, SCOTLAND

ktCO$_2$

Scenario	1990	2007	2010	2020	2030	% diff in 2020 on 1990 level	% diff in 2020 on 2007 level
Central	2,618	2,135	1,590	2,157	3,213	-17.6	1.1
High economic growth	2,618	2,135	1,613	2,279	3,524	-13.0	6.7
Low economic growth	2,618	2,135	1,545	1,931	2,663	-26.3	-9.5
Central, OECD	2,618	2,135	2,166	2,457	2,754	-6.1	15.1

Note(s): OECD

Source(s): NAEI, Cambridge Econometrics.

5.8 Rail emissions

Rail emissions follow the growth in UK rail emissions and do not vary across any of the scenarios. By 2020 rail emissions are 24% higher than in 1990 at 241 ktCO$_2$. The projections do not vary over the period to 2030; neither do the UK projections from the DECC model.

6 Conclusions

6.1 Results overview

The results presented in this report are robust and respond in an intuitively plausible manner with respect to fossil fuel prices, economic growth and household growth assumptions. The results also show an overall trend of increasing emissions in Scotland, particularly arising from transport, with modest growth in road transport emissions being the largest emissions source, and fast growth in aviation emissions. Industry emissions are reduced following the recent trends and expected impact of the recession on emissions projections in the short term. The domestic sector sees a fall in emissions which levels off, but does not really pick up again over the projections period.

6.2 Uncertainty

The fossil fuel price assumptions are reasonably wide ranging and therefore provide a reasonable insight into the potential response to changing world energy prices. However, the economic assumptions, stipulated for use in this study by the CCC, are not wide ranging, as the +0.25 pp and -0.5 pp values used only give rise to economic valuations of between approximately +5% and -10% around the central case by 2030. Although this range broadly reflects the view that economic aggregates are reasonably stable to predict within a certain range, this view should be contrasted against the recent recession which was almost totally unforeseen and has had a substantial impact on GDP, energy demand and emissions. Moreover, the assumptions are independent and exogenous as such we do not capture the secondary effects of fossil fuel prices on energy demand through the effects on industry output.

The input parameters, most of which have been sourced from the DECC model of energy demand are estimates for the UK. There is therefore reasonable justification in challenging whether such elasticities are well suited to Scotland. For example, as it is substantially colder in Scotland, particularly in winter it might be expected, a priori, that energy demanded for heating purposes is considerably less responsive to changes in price. However, there are insufficient data as it currently stands to re-estimate these and provide a more definitive answer. It might be more appropriate, therefore, to test the model using varying price and/or income elasticities estimated from other sources for the UK and to investigate further whether Scotland-specific estimates could be derived.

6.3 Criticisms of the model

The main fundamentals of the projections modelling tool are based on sound theory: carbon emissions resulting from energy demand are a function of economic activity (in the form of output or income) and the price of energy. The modelling tool makes use of the available data to project reasonably robust projections under the assumption of no additional carbon mitigation action beyond those measures outlined in the Climate Change Package in 2006. As such the modelling tool is only designed as a predictor of what might occur with minimal policy or technology interventions and the results are therefore intentionally counterfactual. The modelling tool is broadly consistent with other modelling approaches used in the UK, namely the DECC energy demand model and the MDM-E3 model of the UK economy, energy demand and emissions. However, the model still has a number of general weaknesses and some sector- specific limitations. These are discussed in turn below.

First, and most generally, the model does not include any feedback effects and treats economic parameters as independent and exogenous. For example, an increase in the oil price does not lead to higher prices throughout the economy, a shift in the composition of spending and an increased loss to the economy, other things being equal through more expensive oil imports. Instead the model simply shows the partial response of a relative change in energy prices to energy users. While this is consistent with the DECC model and also consistent with the time and resources available for this project, it is not ideal as whole economy responses are not taken into account.

Second, the various datasets used to inform the model are not consistent. This has the largest impact on the industry energy demand and emissions projections, as the DECC data on regional energy consumption is not consistent with the NAEI emissions data. In addition the EU ETS installation data are not fully consistent with the NAEI data in terms of the report classifications.

The road transport hybrid modelling approach suggested in the Phase 1 recommendations was not carried through in full, such that, instead of several runs of either TMfS or NTM being commissioned under a consistent set of assumptions, we only had one run with minimal results from each model. The recommendation was to use a wide ranging set of results from either of these models to create a simple emulation of the models suitable to give projections under a wider range of assumptions without the need to run the models in full again. Instead we had to use DECC model parameters to infer what a difference in income or price might have on the central road transport projections. This is less satisfactory than the suggested method because it does not necessarily capture the supply side response to changes in assumptions.

The rail emissions projections are not satisfactory, as they do not account for supply side variables in the form of further rail electrification. The projections also do not respond to changes in either fossil fuel prices or income.

Many of the deficiencies of the projections model are due to the assumptions required to deal with the problems arising from missing or inconsistent data. These can be dealt with in different ways, but the only fully satisfactory approach is to improve the underlying datasets.

7 Recommendations for future work

This chapter is divided into two main sections. The first highlights issues with inputs to the model and our recommendations on how inconsistencies might be addressed. The second section identifies areas in which the model treatment could be improved or extended.

The main concern with regard to data is with inconsistencies between statistics from differing sources such as the sum of regional totals not matching the UK totals.

The focus of the second section is more on areas of the model that could be improved but would require more resources and time than this current project allows.

This chapter ends with some concluding remarks on future work.

7.1 Data recommendations

The data used in the modelling tool are inconsistent in places and highly aggregated across sector and fuel. This is mostly a problem for the industry emissions:

- The DECC regional energy consumption statistics are not consistent with the NAEI regional emissions data set. This is a continued problem which is also evident at the UK level. Both sources are accredited National Statistics and so should be compared for consistency and, where they occur, inconsistencies should be addressed and explained.
- The DECC regional energy consumption statistics are aggregated across industry; but more detailed sector/industry disaggregation would be a considerable improvement. It would also help to highlight inconsistencies that exist with respect to the emissions dataset.
- The NAEI data for regions is aggregated across fuels. It would be a considerable improvement if data by fuel was provided at the regional level.
- The SCPnet data is not consistent with DECC regional energy statistics, NAEI emissions data for Scotland or the EU ETS installation data. Although the SCPnet data are much more disaggregated than the other datasets, both by fuel and by sectors, it is not easily identifiable how the data maps to either DECC regional energy consumption or NAEI emissions data.
- EU ETS installation data are highly detailed and sector specific but are not fully consistent with NAEI in terms of sector classification used. It would be a considerable improvement if the NAEI datasets and ETS installation data were made consistent and if documentation highlighting the precise mapping of ETS installation data to NAEI source sectors could be provided.

As shown, there are four sources of related but inconsistent data sets. The data provided are minimally sufficient but because they are often highly aggregated it is not easily possible to infer where the inconsistencies lie between the various sources.

The improvement of these datasets is of paramount importance, if the objective of a better model based on bottom-up Scottish data is to be realised. Inconsistencies between the datasets must be resolved and it is desirable that longer time series are obtained to improve the understanding and analysis of trends at the regional and national levels. If this were to be achieved, not only would it allow the development of substantially improved modelling tools for projections and policy analysis; it would also enable policy makers to monitor more closely the effectiveness of government policy interventions, at a UK, Devolved Administration, regional and even sub-regional level. At a time when the UK hopes to take a lead role at the Copenhagen summit in December 2009 it will need to show considerably more effort in providing the necessary statistics to monitor and highlight where progress is being made. Moreover, the Scottish government's carbon reduction targets are even more ambitious than those of the UK. This suggests that a more concerted effort by the relevant parties than hitherto will be required to improve the quality of the underlying data and indicators.

7.2 Model recommendations

In addition to the improvements which could be implemented to the model as a result of more or better detail; the modelling tool could also be improved, albeit with some considerable effort, in a few key areas:

- Road transport emissions: the road transport emissions projections are based on a hybrid approach which makes use of NTM or TMfS model outputs alongside DECC price and income elasticities. The purpose of using bespoke transport models in the central run was to get an insight into the impact of supply side measures which are not easily captured in a top down econometric approach. However, in the varying fossil fuel price and economic growth projections, the impact on transport supply side measures is lost. It would be more suitable, as suggested in the Phase 1 recommendations, to commission several runs from each transport model under consistent sets of input projections. It would then be possible to create a tool which broadly emulates the transport models' outputs and therefore captures responses to price and income from both the supply and demand side. In the first instance it would be an improvement to have a model run from the TMfS model with the same inputs as the NTM model and the rest of these projections. It would also be an improvement to have more detailed results from the TMfS covering fuel use over differing vehicle types and between diesel and petrol. The transport sub-models are cumbersome and take considerable time to solve; because of this outputs are often only provided for intermediary years. A further improvement would therefore be to have outputs for each year. As it currently stands we have interpolated model results between output years provided by the NTM and TMfS models.
- Domestic emissions: the reference projections include policies announced as part of the Climate Change Package 2006, including a number of policies with domestic focus. A bespoke research effort to analyse the impacts of UK government policy on Scottish housing would improve the reference projections. We have attempted to do this in a stylised manner, but the differences between the UK housing stock and the Scottish housing stock are sufficiently large to warrant further investigation. This could be done in conjunction with the DEMScot modelling tool, however, as discussed in Section 3.11 and Appendix A, it is not easily possible to consider the impacts of a projections or forecasting model with a simulation model.
- Industrial process emissions: process emissions rely heavily on the underlying technologies used in specific industrial processes and in the production of specific products. An upcoming technology change could therefore have a substantial impact on emissions from an industrial process. As recommended in Phase 1 we

suggest that process emissions are scrutinised by industry/technology experts for their validity.

- Rail emissions: although rail emissions are a small proportion of the total, it would be a considerable improvement to make use of assumptions on assumed differences between grid electrification rates in Scotland compared to the UK.
- General: the model offers a range of reference projections for Scotland which can then be used to identify carbon abatement potential, using separate modelling tools and analysis. This method for projecting energy demand and emissions is broadly consistent with the DECC modelling approach for the UK. However, fully integrated energy-environment-economy models exist that incorporate substantially more complex relationships. For example CE's energy-environment-economy model of the UK economy, MDM-E3, captures feedback of changes of fossil fuel prices on the economy in general, rather than simply the partial impact on energy demand. In our view this fully integrated approach offers a much better insight into the impact of fossil fuel price variations and economic growth scenarios. To tailor this approach with regional energy demand and emissions data is a substantial undertaking and outside the scope of this project but could be considered in further work. The REEIO model that CE has developed could act as a blueprint for this type of development.

7.3 Concluding remarks

The points above suggest a number of areas in which regional projections of emissions can be generated. Better data are considered of utmost importance as the inconsistencies pointed out in the Section 7.1 make reconciling the historical data problematic and can increase uncertainty in the projection period.

In addition to this we present a number of areas where greater time and resources could be spent to improve the projections. Most notably, a series of runs from one of the transport models would help to inform an emulation of the outputs to key assumptions. We appreciate that this is time-consuming, but road transport is a significant contributor to CO_2 emissions and a sector for which abatement action is clearly of high priority. The rise in transport emissions contrasts with the overall decline in emissions observed at both the UK and Scotland level and reducing these emissions will be an important goal of mitigation policies.

Similarly, we believe it would be worthwhile to devote more research into differences between the UK housing stock and Scotland's; the domestic sector being another large contributor to non-traded sector emissions.

Further research into industrial process emissions and emissions from rail would, as we point out, be useful but compared to the other two sectors mentioned, these sectors are small in terms of emissions and the potential for abatement smaller.

Appendix A: Comparison of the Projections Modelling Tool with DEMScot

This Appendix contrasts the projections modelling tool outlined in the main text, and its treatment of domestic-sector emissions, with the DEMScot model.

A.1 Differences in approach

The headline purpose of the two modelling approaches would at first sight seem to be the same: to provide a projection of CO_2 emissions for the domestic sector for Scotland under varying sets of input assumptions. However, on closer inspection it becomes apparent that the questions the models are intended to answer are quite different and any simplistic attempt to use both models in tandem is not valid.

DEMScot attempts to provide an answer to the following question: ‘Following a given set of input assumptions on technology take-up and behaviour change over time, what is the likely demand for energy and resulting CO_2 emissions arising from the Scottish housing stock?’ The model takes an engineering, bottom-up approach based on very detailed modelling of the housing stock and incorporates known technical parameters on various technologies/measures which could be implemented, calculating the combined impact of pre-determined levels of input. This approach does not attempt to model consumers’ take-up of technologies under different energy prices or levels of income, instead, take-up is a predetermined input assumption.

By contrast, the projections modelling tool attempts to provide an answer to the following question: ‘Following a given set of input assumptions on energy prices and economic growth and household growth, what is the likely demand for energy and resulting GHG emissions arising from the Scottish housing stock?’ The model takes an econometric, top-down approach to link trends in the aggregates between income growth and energy prices with energy demand and the consequent emissions. The model does not give any insight as to which measures/technologies will be chosen by consumers to deliver the changes in energy demand. Moreover, the model does not distinguish between changes in consumer behaviour, such as turning the lights off, and, say, the installation of cavity wall insulation. The effect is simply captured in the aggregate results, which are of course based on past trends.

However, the DECC energy model does try to combine these approaches before and after policy impact. The ‘before-policy’ impact is simply the result of econometric equations, but the ‘post-policy’ impact is calculated from assumptions and data on the housing stock, the number of measures which will be installed under a particular policy and the effect of such measures, trying to account for the direct rebound effect. This approach has its merits but is not without its drawbacks, not least the difficulty in imposing policy effects that might to some extent already be reflected in the historical data.

CE is also undertaking research alongside the Cambridge Centre for Climate Change Mitigation Research (4CMR) to model the domestic sector more comprehensively at the UK level. The broad approach is to use net present values for particular income groups, living in particular housing types, on the decision to install a particular energy/efficiency measure. However, a number of engineering and economic difficulties have not yet been resolved.

A.2 Data and difficulties in comparison

The models are both calibrated to the DECC regional energy consumption figures, but, the projections tool is calibrated to the NAEI emissions outturn for 2007 and the DEMScot model is not. For comparison of results, percentage differences are taken between the first year in DEMScot, 2009, and the first major target year 2020. Immediately this presents a problem: DEMScot is a technology simulation model, it does not show behavioural responses to economic influences, for example, in response to falling incomes as a result of the economic recession.

To compare the results we have implemented broad-brush measures in DEMScot to sense check the results of the central run with Scotland-adjusted policy impacts for the domestic sector taken from the projections modelling tool. We suggest that this is the most beneficial way to compare the models in their current states and involves the following steps:

1. Choose a model run for comparison with DEMScot
2. Iteratively implement additional technologies based on those which are either most cost effective or seen as likely in DEMScot
3. When the percentage change is the same in both models look at the required technologies to deliver such a change (in terms of direct source emissions, note that users might be more interested in energy demand and as such should use the energy demand outputs as the target variable for tuning)

However, we have chosen to use DEMScot to sense check the impact of cavity wall insulation and loft insulation under EEC1, EEC2 and CERT policy, against the ‘before policy’ DECC model run, with outputs allocated to Scotland. The DECC model assumes that for the UK there will be 3.4m houses fitted with cavity wall insulation and 5.1m with loft insulation by 2020. We have then simulated the impact of 302,000 cavity wall insulations in Scotland and 437,000 loft insulations based on the simple share of households for Scotland relative to the UK in 2020. The DECC policy figures, it should be noted, include rebound effects.

We have calculated, based on DECC figures, that this will lead to a 3.5% reduction in natural gas demand compared to the ‘before’ policy impact run for Scotland’s domestic sector. By contrast the DEMScot model suggests that if cavity wall insulation and loft insulation are installed in every house with a loft in Scotland the reduction will be nearer 1.7%.

For oil, the projection tool indicates a reduction of 5.3% compared to DEMScot’s 1.4%; for electricity 0.5% compared to 0.1%. The differences likely reflect the better bottom-up data in DEMScot which makes estimates of the fuels used by households for space heating. For solid fuels, the estimates are very different. We estimate an impact of 1.2% from the projection tool compared to 3.1% in DEMScot. It is difficult to explain such a wide discrepancy in the results, other than that the more detailed DEMScot model appears likely to assume that all energy from solid fuels is used for space heating.

The results are therefore quite different, especially in terms of the fuel mix. The results are also surprising in that the DECC-adjusted figures are more optimistic than the technology model figures, even though we have adjusted the DECC model figures downwards to allow for a lower impact in Scotland because of the characteristics of the housing stock ie more flats.

A.3 Recommendations

The underlying differences between DEMScot and the projections tool make reconciling the projections problematic. Instead, we propose that DEMScot could conceivably be used to inform the domestic policy impacts that could be applied to the projections from the modelling tool. The difficulties associated with this and the risk of double counting energy savings are described in Section 3.11. Most importantly, the current DECC income elasticities do not obviously isolate the effect of income on energy demand; greater energy efficiency would seem to be captured in the existing estimated value of this parameter.

If the income elasticity parameter were to be improved, DEMScot could then be used to estimate the energy savings of a particular policy by explicitly modelling the effect of increased take up. The difference between the baseline DEMScot projection and the new one, with the additional measures, could then be applied in the projections tool. Issues of double counting could to some extent be circumvented provided, as noted above, that the income elasticity used is purely an income elasticity and that the current state of the housing stock and the projected business-as-usual trends are captured in the DEMScot baseline used.

It is important to note that, because there are no behavioural effects captured in DEMScot, some characteristics and effects will not be captured by the approach suggested, such as the rebound effect[23].

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[23] In this context the rebound effect refers to a response such that the energy reduction from the adoption of an energy-efficiency measure is offset to some extent by additional energy consumption. An example would be insulation measures which reduce the amount of energy required to heat a home to a given temperature. As a result of lower energy costs, the household may opt to consume more energy to increase the internal temperature.

Appendix B: Detailed Phase 1 Findings

This Appendix contains the detailed findings from Phase 1 of the project, the purpose of which was to make a series of considered recommendations which could be carried forward into the development of the CO_2 projections tool in Phase 2.

The overall task of Phase 1[24] was broken down into five sub-tasks:

- to assess the existing method for projecting Industry, Commercial and Domestic emissions
- to assess the coverage of the EU ETS traded and non-traded sectors for Scotland
- to assess the method for including policy impacts for Scotland
- to compare the DfT's NTM against the TMfS
- to propose a methodology for previously omitted sectors, including: rail, domestic and international aviation, domestic and international shipping, offshore oil and gas and process emissions

As noted, briefly, in Chapter 2 of the main report:

- The method for projecting Commercial, Industrial and Domestic emissions in Scotland was assessed against a number of criteria to determine the suitability, relevance, transparency and robustness of the method employed. Broadly, the method was considered sound and we suggest that the CCC continues to disaggregate energy demand and emissions projections at the UK level rather than attempt to project energy demand and emissions for individual regions and nations. However, we believe that there would be benefits from using regional energy and emissions statistics that are more detailed than those currently used by the CCC, specifically the use of SCPnet data would be advantageous as they are more disaggregated than DECC's regional energy consumption statistics.

- The CCC has calculated that the EU ETS covers approximately 76% of Industry emissions. However, we calculate that for Scotland the proportion of emissions covered is lower, around 36%, with some variation between sectors. For example, we find that the largest of these sectors, Other Industry, has an estimated coverage of 42% and the Energy Industry coverage of around 38%. The calculation of EU ETS coverage is complicated by various disparities between the EU ETS dataset on verified emissions and the NAEI data set, the allocation of offshore emissions, and the inclusion of CCA and UK ETS opt-outs. The EU ETS coverage within industries, calculated by supplementing the NAEI data with SCPnet data, is also sufficiently different between the UK and Scotland to merit further analysis in any further set of projections.

- In the CCC's current approach, policy impacts in the reference scenario are assumed to be distributed between regions of the UK according to the disaggregation method. The CCC's recognises this as a weakness. The most obvious area for proposing that a distinctive treatment be applied for Scotland in the impact of policy is the Domestic sector, where there is strong justification for expecting a different impact to the average impact in the UK because of the

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[24] As noted in the main report, the 'existing' or 'current' method refers to that used by the CCC for its inaugural report.

considerable differences in the existing housing stock in Scotland, and there are sufficient data to carry out such an assessment. We also recommend that projections are sense-checked against a detailed bottom-up model of the housing stock, namely, DEMScot. For the transport sector, many of the key policies are best represented at the national level, by making use of the Department for Transport's National Transport Model (NTM) and then split to the Devolved Authorities; as discussed in Chapter B.4, the NTM is able to give regional outputs. While the industrial and commercial structure of Scotland's economy differs from that of the UK as a whole, and although there is reasonable justification to suggest that industry in Scotland will react differently to carbon mitigation policies, there is little policy-specific data relating to Scotland against which to verify this. However, there are a few substantial policies, such as the CCAs, where this could be considered.

- Both the NTM and the Transport Model for Scotland (TMfS) offer advantages for application in Scotland. Both produce the basic outputs that would be needed for the CCC's projections, namely Scottish road traffic and emissions from Scottish road traffic. There are far more outputs available from the TMfS, including sub-regional forecasts and detailed results for more modes of transport. These are a useful supplement to the aggregate results, but are not necessarily required for the CCC's projections. However, the NTM also has some modelling advantages of its own. The most important is that it models Great Britain as a whole, and we might expect that economic activity, policy and transport infrastructure in the rest of UK will have an important impact on Scottish road transport, whereas the TMfS only has a 'skeletal' representation of England and Wales. Further investigation is required to further explore the differences between the two models and to decide which is the most appropriate tool.

- We have proposed methods for projecting emissions from sectors not currently covered at the regional level by the CCC. The methods proposed are quite similar to the existing disaggregation method, ie they calculate shares from the last year of data which are then held constant over the projection period. In the case of rail transport, while we offer a disaggregation method, we recommend that a dedicated transport model could be employed for a more complete treatment of this sector, such as the NTM or TMfS.

- The improvements identified in Phase 1 will be investigated further to explore their feasibility and will feed into the development of the projections tool during Phase 2.

The proposed projections tool, an output from Phase 2, will implement the recommendations in a spreadsheet. The recommended methods satisfy a number of the projections criteria and the use of a spreadsheet offers transparency in the calculations and imposes a constraint on the scope for unnecessary complexity. User options can be easily built into such a tool and alternative assumptions, projection methods and parameters are easily updated and selected. The tool will of course be accompanied with detailed documentation to facilitate its use.

B.1: Structure of Appendix B

The following chapters outline the findings from Phase 1 of the research. In Chapter B.2 we discuss the existing method that the CCC employs to project CO_2 emissions in Scotland. The method is assessed against a number of criteria in order to highlight the strengths and weaknesses of the approach. We also discuss the method used for assessing policy impacts in the projections, while the final part of the chapter draws out the implications for the second phase of the project. The coverage of the traded and non-traded sectors is discussed in Chapter B.3 together with the implications of the findings for the modelling approach. Two possible models for calculating road transport emissions in Scotland, the Department for Transport's National Transport Model (NTM) and the Scottish Government's Transport Model for Scotland (TMfS)[25], are discussed in Chapter B.4 and the strengths and weaknesses of each approach are evaluated. In Chapter B.5 we discuss our method for the sectors currently omitted from the CCC's approach. The conclusions and implications of the findings for Phase 2 are discussed in the final chapter, B.6 and the references for this appendix can be found in Chapter B.7.

For convenience, the page numbers of the subsequent chapters in this Appendix are listed below:

- B.2 - pg 42
- B.3 - pg 61
- B.4 - pg 64
- B.5 - pg 71
- B.6 - pg 78
- B.7 - pg 80

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[25] Also known as the Land-use And Transport in Scotland (LATIS) model.

B.2: Assessment of modelling approach

In this chapter we evaluate the CCC's existing method of forming regional CO_2 emissions projections. We focus on how estimates of energy demand and consequent emissions are formed from UK-level energy and emissions projections. There is no discussion on how emissions from some sectors are split into traded and non-traded emissions; this is dealt with in Chapter B.3. This chapter also examines other possible modelling approaches.

A set of criteria to assess modelling approaches was agreed with the CCC

A set of criteria was agreed with the CCC against which projection methods could be judged. These criteria also provide a metric by which different methods could be compared.

The criteria presented in Section B.2.1 below were presented to the CCC shortly after the start of Phase 1. They represent conditions which, if satisfied, would indicate a useful and feasible forecasting technique. The criteria presented could be applied quite generally to a range of modelling tasks and there is some overlap between them. The following section frames the criteria in the context of the current study and points out areas of particular importance when evaluating emissions-projection methods.

B.2.1 Explanation of criteria used

Nine assessment criteria were agreed upon

The CCC identified three broad criteria that define a useful projections model, of which the first two were considered of most importance:

- robustness/accuracy
- transparency
- efficiency

Underpinning these three core criteria, we proposed nine criteria to the CCC by which a modelling approach could be assessed. The assessment criteria can be divided into four categories, although there is some degree of overlap among them:

- inputs to the method
  - the consistency and suitability of the data used
  - the past performance of the method and its previous applications
  - the underlying assumptions and the application of intuition and theory
  - functional form and parameters
- outputs from the method
  - the scope/detail of the outputs
- forecasting performance
  - learning from history
  - forecast accuracy
  - transparency
- cost (relative to the detail provided)

Of particular importance to the CCC were the criteria relating to:

- the underlying assumptions and the application of intuition and theory
- functional form and parameters
- the scope/detail of the outputs
- transparency

The CCC indicated its particular interest in the evaluation of the method's forecasting performance but appreciated that data constraints might make it difficult to assess the criteria of 'learning from history' and 'forecast accuracy'.

Assessing the inputs to the method

With this group of criteria, we wish to examine the data and assumptions that are used to generate the projections and the way in which they are used to inform the forecast.

Consistency and suitability of the historical data

The data used to inform the projections have a direct bearing on their quality and reliability. This criterion consists of two key questions:

- are the historical data for the indicators for which it produces projections consistent with official sources?
- does it make use of all the available data that, *prima facie*, seem relevant?

To some extent, the problem of inconsistency between the projections and official sources during the historical period can be overcome through a calibration method that ensures the last year of outturn data can be replicated by the projection method, following a number of scaling adjustments which are also applied to the projection period. This is the method currently employed by the CCC. While this method is able to ensure a smooth transition between the historical and projection periods, it would nonetheless be useful to understand the source of the differences between the projection and the historical data, before any adjustments are made.

However, as the CCC is well aware, energy data at the UK and regional levels are inconsistent. There are also inconsistencies between the UK energy statistics and UK-level NAEI emissions data that are likely to be carried through to differences in regional energy and emissions statistics. The extent to which a method is able to reconcile these differences, if at all, is an important consideration.

In evaluating a method against this criterion, it may also be useful to examine other possible data sources that could improve the projections. Other points to consider when evaluating data sources include the frequency at which new data are made available and the ease with which new information can be incorporated into the projection.

Previous practice

By this criterion we wish to answer the question:

- does the methodology conform to the practice used in other studies that have gained acceptance?

By this we mean: can the provenance or pedigree of the technique used be justified from its acceptance in past work? We might consider this criterion to have been met, for example, if there were sufficient evidence that the technique had been used before (as judged by its prevalence in related work) and has been used successfully. If possible, we would also want to evaluate the forecasting performance of the method using some of the criteria discussed in this section below.

Assumptions and logic of determination of outputs

This criterion can be divided into two components/questions and relates to the inputs that will be fed in to produce a projection:

- the method's suitability for scenario analysis: does it include explicitly as assumptions the drivers that policy users may wish to vary?

- the economic explanation/logic of the outputs should make sense: does it include explicitly as assumptions all the drivers that theory or intuition suggests will be important in determining outcomes?

The first point relates to the suitability of the method for scenario analysis. The overall aim of the project is to produce a set of reference CO_2 emissions projections from Scotland's non-traded sectors to 2030 under a range of assumptions including, but not limited to, future fossil-fuel prices, economic growth and the effectiveness of different policies. Clearly, any method that is not capable of incorporating these assumptions (or cannot be adapted to incorporate them) is of limited use when considered against the overarching specification of this study. Among the exogenous variables the CCC is interested in changing (for example, to analyse the uncertainties) are economic activity and population growth. The method should explicitly incorporate these drivers in some way.

The second question relates to the suitability of the assumptions that are entered as inputs into the method. While the CCC has a list of assumptions that it is interested in varying, there may be other assumptions required, determined by theory or intuition that may also need to be captured in order to produce a credible projection with a satisfactory explanation.

Functional form and parameters

The questions that fall under this criterion were specified mainly to account for the possible use of econometric methods to produce the projections:

- can the functional form be justified by appealing to theory, literature or intuition?
- can a correspondence be made between the empirical model and a theoretical model, so that a valid interpretation can be given to parameters?
- are its parameters consistent (in terms of sign and absolute magnitude) with theory and previous studies?
- are its parameters based on empirical evidence, and have best-practice methods been used to estimate them?
- is it reasonable to suppose that the parameters will be constant over time?

This criterion is designed to assess the validity of the equation(s) estimated and accounts for the usual problems faced when conducting such analysis including the trade-off between parsimony and explanatory power in specifying an equation as well as the interpretation, plausibility and (temporal) stability of the resulting parameter estimates. The parameter estimates would typically be compared against previous empirical studies and theoretical literature to assess their usefulness.

Scope/detail of outputs

The criteria described above relate to how the projections are to be generated. This next criterion aims to address the question of what is produced by the method ie the nature of the outputs:

- do its outputs contain sufficient detail to be useful for policy users (either because such detail is explicitly required, or in order to provide supporting evidence to justify an aggregate result)?

Specifically, we wish to assess the level of disaggregation offered by the method by fuel-consuming sector and by fuel type in order to analyse the potentially different impacts, on the different sectors, of changes to key exogenous variables. The level of disaggregation must at least match that of the method currently employed by the CCC, ie it should be (at least) as detailed as the disaggregation presented in DUKES.

Forecasting performance

The next three criteria are used to assess the actual outputs from a particular method in terms of their accuracy, plausibility and complexity of explanation.

Learning from history

The question here is:

- does it produce projections that are consistent with the lessons that can be learned from past trends (taking account of the time horizon for the projections, ie short versus long and very long-term, and taking account of arguments for ways in which the future may differ from the past)?

By this criterion we wish to assess, by comparison with history, the plausibility of the results derived from a particular method (given the data, the drivers included and the assumptions fed in). We might therefore not expect the projected trend to change substantially in a business-as-usual projection. The dynamics of the projection may also be worth considering when assessing a method by this criterion: do the projections reflect the short and long-run responses previously observed?

We may also wish to learn from history about how relationships between variables might change over time. For example, how might the relationship between economic activity and energy demand (and consequently, emissions) change as a result of changes in technology/energy efficiency or industry structure?

Accuracy of forecasts

The question, in principle, here is:

- how well do its projections match actual outcomes?

For short-term forecasts, this requirement is easily tested by comparing a previously-produced forecast against more recent outturn data. A further test is to enter as assumptions the actual values taken by input variables and compare the resulting predicted output to the actual data: this helps to assess whether forecasting errors were due to the use of assumptions that turned out to be inaccurate, or due to an inaccurate model.

However, this is unlikely to be a helpful criterion for a long-term forecasting model, since the test cannot be effectively applied: we cannot wait for, say, 20 years to examine whether projections made now prove to be accurate. Since the desired forecasting horizon for the present purpose is at least 2020, this criterion has relatively low importance for the current study.

Transparency

This criterion relates to whether or not the method is appropriate for the target audience and users:

- can the outcomes be readily explained in relation to the assumptions by the people who are expected to be operating the model?

This criterion builds on the criteria discussed earlier that relate to the specification of the method in terms of its inputs and, where applicable, the functional form and parameters of the relationships modelled. Here we add the additional constraint that the method should be intuitive to those who will use the model and not overly complex.

Cost

By this final criterion, we recognise the balance that needs to be struck between the quality and detail provided by a particular projection method and the investment of resources to develop and carry out the method:

- are its cost of development and operation commensurate with the importance attached to the outputs and the likely quality of the projections (given, for example, the quality of data)?

In proposing and developing an alternative projection method, it may be useful to consider where greater attention and resources may best be directed. For example, of the non-traded sectors, road transport and households are the largest emitters and it is here that the greatest potential lies for the abatement of emissions. A better-quality projection for these sectors (and possibly a more detailed treatment of policy impacts) is likely to have a much greater pay-off than investment in substantial detail in a much smaller sector where the scope for abatement is less.

B.2.2 Assessment of modelling approach against criteria

The existing CCC approach disaggregates projections from the DECC model

The approach used in the CCC's initial analysis of emissions projections at the regional level, reported in its inaugural report (CCC 2008a), was to disaggregate reference projections for the UK that had been generated by the DECC Energy Model[26]. The methodology used is described in a Technical Appendix (CCC 2008b) to the report as well as in a supporting document containing a review of the model by Oxford Economics[27] (2008), in which the method was recommended. Here we briefly describe the approach used and then assess it against the criteria discussed in Section B.2.1.

Energy demand projections from the DECC model (at the UK level) for industry and commerce are disaggregated to the regional level, and the consequent CO_2 emissions calculated, as follows:

1. Output projections by region and sector are used to share out the UK-level sectoral energy demands to form a first estimate of regional energy demand disaggregated by sector and fuel type (at this point the fuel mixes are identical across regions).
2. Each nation's implied energy demand from Step 1, by fuel, is compared in the last year that regional energy consumption statistics are available to produce a set of adjustment factors; when applied to the first estimate calculated above, in the last year in which data are available, these factors have the result that the disaggregated energy demand matches the outturn data. The factors are applied to the figures estimated in Step 1 over the projection period. At the regional level, by fuel user, there is only one series per fuel for industrial and commercial users combined so the sum of the estimates from Step 1 are used to calculate a common set of adjustments.
3. Standard emissions factors (as reported in DUKES, among others) are applied to the energy demand projections from Step 2 to produce a first estimate of CO_2 emissions by region and sector.
4. A further scaling adjustment is applied to the emissions projections such that, when summed across fuel types, the emissions by sector in the last year of available outturn data match official sources (ie the NAEI). This is a similar procedure to

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[26] Henceforth referred to as 'the DECC model'.

[27] The DECC model was known as 'the BERR model' at the time. To minimise confusion, regardless of the date of any publication referenced, the model will be referred to by its current name, the DECC model.

that in Step 2 and the resulting adjustment is then applied to all years over the projection period.

The procedure is similar for households but demographic data, specifically projections of the numbers of households in each region, are used instead of output in Step 1.

Hence, the method forms a regional projection that has been calibrated to the last year of available data and the necessary adjustments are then applied to the remainder of the projection period. The method accounts for differences in energy intensity and industrial structure between regions.

Road transport emissions are projected separately

The only regional CO_2 emissions projections published in the CCC's first report (2008a) not covered by this method are those for road transport for which, as recommended by Oxford Economics (2008), the CCC makes use of projections from the DfT's National Transport Model (NTM). A comparison between the NTM and the Transport Model for Scotland (TMfS) is presented in Chapter B.4.

CO_2 emissions from non-traded sectors not currently covered include rail transport, domestic aviation and shipping, offshore oil and gas, refineries and some industrial processes. How emissions from these sources might be projected is discussed in Chapter B.5.

The traded sectors are not considered in this project because they are covered by the EU ETS and participating installations must buy or sell emissions permits such that, at the end of the period, they effectively only account for the emissions allocated to them under Member States' National Allocation Plans. Thus, the variable component of the net carbon account of interest at the Scotland level is non-traded sector emissions, which will need to be reduced at source to meet the emissions-reduction targets.

Assessing the inputs to the method

Here we assess the method against the criteria presented in Section B.2.1. An assessment of alternative projection methods is discussed in Section B.2.3 and, at that point, a comparison of the methodologies is presented.

Consistency and availability of the historical data

Oxford Economics (2008) notes that much of the detailed regional (and local authority) data published have been constructed from a variety of survey data and other information and are 'likely to have rather higher margins of error than the more aggregate and national data' (p 69). Regional energy data are typically less reliable than the data published in DUKES.

In terms of coverage, regional energy consumption statistics are available for five of the main fuels[28]. An issue is that regional data by sector are more aggregated than the national data published in DUKES: industrial and commercial use is grouped into a single category. Thus, in applying the composite-sector fuel mix, the implicit assumption is that the composition of energy demand by fuel is the same across all sectors (or that the sectoral composition within 'industrial and commercial' does not change). While this is unlikely to be realistic, if the CCC does wish to continue to use these data sources, it seems little can be done to address this problem.

Another problem lies in the fact that DECC regional energy consumption statistics are not fully consistent with those in DUKES; that is the inputs to the method used to disaggregate the UK projections are not consistent with the energy statistics used as inputs to the DECC model. Problems of consistency with the NAEI data make Step 4,

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[28] Coal, Manufactured fuels, Oil, Gas and Electricity. Estimates of consumption of other fuels (including manufactured solid fuels, renewables and industrial petroleum) at the regional level are made available by DECC.

a second scaling adjustment after converting from energy consumed to emissions, necessary in the procedure.

Presumably for consistency in disaggregating a set of UK figures, the existing approach appears to make more use of UK figures. Particularly since devolution, an increasing number of datasets are published by the Scottish government, including more regular publications of the Scottish House Condition Survey[29], which includes information on the proportion of households with access to mains gas, households' energy efficiency, and gives an indication of the state of the country's housing stock.

A possible alternative to calibrating to DECC regional energy consumption statistics would be to use the SCPnet regional energy and emissions data[30]. These data are currently in the process of being updated and contain a more detailed disaggregation of industries (45) and fuels (15). A large time series is not available but given that the CCC method calibrates to the last year of available data, there would seem to be benefit in using data that are more detailed than the industry and fuel classification presented in the DECC statistics. The SCPnet emissions data are broadly consistent with the NAEI regional emissions statistics at an aggregate level. However, at the disaggregated level, there seem to be a number of significant inconsistencies. Moreover, as the methodology for classifying the SCPnet data does not appear to be transparent, it remains to be seen as to whether detailed calibration will be possible and remains an avenue for further research. An additional, significant drawback is that the SCPnet data are not consistent with official sources of regional energy data (DECC), nor are they updated as frequently.

Previous practice

The method used by the CCC was based on one recommended by Oxford Economics (2008) in its review of the DECC model. A similar scaling method was used previously in a study by AEA for the Scottish government to project energy demand[31]. The disaggregation of the UK-level projection on the basis of output is also similar to the method used by CE to extend the MDM-E3 model to produce energy and emissions projections for the Devolved Administrations and English regions as part of previous work carried out for the CCC (CE 2008).

In contrast to the use of demographic projections (household numbers) in disaggregating DECC domestic energy demand and emissions, regional household consumption of energy in MDM-E3 was disaggregated by regional projections of disaggregated consumers' expenditure (including expenditure on fuels such as coal, electricity, gas and oil). In contrast to the CCC, CE made use of data originally prepared for SCPnet. A calibration method was also employed by CE to reproduce historical data on regional energy demand and emissions and the scaling factors applied in the last year of data were held constant over the remainder of the projection.

Assumptions and logic of determination of outputs

The method used by the CCC forms a first estimate of sectoral energy demand in each region using forecasts of output by sector and region. Particularly in the absence of more disaggregated industrial and commercial data, this seems to be a reasonable indicator to use. Moreover, the use of output (by sector) as the basis for disaggregation is consistent with its use as a driver in the DECC model, on the assumption, at least as an initial estimate, that energy demand per unit of output does

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[29] http://www.scotland.gov.uk/Topics/Statistics/SHCS

[30] More details are available from http://www.wwflearning.org.uk/scpnet/

[31] Scottish Energy Study Volume 5: http://www.scotland.gov.uk/Publications/2008/11/14093227/0

not differ between sectors. The limited treatment of efficiency gains over time in the DECC model is carried through to the regional projections by the disaggregation method.

In the case of emissions from households, the projected number of households has been selected as the basis on which to disaggregate emissions (as opposed to household disposable income, which is a driver of domestic energy demand in the DECC model). By using the number of households as a driver, the CCC is implicitly assuming that household-income growth in Scotland follows the UK average. This may not be an appropriate assumption and we have investigated the possibility of using Scottish income data as a driver in the modelling tool. The method makes little allowance for technical differences at the regional level (eg the differing characteristics of the housing stock and the potential for greater energy efficiency) and this is a greater weakness in the case of domestic demand than future developments in energy efficiency are for industry. This characteristic becomes important when considering the impact of policies such as CERT.

Scope/detail of outputs

Ignoring the non-traded sectors for which emissions projections are not currently produced (and which we discuss in Section B.2.5), the criterion that relates to the scope of the outputs, ie their level of disaggregation, is largely met by the existing CCC approach; greater detail, in terms of the level of industrial disaggregation, is desired, but there are data constraints that make this difficult to achieve. An issue, mentioned previously in the section in which the data are reviewed, is that the data used to inform the disaggregation of the DECC model projections are subject to greater uncertainty than the UK-aggregate figures published in DUKES.

Forecasting performance

There are a number of difficulties in evaluating the forecasting performance of the method used which can largely be attributed to the absence of good-quality data at the regional level. As noted by Oxford Economics (2008) uncertainties in the projections can arise from a number of sources, many from original DECC model projections, the starting point for the current analysis.

A weakness of the method, that can be traced back to the DECC model, is its inability to account for possible changes in the relationship between activity and energy demand[32]. While the DECC model does model the share of households with gas central heating over time, this effect is not fully captured in the CCC's disaggregation method. While the calibration to outturn data will capture differences in energy intensity, perhaps most noticeably in the formation of energy consumption projections for Northern Ireland, the greater scope for the take-up of gas heating in some regions, or indeed access to gas mains, is not accounted for at the regional level, nor are the differences in scope for other efficiency improvements such as insulation in the housing stock (and differences in the composition, and the likely evolution, of the housing stock). It is not yet clear to what extent the incorporation of such effects will improve the accuracy of the projections (nor, in a partial analysis, how uptake might change in response to changes in the input assumptions). We are inclined to agree with Oxford Economics' assessment (2008) that the incorporation of Scotland-specific temperature effects is unlikely to yield substantive gains in forecast performance, such effects having largely been captured in the relative differences in the fuel mixes between Devolved Administrations. Apart from the temperature effect, provided such

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[32] In the DECC model, as pointed out by Oxford Economics (2008), no allowances for trend efficiency are made whether in the form of a time trend in the stochastic equations or in some other treatment of technological progress.

factors could be reasonably quantified (perhaps by projecting the change in the fuel mix), there is no reason that they could not be incorporated into the existing method.

Transparency and cost

By making use of the regional equivalents of the drivers that feed into the DECC model equations, the disaggregation method employed by the CCC is intuitive and in line with the assumptions used by the DECC model; it seems a reasonable way of disaggregating energy and emissions projections to the regional level in the absence of better or more complete data. In terms of theory, the DECC model's specification appears quite plausible and, by extension, so is the disaggregation method. The CCC's method is also capable of scenario analysis in the sense that the outputs from a DECC-model projection can be easily disaggregated (and therefore detailed UK projections can be supplied as inputs to the DA projections) and changes to exogenous variables that the CCC might wish to change are immediately reflected in the new DECC projection.

In the absence of a new regional sectoral GVA forecast, the old shares could still be (roughly) applied, the implicit assumption being that a change in the assumptions used to generate the new UK projection has the same impact in all regions and their sectors. Given that regional energy consumption data do not distinguish between individual industries or commercial users, the loss of detail should a new regional and sectoral forecast not be available is probably quite small.

Once a UK projection is produced, the subsequent method is low cost in that it is relatively simple to derive regional projections from DECC model inputs and outputs combined with historical data on regional energy demand and emissions.

The method seems reasonable given the data constraints

As discussed, the CCC's existing method seems reasonable in terms of its use in other studies, its consistency (in terms of its drivers) with the method used to produce the original DECC-model projection and thus its transparency. The method is easily understood (with four clear steps) and is low cost, as demonstrated by the fact that the entire procedure can be carried out within a single Excel workbook.

The availability and quality of the data are perhaps the largest obstacles to the disaggregation method, but there seems little way around this inherent limitation if it is not yet possible to obtain data from official sources that are consistent between the national and regional levels. As will become apparent in the next section, the quality of regional data is not a problem unique to the CCC's existing method.

B.2.3 Assessment of a possible alternative method

The validity of an econometric method

At the UK level, consumption of the principal fuels by each fuel-consuming sector in the DECC model is modelled by an econometrically-estimated equation[33]. In this section we examine the feasibility of applying such techniques at the Scottish level.

There are two possible approaches to forecasting with econometric equations:

- use equations estimated with UK data (on the assumption that the relevant parameters for Scotland are not markedly different from the UK ones) but use Scotland-specific assumptions and data to form the projections
- use equations estimated with Scottish data (and use the same data and Scotland-specific assumptions to generate the projections)

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[33] For most of the industrial users, an equation exists for each of the four main fuels, Coal, Oil, Gas and Electricity. Equations for domestic and commercial users are restricted to Gas and Electricity.

An econometric technique is even more reliant on good-quality data

The decision whether to use Scottish or UK data to estimate equations is largely determined by the availability and quality of the available data and, if the regional data (including Scotland-specific factors not currently captured in the UK equations) are poor, the extent to which the UK data act as a reasonable proxy for trends in Scottish energy consumption. Here, we are presented with an immediate obstacle to using Scottish energy data; its lack of consistency with national totals and the likely, much higher, margins of error in these datasets.

The level of detail offered at the required level of disaggregation is probably no better than the existing method

Another problem relates to the fact that, in the case of industrial and commercial use at the regional level, the data are more aggregated than those published in DUKES. If we use sectoral output (the obvious candidate) to disaggregate such series to produce data to support estimation, this is unlikely to yield much additional insight because we shall undoubtedly use the same indicator as an explanatory factor in the model. Although the SCPnet data are more disaggregated than the DECC data, they are not suitable for use in econometric estimation because there are insufficient data-points.

Parameter estimates based on Scottish data are likely to be less reliable than those in the DECC model's UK equations because the data are likely to be of poorer quality. Less reliable parameters will lead to less accurate projections over the forecast period and so we do not recommend the latter of the two options.

The alternative approach, noted above, is simply to use the DECC model equations but with Scottish data as the inputs. It is difficult to say how such projections would perform over the historical period (though a calibration technique can still iron out the inconsistencies in the last year of data), an important indicator of their suitability. Although the parameters may be more robust, the equations will still fail to capture Scotland-specific factors such as the lower proportion of Scottish homes with access to mains gas.

All techniques are constrained by uncertainties over the changes in certain variables

As mentioned in Section B.2.2, the existing approach does not take into account projected changes, at the regional level, in energy efficiency or likely changes in the fuel mix as a result of changes to infrastructure etc. This remains a constraint of any econometric method, based as it is on past data. There is therefore little to distinguish the existing disaggregation method from a more direct econometric method in terms of 'learning from history' and, if the equations to be used are indeed estimated on UK data, there seems little scope for an econometric treatment of Scotland-specific factors; projecting changes in the composition of the fuel mix, for whatever reason, would likely remain as an off-model treatment.

An econometric technique is possibly inferior to the existing technique in terms of cost

The estimation of a set of Scotland-specific equations is therefore beset by data issues and the possible methods to address these issues are unlikely to yield much additional benefit to justify the time and cost of developing the equations. The approach is also unattractive in terms of the likely complexity of the resulting tool and the CCC's requirement that a number of assumptions be explicitly accounted for.

We do not recommend the use of an econometric technique

If such a method were to be pursued, it is likely that the equations would be estimated on UK data, preventing the incorporation of the Scotland-specific factors that were highlighted as a weakness in the current method. Were sufficient data available, there would be much greater scope, opportunity and benefit to developing a set of Scotland-specific equations estimated on Scottish data, but this is not currently feasible.

We therefore do not recommend the use of explicit econometric equations to generate projections of CO_2 emissions at the Scotland level.

B.2.4 Assessment of policy evaluation methods

In this section we focus on the method used by the CCC to estimate the impact of carbon mitigation policy measures in Scotland. To do this we have investigated the method used to assess the impact of policies in the UK in broad terms, and then sought to understand how policy impacts are evaluated for Scotland. For each main sector (domestic, industry and road transport), we then discuss the main issues, available data and alternative options. To put the discussion into context we also consider the role of uncertainty in the estimates.

In the CCC's first report, the Climate Change Programme (CCP) 2006 measures are considered as part of the set of Reference scenarios[34]. The CCC assumes that the impact of the measures will be as anticipated in the CCP[35]. For the UK the impact of the CCP is estimated to reduce emissions by 105 $MtCO_2$ by 2010 and 122 $MtCO_2$ by 2020 compared to a counterfactual case where the policies are not implemented. The relevant CCP measures considered in the Reference Scenarios are:

Business

- Climate Change Levy
- UK emissions trading scheme
- Carbon Trust
- Building Regulations 2002 and 2005
- Climate Change Agreements
- Carbon Trust support for investment in energy efficiency in SMEs
- Measures to encourage or assist SMEs to take up energy-saving opportunities

Transport

- Voluntary Agreements package including reform of company car taxation and graduated VED
- Wider transport measures
- Sustainable distribution in Scotland and Wales
- Fuel duty escalator
- Renewable Transport Fuel Obligation (RTFO) (5%)

Domestic

- Energy Efficiency Commitment (EEC) / CERT (2002-2011)
- Increased activity in CERT (2008-2011)
- Building Regulations 2002 and 2006
- Warm Front and fuel poverty programmes
- Expansion of Warm Front
- Market Transformation including appliance standards and labelling
- Provision of advice to stimulate early replacement of inefficient boilers and implementation of the Energy Performance of Buildings Directive

Public Sector

- Central Government, NHS, UK universities and English schools including Carbon Trust activities, plus regional Central Energy Efficiency Funds
- Action by devolved administrations
- Additional effort by local authorities
- Revolving loan fund for the public sector

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[34] http://www.theccc.org.uk/pdf/7980-TSO%20Book%20Chap%203.pdf

[35] http://www.defra.gov.uk/environment/climatechange/uk/ukccp/pdf/ukccp06-all.pdf

The CCC used the Reference Scenarios, which include the impact of CCP policies, as the starting point for the DA projections. Consequently, the reference projections for Scotland implicitly include an estimate for the impact of the CCP policies in the UK which has effectively been apportioned to Scotland on a pro rata basis. For example, emissions in industry in Scotland are projected using the relative difference in the growth of GVA. Similarly, for the domestic sector, household projections are used to determine Scotland's energy demand consistent with the UK projections.

This approach has a number of advantages. First, it means that the assessment of the impacts at the DA level is consistent with the estimated impact at the UK level. Second, it is consistent with the approach that changes in prices affect the UK in a consistent manner. This is implicitly assumed by the CCC in the use of the various Reference Scenarios as the starting point for the DA projections. This is especially important when considering price-related policies, for example the Climate Change Levy. The various reference scenarios differ principally in the fossil fuel price assumptions which underpin the projections. Consider then, industrial emissions between two sets of scenarios, one with high fossil fuel prices and the other with low fossil fuel prices. In the scenario where prices are high, industrial energy demand will be lower than in the scenario where prices are low, the extent of the fall in energy demand will be determined by the price elasticity of demand. As currently modelled by the CCC, the percentage change in energy demand between the two scenarios will be the same for Scotland as for the UK as a whole. The response to the change in price is therefore implicitly assumed to be the same in each DA as it is for the UK as a whole. In each scenario the impact of the CCL is also considered. The CCL effectively increases the price of carbon-based energy to industry. Estimating the impact of the CCL in each DA individually, as a response to price, suggests that industry might also respond differently to wholesale fossil fuel prices and as such would be inconsistent with the general approach taken for projecting Scottish emissions.

Finally, the approach implemented by the CCC has the advantage of simplicity. This is not a trivial point. The task of analysing the impact of the CCP policies at a UK level required a great deal of data and resource. To understand the impact of each policy at the DA level and to maintain consistency with the UK impact would be a large undertaking.

However, there are disadvantages to the approach discussed above. These are best discussed in turn for each of the main energy users.

The domestic sector

There are many reasons to suggest that the impacts of carbon mitigation policies in the domestic sector will have different impacts in Scotland to the UK total. Evidence suggests that the impact of EEC Phase 2 (the predecessor to CERT) has had a different impact compared to the UK average, with only 14% of households not installing any efficiency measures compared to 18% for the UK average[36]. This could be due to a number of factors, detailed below.

Housing stock

Both the types of housing and the condition of the housing stock differ in Scotland compared to the UK average. For example, a much larger proportion of homes in

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[36] Evaluation of the second phase of the Energy Efficiency Commitment (2005 – 2008), Eoin Lees Energy, 2008, http://www.defra.gov.uk/environment/climatechange/uk/household/supplier/pdf/eec-evaluation-0508.pdf [last accessed 06/07/09].

Scotland are flats (some 36% of the estimated 2.31m households in the 2007 Scottish Housing Condition Survey compared to 17% in England[37]). This has meant that there have been far fewer instances of cavity wall insulation and loft insulation. Data collected on the first phase (2002-05) of CERT (when it was known as the Energy Efficiency Commitment) suggest that Scotland's proportion of CERT benefits was lower than would be expected, based on population (around 22% lower[38]). Some preliminary evidence on the second phase (2005-08) in Scotland suggests that the benefits may have been even smaller.

Income levels

Income levels and income distributions also vary substantially between Scotland and the UK average. This will affect the impact of policy in three ways. Firstly, it will mean that the number of households which qualify for assistance will differ. If, for example, there are relatively more households that qualify for priority assistance (including those on low incomes), CERT can be expected to have a relatively higher impact because a certain proportion of measures must be targeted at the Priority Group. Secondly, different income levels are associated with different levels of energy expenditure. This relationship is likely to be positive but not necessarily linear because there will be limits to how much heating (or energy for cooking) a house needs. Although this is unlikely to be much of an issue in Scotland, (annual) energy demand may also increase if houses are fitted with air conditioning to cope with higher temperatures. Third, the rebound effect often differs over different income groups, as lower-income groups tend to use improved energy efficiency to deliver higher levels of comfort; higher-income groups have usually already attained a satisfactory level of comfort. This rebound effect can arise because lower-income groups that face lower energy costs as a result of greater energy efficiency may opt to spend the money saved on more energy ie more heating.

Qualifying households (eg CERT, etc)

Data used in the DEMScot model suggest that the proportion of CERT-qualifying residents and pensioners is much higher in Scotland than the UK average. This suggests that there is greater scope for energy-efficiency improvements in Scotland although the data currently available on CERT spending indicate that activity has actually been lower in Scotland. There are a number of possible reasons for this, mainly relating to the structure of the incentives leading to energy-supply companies targeting, for example, core domestic markets in England and Wales and initiatives where the cost of achieving a given energy saving is lower. Improving efficiency in Scotland's (relatively more prevalent) rural and island communities is likely to be costlier.

There are much data which could be used to improve the understanding of policy impacts on the domestic sector in Scotland. In the first instance there is the Scottish Housing Conditions Survey. Both seasonal and annual temperature data are also available for Scotland. There is also information on the take-up of energy efficiency measures by region in the Heating Energy Efficiency Database (HEED) but to date this has only been updated to include data from EEC Phase 1 (2002-5). How to incorporate these data into the projections method will be explored in more detail in Phase 2 of the project.

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[37] Last updated February 2009: http://www.communities.gov.uk/housing/housingresearch/housingstatistics/housingstatisticsby/stockincludingvacants/livetables/

[38] http://www.scotland.gov.uk/Publications/2009/06/12132543/0

Road transport Carbon-mitigation policies aimed at reducing emissions from road transport are also likely to differ in Scotland compared to the UK. However, a decision on the best way to represent policy impacts on the road transport sector and/or the transport sector more generally depends on the method used to project emissions; for example, it might be possible to fully model the effects of some transport policies in the NTM and therefore make use of the consistent UK and Scotland projections, which will also implicitly include Scotland-specific factors.

Industry and commerce The policies which affect industry and commerce tend to be price-based and so it seems consistent to accept the impact on the UK levels and then to share out the projections, as is done currently. However, there may be instances of policy, for example, 'Action by devolved authorities', where the policy impacts should be more accurately reflected in Scotland's emissions projections. In particular, assessments could be made of the impact of Climate Change Agreements on non-traded sector emissions in Scotland, as the estimates tend to be aggregates of site-specific agreements.

B.2.5 Recommendations

We recommend the continued use of the CCC's existing method

We believe that disaggregation of energy demand and emissions projections from the DECC model should remain the preferred method for generating projections for Scotland. This reflects the paucity of good quality data below the UK level and the substantially higher cost of employing econometric methods when compared to the CCC's existing approach.

The method could better incorporate Scotland-specific factors and more disaggregated data

We suggest that the use of SCPnet data, that are more disaggregated, would allow for differences in the fuel mixes of industrial and commercial users and, while a complete time series is not available, the use of historical data in the existing method to calibrate the projections to the last year of available data makes SCPnet data more suitable than the DECC regional energy consumption statistics currently used.

Beyond adjusting the fuel mix in the historical period to reflect differences in industrial structure and infrastructure, the existing technique makes no attempt to project changes that might occur in a region's fuel mix over time. We recommend that work be undertaken to investigate the historical trends in variables not limited to the energy efficiency of the housing stock and the rate of take-up of mains gas in order to determine how these might change over the forecast period. Use of more Scotland-specific data is also likely to improve the accuracy of the projections.

The impacts of policy on the Domestic sector are likely to vary considerably between Scotland and the UK

The most obvious area for proposing that a distinctive treatment be applied for Scotland in the impact of policy is the Domestic sector, where there are strong grounds for expecting a different impact from the average impact for the UK and there are sufficient data to carry out such an assessment. We also recommend that projections are sense-checked against a detailed bottom-up model of the housing stock, namely, DEMScot. For the transport sector, many of the key policies should be evaluated at the national level, by making use of the NTM and then split to the Devolved Authorities; as discussed in Chapter B.4, the NTM is able to give regional outputs. While the industrial and commercial structure of Scotland's economy differs from that of the UK, and although there are reasonable grounds for arguing that industry will react differently in Scotland to carbon-mitigation policies, there is little policy-specific data against which to verify this. However, there are a few substantial policies, such as the CCAs where this could be considered.

B.2.6 Suggested method for model development: Industry and Commerce

In 2007, industrial and commercial emissions accounted for some 14% of total CO_2 emissions in Scotland. For the purposes of this document 'Industry and Commerce' includes all manufacturing, construction and services sectors, with the exception of transport services, power generation, refineries and offshore oil and gas.

Carbon emissions from Industry and Commerce are largely the by-product of demand for energy[39], specifically fossil-fuel energy. Projecting carbon emissions from Scotland's Industry and Commerce sector therefore requires a through understanding of the determinants of energy demand.

Key factors to consider in projecting energy demand from Industry and Commerce are:

- industrial growth projections
- fuel-price projections
- the sector's fuel mix
- trends in energy efficiency
- the projected composition of industry and commerce, ie the size of the sub-sectors which make up Industry and Commerce
- projected intra-industry structure, ie the composition of firms within each sub-sector

The purpose of the modelling tool is to project CO_2 emissions from the non-traded sector in Scotland, ie those emissions not covered by the EU ETS. As such, it is also important to consider the extent to which the composite sector is covered by the EU ETS and how this might change in the future.

In Scotland we estimate that, using the same basis for comparison as the CCC, 37.6% of CO_2 emissions from the Energy Industry are estimated to be traded and 42.3% of Other Industry emissions. This compares with 70% for the UK[40] based on figures for 2005.

Essentially, we propose to follow the same method currently employed by the CCC, namely:

1 Output projections by region and sector are used to share out the UK-level sectoral energy demands to form a first estimate of regional energy demand disaggregated by sector and fuel type (at this point the fuel mixes are identical across regions).

2 Each nation's implied energy demand from Step 1, by fuel, is compared in the last year that regional energy consumption statistics are available to produce a set of adjustment factors (ie residuals). When these residual adjustments are applied to the first estimate calculated above, in the last year in which data are available, energy demand will necessarily match the outturn figures. The residual adjustment factors are applied over the projection period and held constant throughout. At the regional level, by fuel user, there is only one series per fuel for industrial and commercial users combined, so the sum of the estimates from Step 1 are used to calculate a common set of adjustments.

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[39] We discuss process emissions later.

[40] This figure has been calculated based on the CCC methodology but offshore emissions have been excluded, leading to a smaller proportion of coverage calculated for the UK.

3 Standard emissions factors (as reported in DUKES, among others) are applied to the energy demand projections from Step 2 to produce a first estimate of CO_2 emissions by region and sector.

4 A further scaling adjustment is applied to the emissions projections such that, when summed across fuel types, the emissions by sector in the last year of available outturn data match official sources. This is a similar procedure to that in Step 2 and the resulting adjustment is then applied to all years over the projection period.

However, rather than combine and sum energy demand to the Industry and Commerce totals in Step 2, we propose to scale each sector to the Commerce and Industry energy totals, by fuel, and preserve the industry breakdown. While we recognise that these are broad-brush estimates and will not necessarily accurately reflect the fuel share for each sub-sector, it is useful to have this disaggregation to apply the estimated coverage of the EU ETS. The largest drawback here is that the implied fuel mix for each industry is almost entirely arbitrary, reflecting only the fuel mix for that industry at the UK level and the total fuel mix for Scotland's Industry and Commercial sector as included in DECCs regional energy data.

Clearly, it would be advantageous at this stage, instead of the suggested approach, to make use of the SCPnet data as an additional calibration for each sub-sector's fuel mix, rather than use crude estimates. We therefore propose to calibrate the fuel mix for each industry, ahead of scaling to the DECC Industry and Commerce aggregates. This would allow for a more informed view of the fuel mix and fuel demand of each individual sector in Scotland its relative position compared to the UK, rather than simply infer that they are identical.

On a positive note, the SCPnet data (the dataset includes consistent energy data and emissions data) have been compared to the NAEI emissions data for Scotland and are, encouragingly, quite similar. However, as the SCPnet data are not a set of official national statistics, we will build in the option to remove the intermediate calibration to the SCPnet data. This will have implications for the fuel demand in each industry and the fuel mix for each industry, but not the overall fuel demand and aggregate fuel mix.

By preserving this level of disaggregation we can better account for the response to price of each industry and the coverage of the EU ETS.

We also propose to add a price response based on the DECC parameters. Currently, the CCC estimates the price response for industrial emissions in Scotland by running the DECC model for the UK with differing fossil fuel price inputs and deriving Scotland's share of the consequent emissions. We propose to make use of DECCs activity and price elasticities so that changes to income and fossil fuel prices can be assessed directly in the Scotland modelling tool, without the need to run the DECC model under different fossil fuel price and activity growth scenarios. To achieve this objective, it will require that we model a simple relationship between fossil fuel prices and the electricity price. Alternatively the CCC could provide the electricity price from the DECC model runs with different fossil fuel.

To summarise, we will estimate the central run in the same way the CCC have done before by calculating emissions from regional energy demand based on industry growth in Scotland relative to the UK (as described above in Steps 1-4), but we will preserve the sector disaggregation and apply the EU ETS coverage at this disaggregated level. This will happen between Steps 2 and 3 in the previous method.

The other reference scenarios will be produced as deviations from the central run (the baseline) using the elasticities of demand in the DECC model, such that for each industry and each fuel:

$$ie_t^v - ie_t^b = \beta_1(y_t^v - y_t^b) + \beta_2(p_t^v - p_t^b)$$

where:

- β_1 is the activity elasticity of demand
- β_2 is the price elasticity of demand
- ie is industry energy demand
- y is industry value added
- p is the price of fuel
- b denotes a baseline value (central run)
- v represents an industry output and price variant
- t is time

B.2.7 Suggested method for model development: Domestic

In Scotland domestic emissions accounted for 15% (6.9 $MtCO_2$) in 2007. In the domestic sector, the combustion of fossil fuels, mainly natural gas, for heat is the main source of carbon emissions. The main drivers are therefore the number of houses requiring heating, the price of fossil fuels, the heating technology employed (e.g. gas central heating) and the thermal (insulation) characteristics of the house. However, it might be more relevant to consider household income or expenditure, rather than simply the number of households as this measure captures the increase in comfort levels that households might choose if their incomes were to increase. The DECC approach is to use both the number of households and household income, in turn, the CCC has, in its previous method, used the number of households to share out Scotland's domestic carbon emissions from the UK total. As mentioned previously, the implicit assumption is made that Scottish household-income growth follows the UK average. Possibly different trends in income at the regional /national level are not accounted for and may be unsatisfactory in light of the discussion of regional income differences and the likely effects on energy demand discussed in B.2.4.

The method does not currently look at the trends in fuel switching and the differences in fuel switching between Scotland and the UK. Moreover, nothing is currently done to allow for differences in the thermal characteristics of the housing stock between Scotland and the UK.

We do not propose to drastically change the existing method. We propose to try to allow for changes in the fuel mix, by examining recent trends and making judgments regarding the plausible limitations to fuel switching, if possible. We propose to do this by looking at the energy supply characteristics of the households, to determine, for example the maximum limit for switching towards natural gas grid connection. We also propose to introduce an off-model adjustment to allow for differences in the current housing stock between Scotland and the UK and to allow for differences in the policy effectiveness of CERT, based on past data and the number of qualifying homes. To do this we will first need to understand the method employed by DECC for estimating the impact of the CERT policy. We will then derive an estimate for Scotland based on the differences in the housing stock and the limits this puts on the effectiveness of each measure. We will also look at the number of households in

Scotland qualifying for CERT assistance compared to that of the UK. We may further investigate this using the DEMScot model as a first estimate.

It is not easy to reconcile a projections model, such as the DECC model, with a simulation model, such as DEMScot, as their objectives are intended to be quite different. In a projections model, domestic energy demand projections respond to changes in household growth, incomes and the price of energy, typically based on historical estimates of these relationships. The projections are implicitly taking into account behaviour changes based on those which have occurred in the past, either in the form of installing measures to affect energy demand, such as cavity wall insulation, or through a change in comfort levels, such as turning the thermostat down. It is not easy to distinguish in practice between these two effects. A simulation model, such as DEMScot, on the other hand, captures the effect of the uptake of measures on energy demand and carbon emissions but does not seek to explain why such measures might be taken up, eg policy, price, or income changes.

Rather than ignore the available information on the housing stock, we propose instead to run the DEMScot simulation model to test the robustness of the top-down projections for each scenario. This will provide a solid robustness test on the scale of the change in energy demand between the last year of history and 2030.

Currently, the CCC estimates the price response for domestic emissions in Scotland by running the DECC model for the UK with differing fossil fuel price inputs and deriving Scotland’s share of emissions. We propose to make use of DECC’s household growth and price elasticities so that changes to fossil fuel prices can be assessed in the Scotland modelling tool, without the need to run the DECC model under different fossil fuel price and household growth projections. This will require that we model a simple relationship between fossil fuel price inputs and the electricity price. This will require an electricity price from the previous DECC model runs which is consistent with each set of fossil fuel price projections.

To summarise, we will estimate the central run in the same way the CCC have done before by sharing emissions based on household growth in Scotland relative to the UK. We will provide an option to share the policy impact of CERT at a UK level to Scotland (following the previous CCC method) or to use an estimate derived as part of these projections, as discussed.

Projections for the other income, price and household growth scenarios will then be derived using the elasticities of demand in the DECC model, such that for each fuel:

$$de_t^v - de_t^b = \beta_1(h_t^v - h_t^b) + \beta_2(p_t^v - p_t^b) + \beta_3(i_t^v - i_t^b)$$

where:

- β_1 is the response to the number of households
- β_2 is the price elasticity of demand
- β_3 is the income elasticity of demand
- de is domestic energy demand (differentiated by fuel)
- h is the number of households
- p is the price of fuel
- i is income
- b denotes a baseline value (central run)
- v represents a household number, income and/or price variant
- t is time

It is important to note that, because we propose to use the elasticities used in the DECC model, counterintuitive negative income elasticities of demand for energy will be incorporated. These values presumably capture efficiency gains that are not explicitly represented in the DECC-model equation specifications. The result is that feeding in income assumptions with higher growth than the baseline set, all other things being equal, will lead to higher projected energy demand and emissions when compared to the baseline.

B.3: Traded vs non-traded sectors

As discussed earlier in this report, the non-traded sector is of interest because, on a net carbon account basis, these are the sectors for which emissions must be reduced at the point of source to meet emissions-reduction targets; they cannot be traded away. At a sufficient level of sectoral disaggregation, the consideration of EU ETS coverage would be restricted to the binary distinction between participating and non-participating sectors. However, the level of sectoral disaggregation in the data may not be sufficient to make this distinction and it then becomes necessary to establish the proportion of emissions from a sector that arise from 'traded' installations (EU ETS participants) and 'non-traded' installations.

The CO_2 projections for the devolved authorities presented in Chapter 14 of the CCC's inaugural report[41] are for the non-traded sector. The CCC has calculated that, after accounting for CCA opt-outs, the coverage of industry in the traded sector in the UK is 76% for Phase 2 and onwards.

The Scottish projections do not make use of information about the coverage of the traded sector at a more disaggregated industry level. For example, there are no iron and steel plants covered by the EU ETS in Scotland, while a considerable proportion of Scotland's chemicals emissions are covered. While detailed industry GVA projections are used to split the emissions arising from industry in Scotland into traded and non-traded, the method may prove quite inaccurate if either fast or slow-growing industries are in fact covered by the EU ETS.

B.3.1 Broad coverage

To assess the coverage of the traded sector in Scotland, we first calculated the implied proportion of emissions covered using EU ETS installations data from DECC and regional emissions data from the NAEI. A number of discrepancies became apparent in this analysis with some estimates of coverage exceeding 100% and others that would be expected to be fully covered (eg Power Generation) not fully covered. In the case of offshore emissions, it is possible that the categorisation of these emissions to another 'region' distinct from England, Scotland, Wales and Northern Ireland may be a factor, leading to overlap and, in turn, double counting.

In the event, the largest problems appeared to be related to the sectors that we would have expected to be fully traded and these are excluded from current analysis (we are interested in the non-traded sector only). We have calculated estimated levels of coverage for three broad sectors in 2005 (a further two have been considered but coverage for these in Scotland was, and still is, zero). These are shown in Table B.3.1. The calculations take into account opt-outs from UK ETS participants and CCAs and indicate that the estimated levels of coverage are markedly lower than the UK estimate originally made by the CCC. The coverage for Other Industry, for example, is estimated to be 42.3%. The total coverage for industry in Scotland is estimated to be 35.6%, much lower than the 76% estimated by the CCC and the value of 70%, once offshore emissions are excluded.

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[41] http://www.theccc.org.uk/reports/building-a-low-carbon-economy

TABLE B.3.1: ESTIMATED TRADED SECTOR COVERAGE, 2005

Sector	2005 CO_2 emissions ($ktCO_2$)					
	EU ETS	Opt-outs	CCAs	Total Traded	Total Scotland Emissions	Coverage (%)
Energy Industry	752.3	-	-	752.3	2002.4	37.6
Iron & Steel	-	-	-	-	-	-
Other Industry	1,213.0	-	1,347.5	2,560.6	6059.3	42.3
Services	215.0	16.4	-	231.3	1905.9	12.1
Agriculture	-	-	-	-	-	-
TOTAL	2,180.3	16.4	1,347.5	3544.2	9,967.6	35.6

Note(s) : ‘Energy Industry’ covers the production of manufactured fuels.
‘Other Industry’ covers manufacturing activities not classed to Iron & Steel.
In the absence of 2005 data on Opt-outs and CCAs, ‘relevant emissions’ have been used instead.

Source(s) : DECC, NAEI and CE.

In the absence of 2005 outturn data on Opt-outs and CCAs, figures for ‘relevant emissions’ have been used instead. The estimates would be improved with the release of actual data for 2008, which would capture the expansion of the ETS to include installations which previously were allowed to opt out of the scheme.

The discrepancies in the fully-traded sectors are important because they suggest that users of the data cannot have confidence in the data for all sectors. This issue would be resolved by using the verified EU ETS emissions as the starting point for the NAEI dataset[42].

B.3.2 Detailed sector coverage

An insufficient level of disaggregation makes more detailed industry-coverage estimates difficult and inconsistencies between the NAEI and SCPnet data make using the latter dataset difficult to employ explicitly in the calculations, even though they could potentially inform a much more detailed estimate of coverage because sectors such as Paper and Pulp, Wood and Wood Products, and Chemicals are distinguished separately.

The SCPnet data would also be useful in considering the weighting of the chosen activity indicator, industry GVA, used to project Scottish CO_2 emissions for the non-traded sector.

A lack of consistency makes it problematic to incorporate the SCPnet data.

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[42] Although our figure for Other Industry does compare favourably to the most recent analysis by AEA for 2007 that indicates that some 37% of emissions from the sectors that correspond to Other Industry are traded.

B.3.3 Recommendations

The data suggest that emissions covered by the EU ETS in the UK compared to Scotland vary in scope and probably structure. Overall, a smaller proportion of industry emissions are covered for Scotland than for the UK, suggesting that non-traded sector emissions for Scotland would be underestimated were the same proportion to be assumed. Secondly, as the detailed coverage may well differ between Scotland and the UK, the implicit weighting of industry GVA to apportion projections might well introduce a bias. Our recommendation is to include more detailed estimates of EU ETS coverage in the projections and to account for differences, in terms of both overall coverage and detailed sector coverage, between Scotland and the rest of the UK. The proportions of coverage estimated would then be held constant over the projection, implying that the composition of a sector in terms of traded and non-traded emissions will not change over time.

The use of a constant share may not be a valid assumption not only because the EU ETS may lead to behavioural changes (ie industrial output becomes less energy-intensive over time as activity shifts to firms outside the EU ETS) but also because the scheme may evolve in the future as policies change. As the scheme has not been running for a long enough time to extrapolate any changes in the sectoral split, the uncertainty regarding future developments and trends is therefore difficult to predict. At the time of writing, a constant share is probably the safest assumption that can be made.

B.4: Assessment of road transport emissions

In 2007, road transport accounted for the second-largest share of Scotland's CO_2 emissions at 22% (10.1 $MtCO_2$) and the largest share of non-traded sector emissions. Ideally, any projections model for the transport sector should be able to account for complex supply-side measures such as vehicle stock parameters, network availability, network speed, network safety, land use, alternative modes of transport available; and the demand-side factors, trip purpose, income, fossil fuel prices etc.

This chapter discusses the transport model currently employed by the CCC for projecting road transport emissions in the UK and Scotland, namely, the DfT's National Transport Model (NTM). In Scotland, a second model has been developed to project transport flows for the region, the Transport Model for Scotland (TMfS). We contrast this modelling approach with the NTM to discuss whether a hybrid approach would be more suitable for projecting emissions from road transport in Scotland or whether one model is preferable to the other.

B.4.1 Assessment of the DfT model (National Transport Model)

The National Transport Model is a multi-modal model for Great Britain

The Department for Transport's National Transport Model (NTM) generates projections for, among other outputs, passenger kilometres travelled, modes of transport, journey times and emissions from transport, covering all of Great Britain (Northern Ireland is excluded). The model covers six modes of transport, in varying degrees of detail: car driver, car passenger, train, bus, walk and cycle.

It includes a number of sub-models that feed into, and out of, the main 'Demand Model'. This model takes information on the number of 'person-trips' and the costs of each mode of transport, and from this forecasts the number of person-trips by distance, purpose and mode. The number of person-trips is generated by the car ownership and trip end models, to which the main inputs are regional demography, land use and income. Information on the costs of each mode of transport are a mixture of direct data inputs and inputs from other sub-models, including the Vehicle Market Model (VMM), which forecasts the composition and characteristics of the car stock, and a rail sub-model.

Forecasts from the Demand Model are output to the Distribution and Highway Assignment models, which assigns all car journeys with a geographic start and end, and estimates their distribution across road types. This information is then passed to the FORGE model, which models congestion and journey times, and also projects emissions from car use. Output from FORGE can then be passed back to the demand model, so that the model eventually settles on an iterative solution. However, the Distribution and Highway Assignment models are only solved once, due to computational difficulty and time.

The NTM uses a wide range of official data sources, but the sources lack detail in many cases

The parameters in the NTM are calibrated to a wide range of data in a historical base year. There is little time series data in the model. The NTM's various sub-models mostly use official data sources, as well as some more specialist sources, including:

- the National Travel Survey
- the 2001 Census
- Family Expenditure Survey income and car ownership data

- core and manual count data from the Traffic Census
- the Department for Transport's Road Traffic Speed Surveys
- rail passenger origin/destination data from ticket sales
- rail service level data from timetables
- Continuing Survey of Road Goods Transport
- projections of population, households and jobs
- cost data from various sources

The Car Ownership and Trip-End models are calibrated to data on population by age band, employment by sector, households by size band, income and various data on car ownership rates and costs. This covers most of the obvious drivers of drivers of demand for trips for which reasonable data are available: the main exception is that income growth is measured as growth in GDP per household at the UK level, with no disaggregation by region or type of household. The model also does not incorporate data on the relative location of households and employment areas. The data sources are much more centralised than some of those used in the TMfS, which has a database of planning information from regional authorities.

The Demand model and the road use and congestion models are calibrated to a variety of data on transport costs and use, but the data are often simplified considerably for understandable reasons of modelling complexity. For example, bus fares for short trips have been represented as 50p plus 12.5p per mile. While the data cover most areas, they are somewhat less varied and detailed than in the TMfS, which in particular calibrates results to journey times recorded by roadside surveys, and has a detailed map of the road network built into the model (the NTM has data on regional road types, but not for specific roads).

The NTM has many assumptions that can be varied to simulate policy, but the scope is limited at the local level

The NTM has a range of assumptions and variables that can be altered to represent the impact of policy. The future values of the dataset discussed above are incorporated in the model by assumption, and can be adjusted to replicate policy impacts. The main drivers of trip and car demand in this model (land use, population and income) are all included by assumption, and are therefore easily manipulated by the user. Fuel costs, public transport fares and transport infrastructure can also be adjusted. However, it does not appear that the costs of different types of fuel are differentiated, which would make it difficult to model, say, the effect of tax breaks for clean fuels.

The NTM is not as well equipped as the TMfS to vary specific assumptions at a local level. The approach to local policies in the NTM is to build a database on the generalised impact on costs of general local spending on transport policies. Schemes such as park and ride or high occupancy lanes are not modelled.

The NTM assumes that parameters do not change over time

Many of the parameters in the NTM, such as the elasticity of traffic to fuel prices, are estimated econometrically, and other parameters are calibrated to match these and the data in the base year, mostly notably the value placed on time. In most cases, the model’s forecasts rely on the assumption that the parameters will not change in the future. This is a reasonable assumption in many cases, but it may be questionable in less detailed parts of the model. For example, the trip end model assumes that the number of trips per person is constant for each category of person (defined by age, employment and car ownership, among others), regardless of changes in income or travel cost. The NTM would therefore not be able to model the impact of many policies on trip rates.

The NTM generates a range of outputs that would be appropriate for this project

The outputs from the NTM most relevant to the CCC's projections come from FORGE, the sub-model that fits projected traffic and road demand to the road network. Outputs include road traffic (bn kilometres), congestion and emissions from road traffic (CO_2, NO_X and particulates). Other parts of the NTM give less detailed outputs on demand for other modes of transport. The emissions output has substantial detail for emissions, being based on traffic levels, traffic speed and the fuel consumption of the car stock. The traffic output is disaggregated in terms of vehicle types, and was used in the First Report of the CCC[43], where it was combined with the CCC's own Marginal Abatement Cost (MAC) curves for the car stock to produce a different forecast of emissions. The CCC's MAC curves are more detailed in terms of carbon abatement technologies than the VMM sub-model, but using the NTM's own emissions projections has some advantages: the VMM models behaviour and take-up of fuel efficient technologies and the final emissions output takes into account vehicle speeds.

The main weakness of the outputs from the NTM is that they cannot be much disaggregated in terms of regions and sub-regions. FORGE generates outputs for the 11 regions and nations of Great Britain, one of which is Scotland, but there no detail at a lower geographical level. A more detailed sub-regional breakdown, as is available from the TMfS, would enrich and help justify the overall results for Scotland.

However, the Great Britain focus of the NTM has the advantage that it is well equipped to forecast the impact of transport demand and infrastructure from and in England and Wales. This may well be an important driver of road traffic in Scotland, though we are not able to assess how important within this study.

B.4.2 Assessment of the Transport Model for Scotland

The Transport Model for Scotland covers Scotland only, but at a high level of sub-regional detail

The Transport Model for Scotland has a broadly similar structure to the NTM, but there are several differences in scope and detail. The TMfS only covers Scotland, except for a 'skeletal' representation of England and Wales, but does so at considerably more sub-regional depth than the NTM. It also covers more modes of transport, including domestic ferry services and the Glasgow subway, as well as the transport modes covered in the NTM.

Like the NTM, the centrepiece of the TMfS is a demand model that has a trip end model feeding into it. However, rather than setting housing, population and employment by assumption in the trip end model, there is a separate model that solves and forecasts these variables endogenously: the Transport, Economic and Land-Use Model of Scotland (TELMoS). This model produces detailed projections on how employment and households will be spread throughout Scotland and within Scottish cities, given overall growth assumptions and feedback from the main TMfS on transport links. The trip end model uses this to generate a series of possible trip origins and destinations, by trip purpose, time of day and possible modes of travel.

The demand model uses this information to generate a forecast of trips by origin and destination, private or public transport and frequency at each time of the day, with generalised cost feedback at each stage. Then, in the supply area of the model, the demand for car transport is assigned to the road network and the demand for public transport is split between different modes of public transport. The model is run

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[43] http://www.theccc.org.uk/reports/

iteratively until both supply and demand are equal. There is also a park & ride sub-model, which is effectively an extra mode of transport, and a high-occupancy vehicle sub-model, which calculates the proportion of road traffic carrying a single passenger.

In addition to official data sources, the TMfS uses its own highly detailed transport surveys

The various components of the TMfS are set by and calibrated to data in a base year. The data come from a mixture of official sources and also surveys made specifically for the TMfS, including:

- 2001 Census
- Scottish Household Survey
- Local authority planning data
- Road network information and public transport timetables and fares
- Roadside interviews and public transport interviews
- Traffic count and travel time data

TELMoS is more data-intensive than the equivalent parts of the NTM, as it solves for future land-use endogenously. The main data are similar to those in the NTM: employment, population households and car ownership from the 2001 Census. However, these are supplemented with further data sources, including planning information from local authorities that is used to help project future changes in land-use. TELMoS therefore makes greater use of available data than the NTM, including disaggregating households by income and plotting the relative location of employment and households. Various parameters in TELMoS are also estimated econometrically over a time series.

In the demand model, the TMfS makes comparatively little use of the (UK) National Transport Survey, and instead uses its own roadside interviews and public transport interviews to define parameters in the model. These collect very detailed data on road and public transport use, by journey origins and destinations and travel purpose. The results are corroborated with traffic counts and travel time surveys. Therefore, while the TMfS does not always use centralised official data sources, its sources are very detailed and tailored to its needs (and are specific to Scotland). The TMfS also includes much more data on the road network than the NTM: the model itself incorporates a full map of the network. Data on emissions from fuel consumption come from sources from the UK Department for Transport; these appear to be less detailed than those used in the NTM.

The TMfS can simulate local policies in great detail, but may be inappropriate for modelling policies aimed at the vehicle stock

As more of the TMfS's variables are solved endogenously than the NTM's, there is occasionally less scope for policymakers to manipulate assumptions. The main assumptions that feed into the trip-end forecasting process are for overall economic and population growth. Projections on land-use are partly set by data from local authorities, and there may be some scope for the policymaker to manipulate these data.

In contrast, the composition of the vehicle stock in TMfS appears to be set by assumption, rather than being solved endogenously as in the NTM. This may be useful for scenario analysis on the vehicle stock, but limits the ability to model the effectiveness of policies aimed at improving fuel consumption. The composition and fuel consumption of the vehicle stock in the TMfS is based on modelling guidance from the UK Department for Transport[44].

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[44] http://www.webtag.org.uk/webdocuments/3_Expert/5_Economy_Objective/3.5.6.htm

There is extensive scope for policymakers to adjust assumptions in the demand model. The fuel and/or ticket costs of transport modes can be adjusted (and as more modes are covered in the TMfS, there is more scope to do this than in the NTM). In addition, TMfS is well suited to modelling the impacts of specific policies on road or public transport at a local level, since it has a detailed map and database of Scottish transport infrastructure. However, as with the NTM, it appears that there is little or no scope of vary the relative prices of different types of road fuels.

Parameters are derived in a similar way to those in the NTM

The overall modelling approach in the TMfS is very similar to that in the NTM: both estimate several of their parameters, with the remainder calibrated to match the data in a base year. The parameters do not model household preferences in any great detail, and are therefore very reliant on the assumption that parameters do not vary over time or in response to policy. However, this assumption seems slightly more valid in the case of TMfS than that of NTM, given the greater level of detail and coverage of parameters in the model.

The TMfS generates detailed outputs at the Scottish and sub-regional level

The outputs generated by the TMfS include road traffic, public transport use, congestion and emissions; this scope is similar to that of NTM, except for the obvious point that TMfS results only cover Scotland. The main difference is the level of sub-regional detail available: TMfS can provide detailed traffic and emissions results at the local authority level, or for maps of the Scottish transport network. This provides substantial evidence and justification for the aggregate result, as well as being of interest in itself. A further advantage of TMfS is that it produces detailed outputs for more transport modes than the NTM. The model also forecasts demography and land use through the TELMoS model.

B.4.3 Recommendations

There are advantages to both the National Transport Model and the Transport Model for Scotland. Both produce the basic outputs that would be needed for the CCC's projections: namely Scottish road traffic and emissions from Scottish road traffic. There are far more outputs available from the TMfS, including sub-regional forecasts and detailed results for more modes of transport. These are a useful supplement to the aggregate results, but are not necessarily required for producing the CCC's projections; the level of detail is likely more than sufficient.

The TMfS is generally more comprehensive in its treatment of Scottish transport

The more detailed outputs from the TMfS are, of course, a consequence of the model itself being more detailed, in terms of its coverage and data. In addition, more of the inputs to the TMfS are solved endogenously. The greater detail and scope (within Scotland) of the TMfS may lend more creditability to its forecasts.

However, there are potential disadvantages to greater detail. The simpler data inputs of the NTM may improve transparency. For the CCC's projections, it may be preferable that regional demography and land use are set by assumption rather than solved endogenously, since outputs for land use are not required. Once again, setting these variables by assumption may improve the transparency of the main result.

However, the NTM covers all of Great Britain, and has a more detailed treatment of the vehicle stock

The NTM also has some modelling advantages of its own. The most important is that it models the Great Britain as a whole, and we might expect that economic activity, policy and transport infrastructure in the rest of UK will have an important impact on Scottish road transport, whereas the TMfS only has a 'skeletal' representation of England and Wales. In addition, the NTM produces consistent results for all Great Britain regions, so that the Scotland results can be compared to those for other British regions. The endogenous land-use model and specialist data sources in the TMfS would make its results difficult to compare with those from models covering other UK regions.

In addition, the NTM has a sub-model (the VMM) that endogenously solves for the composition of the vehicle stock, based on consumer take-up. This appears not to be modelled in the TMfS, but set by assumption (in little detail). Therefore, when modelling policies that are intended to improve the fuel efficiency and emissions of the vehicle stock, the NTM is more appropriate.

An endogenous representation of the vehicle is desirable because vehicles are durable goods and are thus akin to an investment in that they yield benefits over a number of periods (in contrast to standard economic goods which are consumed close to the time of purchase). The time element becomes important and, in turn, turnover of the stock matters. In terms of forecasting, these elements are likely to offer a more consistent and plausible projection, particularly once alternative policies are introduced.

We recommend that the CCC use the NTM to project Scottish road-transport emissions

While the TMfS offers more detail than the NTM with regard to Scotland, the NTM is in our judgment, sufficiently detailed for the CCC's purposes and, as important, incorporates a more integrated treatment of Great Britain's transport network. There is also more scope to assess the impacts of policies that target fuel efficiency and emissions. Moreover, for TMfS, with greater detail comes greater complexity. In some cases this complexity is in areas of relatively little direct interest as far as the CCC is concerned (eg land use[45]) and may be difficult to justify when set against the transparency criterion.

B.4.4 Suggested method for model development: Road Transport

The previous section compared two bespoke transport models which capture all these variables. The recommendation was that the CCC should make use of the NTM. Moreover, in the end the Transport Model for Scotland was not commissioned to produce a run which has consistent inputs with the rest of the projections which will be used as part of this modelling development. Should these outputs be made available, further analysis may be required to assess how they may be used and in explaining the reasons for possible differences in the projection.

However, we acknowledge that the NTM is time consuming to run and the CCC has limited scope and resources to call on model runs as required. Therefore, we propose taking a set of NTM results and building a hybrid ready reckoner which would allow the CCC to make estimates of road transport fuel demand in response to changes in income and prices, but assumes that the other, mainly supply side, variables are constant. While this is slightly limiting assumption, in the sense that it only implicitly captures the supply side impact, it is not obvious that the supply side variables will alter over income growth and fossil fuel price which are the two key variants to be modelled in the reference projections. In the central reference case we will take the energy demand projections from the NTM and apply emissions factors, calibrating to

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[45] In the case of land use, we do accept that it is an important supply-side factor and the two models' treatment of these assumptions, and how frequently they are updated, may affect their suitability. Such comparisons are, however, beyond the scope of the current project and further investigation may be necessary in the future to derive a fuller assessment of the models' respective strengths and weaknesses.

Scotland emissions data. We then propose to make use of four additional runs of the NTM:

- high fossil fuel prices, high income
- high fossil fuel prices, low income
- low fossil fuel prices, high income
- low fossil fuel prices, low income

We propose to use these outputs to create a hybrid approach to estimate a ready reckoner such that;

In the NTM: $re_t^b = f_{NTM}(y^b, p^b, s^b)$

where

- f_{NTM} is the functional form of the NTM model
- re is road transport emissions
- y is income
- p is the fuel price
- s represents the supply-side variables
- b denotes a baseline value (central NTM run)
- t is time

The ready reckoner would take the form, where v represents an income and price variant.

$$re_t^v - re_t^b = \alpha + \beta_1 (y_t^v - y_t^{b)}) + \beta_2 (p_t^v - p_t^b) + \varepsilon_t$$

In the event that NTM runs cannot be commissioned, we will use DECC energy model elasticities to estimate the impact of price and income changes on road transport. The DECC model elasticities are spread across Cars (passenger vehicles) and Commercial Vehicles (freight). We will use Scotland drivers and apply the elasticities estimated for the UK as part of the DECC model. This method is not as good as creating a ready-reckoner from the NTM model itself, because it does not cover the impact that income (or GDP growth) might have on the supply side elements of the NTM.

However, applying the DECC estimates would allow us to incorporate an option to make use of the TMfS outputs, if a model run were to be commissioned with the same input assumptions as the rest of the model inputs based on central growth and central fossil fuel price assumptions. The model could then incorporate an option to switch between the NTM central run and the TMfS central run.

B.5: Proposed method for including previously-omitted sectors in the projections

B.5.1 Sector coverage

A number of sectors' CO_2 emissions are not projected by the CCC

There are a number of sectors for which emissions projections are not currently produced by the CCC:

- rail transport
- international and domestic aviation
- international and domestic shipping
- offshore oil and gas
- refineries
- industrial processes

This chapter proposes methods to project emissions from these sectors for Scotland.

Developments in Scotland's future rail infrastructure may need to be considered in the projection methods proposed

In the case of rail transport, an obvious issue over the projection period is how Scotland's rail infrastructure might be expected to evolve, for example, through the work to electrify the main Edinburgh-Glasgow rail line via Falkirk. While the switch is not expected to take place for some time yet, the estimated date of completion (2017) is within the desired projection period and needs to be considered. Oil will be replaced by electricity as the fuel of choice over time, shifting the emissions burden from the non-traded rail sector to the fully-traded power sector.

Around 49% of passenger journeys take place on electrified networks in Scotland and it is expected, under current policies, that this share will rise to 64% by 2020[46]. Indeed, the Scottish government has committed to the 'significant electrification of rail by 2050'[47]. The addition of (electric) trams to Edinburgh, the first of which are expected to begin running in 2011 will also need to be considered in informing the projections.

At the UK level, demand for fuel (oil and electricity) from rail transport is modelled by a set of econometric equations with the length of electrified and non-electrified rail track obtained from DfT projections and fed in as an exogenous assumption. This variable (network availability) is included explicitly as a driver in the rail equations. No efficiency gains are explicitly modelled; they are instead imposed from off-model estimates.

Activity in these sectors may be related

Similarly, the importance of domestic aviation and shipping over time may change, reflecting modal shift in the case of the former and changes in freight behaviour in the case of the latter. Moreover, there may be some link between demand for domestic aviation and rail transport; an improvement in the provision of rail services, for example, may lead to a reduction in domestic aviation.

Sectoral impacts may differ across regions

An example of a sector that might be expected to behave differently across regions is oil and gas. As the UK Continental Shelf (UKCS) becomes increasingly unviable, the decision to close particular installations, such as oil wells will be dictated by economic

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[46] Scottish government (2009), Climate Change Delivery Plan.

[47] News release for Scotland's Climate Change Delivery Plan, June 2009, http://www.scotland.gov.uk/News/Releases/2009/06/17112350

(the profitability of continued operations influenced in part by future level of oil prices) as well as physical constraints (the depletion of reserves). Changes in activity could potentially be very uneven and, as will become clear in Section B.5.2, the possibility of these different regional impacts is not necessarily captured by the methods proposed.

We propose that, like the CCC's current approach for other emissions sources, a disaggregation approach be used to project CO_2 emissions from the sources listed above. The main weaknesses are discussed alongside each proposed method in Section B.5.2 while assessments against the key criteria outlined in Chapter B.2 are provided in Section B.5.3.

B.5.2 Overview of proposed methods

In this section we propose methods to project emissions from each of the sectors not currently covered by the CCC's existing approach. The extent to which they meet the criteria proposed in Chapter B.2 is discussed in Section B.5.3. In many cases, the data constraints are more binding for these sectors and so the methods tend to resemble the CCC's existing method which is designed to accommodate a lack of data at the regional level.

We propose that the CCC use inputs from the NTM to produce CO_2 emissions projections for rail in Scotland

The DECC model has a relatively simple treatment of rail demand for energy (both electricity and oil) that is related to exogenous assumptions provided by the DfT on the length of track for electrified trains and the length of track that supports petroleum-fuelled trains. It would be possible to take the DfT's assumptions on the evolution of Scotland's rail track network, broken down by electrified and oil-supporting track, to estimate the share of electricity and oil demand from rail transport accounted for by Scotland in the UK total. This method would have the advantage of accounting for the likely changes in Scotland's rail infrastructure over time, as mentioned in the previous section.

As with the existing method, the emissions could be scaled in the last year of history to produce a set of adjustment factors that could then be applied over the projection period. The disaggregation treatment proposed would be consistent with the principal driver in the DECC model. As an indicator of the supply of rail services, track length is quite a crude indicator and the assumption that underpins this approach is that Scottish rail activity per km of track length is the same as for the UK as a whole. This seems somewhat unlikely.

The method proposed above is able to take account of factors specific to Scotland but, because of the limitations outlined above (weaknesses that to some extent can be traced back to the specification in the DECC model), we are of the opinion that emissions from this sector would be better projected using a transport model specifically designed to model rail transport. The use of such a model would produce a more complete explanation of energy demand from rail by region. A comparison of two relevant transport models is presented in Chapter B.4.

In the historical period, the split between domestic and international aviation emissions can be calculated from NAEI sources

Data for aviation emissions split by domestic and international flights are available from the NAEI. Using a projection for air transport energy demand from the DECC model, the share of domestic and international CO_2 emissions for all regions can be used to establish the share of kerosene (assuming the same emissions factor for all regions and flight types) in each region, split by domestic and international purposes. These shares are then held constant over the projection period. An obvious weakness with this method is that fact that the split between domestic and international flights is not allowed to change over time[48] nor are the shares of passenger traffic at different airports in the UK[49]. The SCPnet data also distinguish between domestic and international demand for aviation fuel and it may be useful to check how the shares compare, although they are also based on an allocation of the NAEI data.

Shipping emissions would be split in a similar way to air aviation emissions

We propose that Scottish water transport demand for fuel be disaggregated in a similar way to emissions from air transport. As with the disaggregation of the air transport projections, relative changes in regional port activity will not necessarily be reflected. This is a possible weakness of this approach.

Emissions from offshore oil and gas and refineries would be driven by sectoral forecasts at the regional level

As with emissions from aviation and shipping, we propose to use historical NAEI emissions data to establish the emissions accounted for by each region for these two sectors. These will be related to regional, sectoral projections of output and the shares held constant over the forecast period. A clear weakness here is that the regional distribution of these sectors is uneven; for example, oil and gas activity is much greater in Scotland than in the rest of the UK and the method will not necessarily capture the likely path of developments in these sectors (which will also differ across regions) in response to changes in fossil-fuel and other commodity prices (which will alter the attractiveness of activities including exploration) and the decline of the UKCS; the order of decommissioning may not be spread evenly across the UK. The treatment of the traded element of these sectors is discussed in Chapter B.3.

Process emissions will be mapped to their respective sectors in Scotland

With regard to emissions from industrial processes, once again, historical CO_2 emissions data are available by region and sector in the NAEI. Again we propose that shares be calculated and used to disaggregate DUKES energy demand data at the UK level to the regional level (such that the emissions factor for process emissions in equivalent in all regions). By relating energy demand to sectoral output projections, we will be implicitly assuming a relationship between output and energy demand (and in turn process emissions) that does not change over time. The assumptions that underpin this method, like the others in this chapter, preclude efficiency gains.

B.5.3 Suggested method for model development: Industry and Commerce (process)

Process emissions accounted for around 1% of Scotland's CO_2 emissions in 2007 at just 476.9 $ktCO_2$. Process emissions are emissions which arise from industrial activity but are not themselves related to energy use, for example, cement decarbonisation.

Ideally, projections of process emissions would be based on a bottom-up modelling approach which incorporated a comprehensive treatment of each industrial process, potential technological changes to each process and a clear treatment of how the process fits into the supply chain of final products.

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[48] The number of passengers on domestic flights to and from Edinburgh was 5.3m in 2008 compared to 5.6m in 2007.

[49] Edinburgh was the only one of BAA's airports to record a year-on-year increase in passenger growth in May 2009.

This would require a combination of bespoke industry expertise and modelling experience that are outside the time and cost constraints of this project. A simpler, cruder, method is to link an activity indicator to each relevant industrial process, we have suggested industry gross value added as it is consistent with the energy activity indicators but, if available from the DECC model, gross output would be a more suitable driver. Gross output is a suitable driver because unlike GVA it alters with inputs. As an example, a firm could increase its inputs by a greater amount than it is able to increase its outputs, becoming less efficient. GVA would fall, whereas gross output would increase and therefore better reflect the increase in inputs and process. If possible the results of the projections could be further improved by validation from industry experts.

We therefore offer the following dynamic specification

$$\log(pe_t^i) - \log(pe_{t-1}^i) = \alpha(\log(q_t^i) - \log(q_{t-1}^i))$$

where:

- i is industry
- t is time period
- pe is process emissions
- q is output as measured by value added

B.5.4 Suggested method for model development: Aviation

Importantly, all aviation emissions are likely to become part of the traded sector by 2012. For completeness however, we will project aviation emissions to 2030.

To model fully aviation emissions for Scotland it would be necessary to have a global transport model which explained the motivation for air travel by the underlying economic factors, eg business travel might be driven by economic growth in a specific area (eg business services), tourism by income levels etc. However, this would be an enormous undertaking.

To project UK emissions from international and domestic aviation the DECC model links aviation to growth in OECD demand as a proxy indicator for demand for air travel. The OECD demand proxy is broad but adequate as recent history prior to the current global economic and financial turmoil has shown the rapid expansion of air travel as the income of OECD industrialised countries has increased. However, it does not account adequately for some of the other factors affecting air transport demand, such as the price of travel.

We propose the following method

$$\log(ae_t) - \log(ae_{t-1}) = \alpha_1(\log(oecd_t) - \log(oecd_{t-1})) + \alpha_2(\log(p_t) - \log(p_{t-1}))$$

$$ae_t^i / ae_t = \beta(ae_{t-1}^i / ae_{t-1})$$

where:

- α_1 is the response to a change in the activity indicator
- α_2 is the response to a change in price
- β is the rate at which the international share of aviation energy demand changes compared to the previous year (discussed below)
- ae is aviation energy demand
- $oecd$ is OECD GDP

- p is the price (of oil)
- i denotes a variable relating to international aviation
- t is time

For all aviation emissions, the α terms will be imposed as the parameters used in the DECC model to link aviation emissions to a demand side driver, in this case OECD growth. We will also try to derive the parameter β to reflect the changing share of international emissions in all aviation emissions. This will be based on the changing trend in the existing dataset which shows a significant change in the share of international vs domestic emissions in Scotland's aviation. OECD demand is an assumption input in the DECC model, and we will take the same assumption. If necessary we may have to limit international aviation emissions to a plausible range of the share of all aviation emissions. We will determine domestic aviation emissions as the remaining share of all aviation emissions.

B.5.5 Suggested method for model development: Offshore

In 2007, Scottish carbon emissions from offshore oil and gas extraction sites accounted for 5% (2.2 $MtCO_2$) of total CO_2 emissions. In the UK we estimate that all offshore carbon emissions are covered by the EU ETS. As such we are not proposing to model them here.

In the UK in 2005, offshore emissions accounted for 20.6 $MtCO_2$[50] and it is estimated that 10.8 $MtCO_2$ were covered by the EU ETS as reported in the verified installations emissions, a further 4.7 $MtCO_2$ was to be included in the EU ETS following the inclusion of Offshore flaring and a further 5.3 $MtCO_2$ was previously covered by the UK ETS and has now opted out of the UK ETS and will enter into the EU ETS. In total this is 20.8 $MtCO_2$[51], which is a slight discrepancy from the NAEI figures, possibly because the Offshore flaring figure was calculated on a different year.

B.5.6 Suggested method for model development: Refineries

In 2007, Scottish carbon emissions from refineries accounted for about 4% (1.9 $MtCO_2$) of total CO_2 emissions. In the UK we estimate that all refineries' carbon emissions are covered by the EU ETS. As such we are not proposing to model them here.

In the UK in 2005, emissions from refineries accounted for 18.7 $MtCO_2$ of which 18.1 $MtCO_2$ was covered by the EU ETS. We believe the difference to be a statistical discrepancy caused by the misallocation of Grangemouth's emissions, approximately 0.7 $MtCO_2$ in 2005, to the ETS sector Chemicals rather than Refineries. We therefore believe that Refineries are wholly accounted for by the EU ETS.

B.5.7 Suggested method for model development: Rail Transport

Modelling transport energy demand is a complex task and, as with road transport, we suggest that the use of the NTM to project emissions from rail transport would be most desirable. In light of the resources that would be required to run the NTM for each scenario, we propose a much simpler method to derive an emissions projection

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[50] NAEI, 2008.

[51] Based on data provided to CE by the CCC.

for Scotland using a DECC projection of rail-transport energy demand for the UK. The implied emissions will be calculated using standard coefficients and then calibrated to NAEI outturn data. These growth rates will then be applied to Scottish data to form a projection.

B.5.8 Suggested method for model development: Shipping

Estimates of emissions from shipping, both domestic and international, at the regional level are available from the National Air Emissions Inventory (NAEI). There are significant data constraints for this sector and there is not currently an agreed international protocol that defines how the sub-UK split should be calculated or how international emissions might be allocated to the regions[52]. The absence of detailed data on shipping movements means that fuel use for shipping by region has been proxied by the mass of port traffic in the historical period.

We propose to consider and then select one of two alternative activity indicators in projecting shipping emissions:

(iii) projections of OECD activity (as will be used to project aviation emissions) and,

(iv) projections of UK trade activity (proxied by manufacturing GVA, on the basis that shipping activities relate predominantly to cargo rather than tourism etc).

The latter would initially seem more preferable, as these projections will to some extent capture the projected trends in global activity and are obviously more UK-oriented, but it would be useful to compare how well each of the indicators fare in predicting historical CO_2 emissions before making a firm decision. Manufacturing GVA would also be more preferable because it captures tangible physical goods, whereas OECD activity may also be driven, as it is in the UK, by growth in value added from services. As manufacturing GVA is available for Scotland the proxy indicator is also more reflective of Scottish economic activity. However, the proxy does not contain explicit information on the impact of higher incomes on the imports of manufactured items, or a shift towards imports caused by changes in exchange rates, although this might to some extent be offset by a change in the opposite direction of exports. As such we identify manufacturing GVA as a suitable but imperfect indicator of the growth in shipping emissions in Scotland.

$$\log(se_t) - \log(se_{t-1}) = \alpha(\log(y_t) - \log(y_{t-1}))$$

where:

- α is the response to activity
- se is shipping energy demand
- y is activity (either OECD GDP or Scotland manufacturing GVA)
- t is time

We are not aware of any evidence for deriving a suitable price elasticity term in the literature and so we have not included a price response in the shipping emissions

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[52] http://www.airquality.co.uk/archive/reports/cat07/0811180855_International_aviation_and_shipping1990-2006_final_v5.xls.

equation. Given the paucity of data, it seems unlikely that it would be possible to estimate a robust parameter.

B.5.9 Evaluation of the proposed methods against the Chapter B.2 criteria

The availability of data continues to be an issue

As with many projections at the regional level, a lack of good data is a major obstacle in producing accurate forecasts, and the methods proposed in the previous section resemble those adopted by the CCC, among others, in disaggregating UK projections in the absence of better data.

The methods remain logical (typically activity-driven) and consistent with intuition but where they fall particularly short is in their failure to capture factors that we expect to occur in the future. The methods typically assume away changes in economic infrastructure or development, for example, in efficiency or different regional impacts. This, of course, affects the (likely) accuracy of the forecasts as new outturn data become available.

As with the method applied to form the existing projections of energy demand and emissions at the regional level, the methods are relatively low cost and intuitive.

B.6: Summary recommendations for future projections

In earlier chapters we have highlighted a number of difficulties in projecting CO_2 emissions for the non-traded sectors for Scotland. Broadly we believe that the methods currently employed by the CCC are well considered and appropriate to meet the CCC's requirements of such projections. However, we believe that there are a number of areas for improvement and these are discussed below.

Industrial and commercial emissions

- The method employed by the CCC is suitable, but could be better informed by more detailed data from SCPnet to better differentiate energy demand from industrial and commercial users.
- At the Scottish level, and possibly at the UK level, we recommend that industry energy demand projections follow drivers which more accurately reflect the coverage of the EU ETS using a more disaggregated breakdown which makes further use of the NAEI data supplemented by SCPnet emissions data.
- When considering policy impacts, consideration should be given to the EU ETS sector coverage and the fuel mix composition of the targeted industry within Scotland.
- In the same way as for the emissions from energy use, we propose that process emissions from industry be driven by activity in the relevant sectors, once again making use of NAEI data.

Domestic emissions

- In the domestic sector, while the existing method is broadly satisfactory for projecting 'business-as-usual' CO_2 emissions, there is strong justification for expecting a different policy impact in Scotland from the average impact in the UK and there are also sufficient data to carry out such an assessment.
- The domestic projections for Scotland should be compared with those from a bottom-up modelling approach, such as DEMScot, to ensure that the projections are technically valid. This is particularly important considering the distinct characteristics of the Scottish housing stock *vis-à-vis* the rest of the UK.
- Other Scotland-specific factors that are not currently considered over the projection include the scope for fuel switching as a result of, say, more households having access to mains gas. This is a feature that is not captured in the calibration method used and warrants an investigation of the available data.

Transport emissions

- Road transport emissions projections should continue to make use of the NTM model. Although the TMfS makes use of more detailed survey data for Scotland and Scottish sub-regions and has more detailed land-use data, the consistency which is attained by using a UK-wide transport model means that the NTM is a better option for carbon mitigation policy.
- If a central model run from the TMfS is available with consistent input assumptions then we will build in the functionality to switch between the NTM and TMfS model runs.
- In the case of rail transport, while we have discussed a disaggregation approach in this report that would be able to account for Scotland-specific factors in the evolution of energy demand from rail transport, we recommend that a transport model (ie the NTM or TMfS), if available, be used that is able to capture the factors that affect energy demand from this sector more fully.

- Data on CO_2 emissions from domestic and international aviation are available in the NAEI. We propose to use the regional shares of these emissions to split out aviation emissions over the projection period.
- Projections of international and domestic shipping emissions should be formed in a similar way to those from aviation.

We propose to develop a spreadsheet-based modelling tool in Phase 2

Based on our recommendations, we propose that a relatively simple spreadsheet-based tool be developed to form emissions projections for Scotland. Our review of the projection methods has assessed the various modelling criteria and we conclude that the use of a spreadsheet will offer transparency (the user will be able to easily see how the final numbers have been calculated) and will also provide a constraint on the model, becoming unduly complex.

The data required, from previous DECC projections and the associated parameters will all be contained in worksheets within the model, allowing for easy updating.

We intend for the various alternative projection methods (the drivers) and the assumptions to be user selectable with clear documentation both within the model and as part of an accompanying user guide.

B.7: Appendix B References

Cambridge Econometrics (2008), *'Projections of UK CO_2 emissions and assessment of the economic impacts of carbon budgets'*. http://www.theccc.org.uk/pdf/Projections%20of%20UK%20CO2%20emissions%20and%20assessment%20of%20the%20economic%20impacts%20of%20carbon%20budgets%20%28Cambridge%20Econometrics%29.pdf

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