# Estimating emissions associated with future UK consumption patterns

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# 1 Introduction

The Committee on Climate Change (CCC) is undertaking a review of current and projected UK emissions as measured on a consumption, rather than production, accounting basis to explore if there are any implications for the UK's decarbonisation strategy and policies. This document reports the contribution by the University of Leeds in estimating a times series of past UK consumption emissions (1993-2010) and future emissions (out to 2050) under various scenarios. The technical details of the modelling are provided, documenting the methods employed; data sources; aspects of uncertainty and comparison of results with alternative global models estimating consumption-based emissions. The CCC has provided a technical annex describing how the scenario assumptions were constructed. A summary of results is provided, but not a detailed analysis of these. Emissions datasets in Excel have been provided to the CCC for publication alongside this report.

## 1.1 Aims and objectives

The aims and objectives set out in the agreed proposal between the University of Leeds and the Committee on Climate Change were:

I. Using Eora, a global multi-regional input-output model (MRIO) developed by the University of Sydney, develop a comprehensive time series of UK consumption emissions by a number of sectors (maximum of 26) and regions specified by the CCC between 1993 and 2010.
II. Develop scenario framework, including all factors that can be varied in the model to allow for the construction of scenarios (i.e. final demand, carbon intensity, trade balances, etc.). This will allow scenarios to be developed up to 2050 through the adjustment of the individual factors.
III. Working closely with the CCC, develop the inputs for modelling scenarios. Variables will be modified in consultation with the CCC, including assumptions for future carbon intensities (both inside and outside the UK) and trade patterns. Approaches to project future emissions should be consistent with approaches to estimate past emissions.
IV. Scenarios based on input data decided in the last work package will be modelled in Matlab and each scenario will produce a separate emissions results file ensuring complete transparency.
V. A short report will be provided that describes the methodology employed, the scenarios selected and show the results; accompanied with data sets in Excel.

## 1.2 Research context

There is an increasing separation between the location of production and consumption, where embodied emissions in trade have grown substantially over the past 15 years (Peters and Hertwich 2008; Davis and Caldeira 2010). This has resulted in a considerable variation between the emissions occurring within the territory of some countries and the emissions associated with consumption of its residents. Consumption-based emissions methodologies have been developed to provide an understanding of the total embodied emissions associated with a country's consumption patterns, irrespective of where the emissions occur.

This is a particularly important issue for the UK compared to other large global emitters. A number of independent estimations highlight that the difference between growth in consumption-based and territorial-based emissions was the largest for the UK compared to other industrial nations in the top ten global emitters of carbon dioxide ($CO_2$) emissions over the past two decades, with the gap growing by 23% compared to 8% for the US, 7% for Canada, and decreases in the gap in other countries (Barrett et al., 2013).

The UK Government has recognised the importance of different carbon accounting approaches to provide a complete picture of the UK's contribution to global emissions. Since 2011, the UK Government has adopted "Consumption-based GHG Emissions" as a headline indicator and reports these results annually (Defra, 2012). In April 2012 the UK Parliament Energy and Climate Change Select Committee undertook an inquiry into consumption-based GHG emissions and made further recommendations to the Department for Energy and Climate Change to consider approaches to reduce both emissions occurring within the UK and embodied in trade to satisfy UK consumption (House of Commons, 2012).

The Government estimates of UK consumption-based emissions are calculated by the University of Leeds for the Department for Environment, Food and Rural Affairs (Defra) using an environmentally extended multi-regional input-output model (EE-MRIO). This model has also been employed for the CCC study but with a greater regional disaggregation.

A European project commissioned by a collation of European Environment Agencies (ERA-NET) (Wiedmann et al, 2009a) has identified EE-MRIO as a favourable approach for assessing the environmental impacts of trade. EE-MRIO is emerging as a comprehensive, versatile and compatible approach for consumption-based accounting of GHG emissions and has already become the norm (Davis and Caldeira, 2010; Peters and Hertwich, 2008; Peters et al., 2011; Wiedmann, 2009; Wiedmann et al., 2011). Strengths and weaknesses of the EE-MRIO approach were assessed in the European EIPOT project that is widely quoted by many European countries considering consumption-based GHG emission accounting (Wiedmann et al., 2009a).

# 2 UK consumption emissions historical time series (1993 – 2010)

Eora, a new global EE-MRIO model developed by the University of Sydney, was used to provide a comprehensive time series of UK consumption emissions, both $CO_2$ and GHGs, between 1993 and 2010 for the CCC.

## 2.1 Method

EE-MRIO analysis is a peer-reviewed method with applications in the calculation and reporting of consumption-based emissions accounts and in climate change policy (Minx et al., 2009; Wiedmann and Barrett, 2013; Barrett et al., 2013; Hertwich and Peters, 2009). A consumption-based account can quantify those emissions occurring in foreign nations to satisfy domestic consumption and similarly quantify the proportion of domestic emissions embedded in products for export (Peters, 2008; Wiedmann et al., 2011; Wiedmann, 2009).

### 2.1.1 The basic principles of input-output analysis (IOA)

Input-output analysis (IOA) is a method used to examine the inter-relationship among the productive sectors of an economy represented by an IO matrix. A good description of IOA is provided in Wu and Zhang (2005) and has been adapted here. The IO matrix describes the complex process of production, the use of goods and services and the value added and income generated within various sectors of an economy, where the set of producers of similar goods and services forms a homogenous industry. Economic sectors purchase goods and services from other sectors; pay wages; pay taxes and potentially receive subsidies in the process of making their own product (Miller & Blair, 2009). The income generated in wages is transferred to final consumers to buy goods and services such as food, energy, transport, domestic appliances, leisure activities and so forth. IO tables are based on observed economic data for one year. A series of tables along a timescale reveals the structural change of an economy and specific sectors' economic characteristics.

An IO matrix consists of four quadrants:

- The first quadrant (Z) shows the monetary transactions between sectors that both produce goods (outputs) and consume goods (inputs) from other sectors in the process of making their own product. Reading across a row reveals which industries a single sector sells to (i.e. its sales profile) and reading down a column reveals who a single sector buys from (i.e. its expenditure account). This quadrant is at the heart of IOA and referred to as the 'transactions' or 'intermediate matrix'.
- The second quadrant (Y) represents the sectoral distribution of final demand. Final demand is comprised of households, government, fixed capital and exports[1].
- The third quadrant (V) shows primary inputs (i.e. the sectoral distribution of wages, operating surplus, value-added, indirect taxes, subsidies and depreciation)
- The fourth quadrant (X) shows that an industries input (its expenditure) is equal to its output (its sales).

| | Industries | Net final demand | Total output |
|---|---|---|---|
| Industries | Z | Y | X |
| Value added | V | | |
| Total input | X | | |

IOA is a demand driven model and the level of production activities is determined by demand for goods and services and the interdependencies of sectors in an economy. Using a simplified example, for sector A to produce its product it requires material and energy as intermediate inputs from sectors B and C respectively. If the total input of Sector B to Sector A is 2, for every unit produced by Sector A, Sector B has to produce 2 units to support it. The same principle applies for sector C. In turn Sector B and C each require a recipe of inputs to produce their 2 or equivalent units and so forth, creating an economy-wide pull effect from demand for Sector A. The production value generated throughout the economy to produce 1 unit for Sector A is measured quantitatively by a direct and indirect coefficients matrix called the Leontief inverse; the sum of the columns representing sectoral output multipliers. For example if the output multiplier for sector A is calculated as 3, the entire economy will be induced to generate the value of £3 if sector A produces

[1] These are the final destination of products, whereby they do not flow into other sectors as intermediate inputs

£1. Final demand determines the number of units produced. See Appendix 1: EE-MRIO methodfor detailed methodology.

### 2.1.2 The environmental extension

Since the 1960s, the IO framework has been extended for environmental analysis (e.g. to account for increases in the pollution associated with industrial production due to a change in final demand (Miller & Blair, 2009)). This extension is referred to as an Environmentally Extended Input-Output model (EE-IOM). In the model used to estimate the UK's consumption emissions, the IO tables are appended with a row vector that includes direct sectoral emissions[2]. Direct sectoral emission intensities are quantified by measuring the emissions required to produce one unit of output. Continuing the IOA example from above, if Sector A emits 20 grams of $CO_2$ to produce £20 of output, one production unit emits 1 gram of $CO_2$ (i.e. it's production intensity is 1 gram $CO_2$/£). However, Sector A has additional indirect emissions embodied in its intermediate inputs. Sector A requires 2 units from Sector B and 3 units from Sector C. If sector B emits 10 grams of $CO_2$ to produce £20 of output and sector C emits 10 grams of $CO_2$ to produce £50 of output, their production intensities are 0.5 grams $CO_2$/ £ and 0.2 grams $CO_2$/ £ respectively. 2 units at an intensity of 0.5 grams $CO_2$/ £ and 3 units at an intensity of 0.2 grams $CO_2$/ £ are reallocated to sector A as indirect intensity multipliers. Sector A's total intensity multiplier (i.e. direct plus indirect) is 2.6 grams $CO_2$/ £. In reality, Sector B and C will have intermediate inputs and emissions will be reallocated from the point of origin through supply chains to the final product. Final demand determines the total consumption-based emissions: if householders purchased £5 of Sector A's products the associated consumption emissions would be (5 * 2.6) = 13 grams $CO_2$. See Appendix 1: EE-MRIO method for detailed methodology.

### 2.1.3 The trade extension

In its basic format the transactions matrix described above represents domestic sectors (e.g. economic transactions and emissions arising in domestic sectors of production). Multi-regional input-output (MRIO) tables extend the transactions or intermediate matrix to represent purchases and sales to sectors in other countries (i.e. imports and exports). The row of the matrix is extended to represent each sector's exports to international intermediate sectors and the columns are extended to show the intermediate imports from foreign sectors. Sector A might source intermediate inputs from sector B domestically or import the same product from another country. Demand for sector A will not just induce production in its own economy but will induce global production activities, resulting in emissions being released outside of its national territory. Emission intensity multipliers will be allocated to trade flows indicating the production intensity of the origin country. A consumption-based emission account sums the direct and indirect emissions associated with a nation's demand for products.

In the last five years, several MRIO databases and models capable of tracking flows of goods and services between nations have been developed. These are described in Table 1.

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[2] This report investigates emissions, however, other environmental indicators can be used e.g. water consumption and material use

| Model | Sector coverage | Country coverage | Years available | Potential updates | Reference(s) |
|---|---|---|---|---|---|
| **Eora** | Varies by country from 26 to 515 sectors[3] | 187 | 1990 – 2010 | Annual updates with 2 year time lag | Lenzen et al. (2012) |
| **GTAP** | 57 | 127 (yr '07); 113 (yr '04); 87 (yr '01) | 2001, 2004, 2007 | 3 year intervals with a 4 year lag | Peters et al. (2011) |
| **EXIOPOL** | 130 | 44 (EU27, 16 others + ROW) | 2000 | Funding dependent | Tukker et al (2009) |
| **WIOD** | 35 industries, 59 products | 41 (27 EU, 13 others + RoW) | 1995 – 2009 | Funding dependent | Timmer et al (2012) |
| **AIIOT** | 76 | 11 (9 Asian, USA and ROW) | 1985, 1990, 1995, 2000, 2005 | Every 5 years | Zhou and Kojima (2009) |

Table 1: EE-MRIO models

## 2.2 Data

The model used to develop UK consumption emissions estimates for Defra and the CCC relies on data obtained from Eora, an EE-MRIO model developed by the Integrated Sustainability Analysis (ISA) group at the University of Sydney. There are several peer-reviewed articles on both the construction techniques and application of Eora data (Lenzen et al., 2011; Kanemoto et al., 2011; Lenzen et al., 2011a; Lenzen et al., 2012a; Lenzen et al., 2012b). The Eora database became available online in 2012 and will be updated annually.

### 2.2.1 Eora structure

Eora provides a global transactions matrix showing inter-industry trade between 187 countries for a time series from 1990-2010. The original sector classification of the countries accounts are retained, with country sector resolution ranging from 511 sectors to 26 sectors. Using the common bottom denominator, a 26 sector harmonised system was also developed to enable easier cross-country comparisons and sector analysis. For the 98 countries where IO tables are not available, but total sectorial economic outputs are, a representative economy is applied using the average of tables from U.S., Japan and Australia. For missing years, a country's IO table from a previous year is updated using available economic indicators.

### 2.2.2 Environmental extension

The database has over 50 environmental extension datasets allowing measurement of, for example, energy, greenhouse gas, water, labour and land use footprints. Global sectoral emissions in Eora are sourced from a combination of data from EDGAR, UNFCCC and CDIAC. This study utilises global carbon dioxide emissions arising from fuel combustion and all other greenhouse gas (GHG) emissions excluding Land Use, Land Use Change and Forestry. It is important to note that there is less confidence in the Eora emissions data for non-$CO_2$ emissions, due to the use and allocation of Global Warming Potential multipliers (Reisinger et al., 2010).

[3] The original database has heterogeneous country sector classification systems, however a harmonised 26 sector model is available

### 2.2.3 Trade data

Alongside the domestic tables, countries report import tables. For each sector, the import tables report spend on imported products but the region of origin is not reported. Eora estimates trade between regions by disaggregating the imports matrix to show share by region using international trade data from United Nations commodity trade statistics database COMTRADE. Some estimation is required in the allocation of trade data to the sector classification used by different regions, and where countries do not report to COMTRADE, a proxy nation's trade structures are used instead.

### 2.2.4 Region and sector aggregation selected

Exploring potential global emissions pathways at a detailed sector and individual country level requires a substantial amount of data manipulation and potentially presents a false impression of the detail and accuracy of anticipated futures. To make the analysis more manageable and in recognition of the uncertainty of projecting the future, the harmonised 26 sector classification was adopted (a full list of sectors analysed is provided in Appendix 2) and countries were aggregated into eight regions. Regions were selected based on their current and anticipated future contribution to the UK's final demand for imported goods and services (i.e. imports) as well as on the basis of detailed modelling of future emissions trajectories available in the International Energy Agency's *Energy Technology Perspectives* (2012) publication. The eight regions selected by the CCC were:

- The UK
- OECD - Europe
- Rest of OECD
- China
- India
- Rest of developing Asia
- Russia
- Rest of World (RoW)

Due to the UK focus, more sector detail is included in its domestic tables than for the rest of the world. Full input-output tables for the UK for 110 sectors according to UK Standard Industrial Classification (2007) was provided by the Office for National Statistics (ONS, 2009) and integrated into the 26 harmonised sector Eora model (Owen et al., 2012). The sector classifications are listed in Appendix 2: EORA sector classification.

### 2.2.5 Trends data

For each region and sector, annual economic and intensity multipliers of production were provided to the CCC in a database of trends described in Table 2. These data inputs provide information on how the global economy has evolved over the time series (1993-2010), including trade, sectoral output, and emissions intensities of production, and provide information on what influences changes in consumption emissions. These can also be used to project future variables in line with historic trends (see Section 3).

| Economic variable | Description | IO notation[4] | Units |
|---|---|---|---|
| Sector output | Annual economic sector output | *X* | £M current basic prices |
| Technical coefficients | Production recipe of first order inputs to produce a unit of sector output | *A* | £M/ £M |
| Final demand | Sectoral distribution of final demand | *Y* | £M current basic prices |
| $CO_2$ and GHG intensity of production | Sectoral emission intensity production multipliers | $F_x$ | Kt / £M |

Table 2: Economic and intensity production factors

### 2.2.6 Reliability statistics

The Eora database contains standard deviations for each matrix element in the MRIO. These measures indicate how reliable the Eora researchers consider each element in the database to be. The reliability statistics are either sourced from the original economic data or proxy information available in the literature. Standard deviations are often reported for economic sector totals, rather than individual elements in the table. The Eora team then uses matrix balancing techniques to spread the error measurements throughout the table (Kanemoto et al., 2011).

### 2.2.7 Results format

A results emissions matrix was provided to the CCC for each year with dimensions 292 by 292 (UK 110 sectors and 26 sectors for 7 regions). In the matrix the rows specify the country and sector in which the emissions originate, and the columns determine the product in which the emissions become embodied. The sum of the rows are the emissions released by the equivalent sector to satisfy UK demand (e.g. how many emissions are emitted in the power sector to produce goods and services that are consumed by the UK) and the sum of the columns are the emissions embodied in the equivalent product to satisfy UK demand (e.g. for a given product consumed in the UK such as Food and Drink products, the associated supply chain emissions). A single cell in the matrix represents the share of emissions transferred from one production industry (the row) bought by another (the column) to produce the level of output demanded by UK consumers. The sum of the matrix is the total UK consumption emissions (excluding household direct emissions[5]).

To summarise, the emissions matrix enables analysis of results from both an origin and product perspective:

- An origin perspective shows the country and sector in which emissions are directly released before becoming embodied in products for final consumption in the UK.
- The product perspective shows the sum of supply chain emissions embodied in products for final consumption in the UK.

[4] The notation is attributed to variables in the equations in appendix 1

[5] Emissions from direct burning of fuel by households for heating and private transport are added separately. The production and distribution of fuels has been included, however, the burning of the fuel occurs in the household and not the industry, which is what the IO analysis captures. For the UK these are provided in Environmental Accounts and added to the emission account.

The sum of emissions results from an origin perspective is equivalent to the sum of results from a product perspective (e.g. all emissions produced in the UK and abroad to support final UK consumption). It is the allocation to industries and products which differs.

## 2.3 Summary of results (1993 - 2010)

Results matrices for UK consumption emissions (for $CO_2$ and for all GHGs) from 1993 to 2010 have been provided to the CCC. Figure 1 and Figure 2 summaries historic UK consumption-based emissions from an origin and product perspective for $CO_2$ and GHGs respectively. Total overall consumption emissions from an origin and product perspective are the same, but their attribution to countries and sectors differs depending on whether they are assigned to the sector of origin or the product of embodiment.

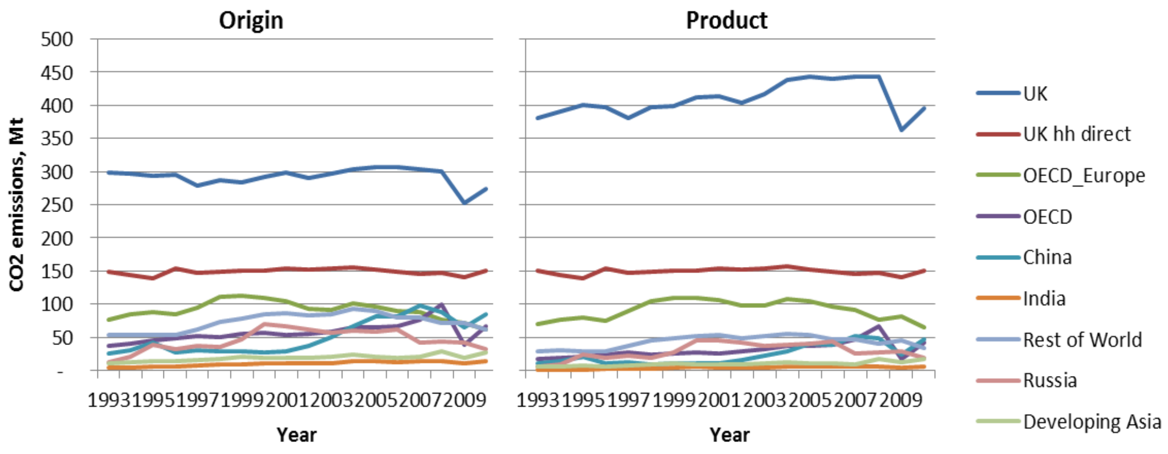


Figure 1: Summary of UK consumption $CO_2$ emissions time series by an origin and product perspective

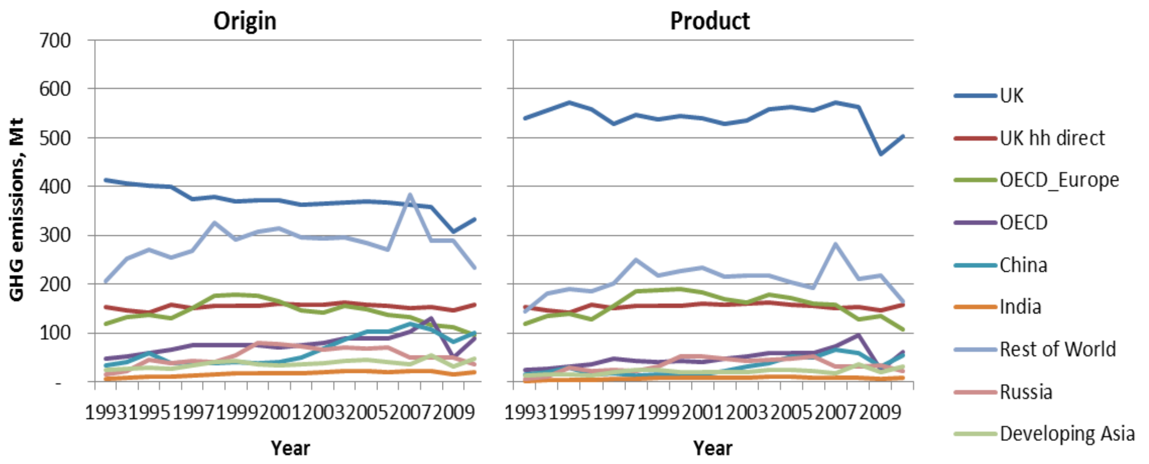


Figure 2: Summary of UK consumption GHG emissions time series by an origin and product perspective

Table 3 summarises changes in absolute emissions between 1993 and 2010. Both consumption-based $CO_2$ and GHG emissions have been on an upward trajectory, dropping significantly in 2009; entering the period of global recession. Emissions from UK industry and embodied in UK final products are isolated and compared to overseas industry and product emissions. Emissions originating in UK industry to satisfy UK final demand have declined (by 5% and 14% for $CO_2$ and

GHGs), in contrast to emissions originating in overseas industry which have increased by 59% and 38% for $CO_2$ and GHGs respectively. When all GHGs are included, emissions originating overseas have become more significant than those released domestically.

Emissions embodied in products sold by UK sectors to UK final consumers are higher than emissions originating in UK industry. A product perspective includes all upstream emissions, some of which will be imported. The overseas emissions included in a product perspective create the difference. Emissions embodied in UK products have remained somewhat stable; a 3% increase in $CO_2$ emissions and a 5% reduction in GHG emissions. However, again there is significantly higher growth in overseas emissions to satisfy UK demand (39% and 38%). Final consumers in the UK are increasingly becoming reliant on imported products.

| | $CO_2$ | GHG |
|---|---|---|
| Change in total UK consumption emissions (1993 and 2010) | ↑16% | ↑9% |
| Change in UK only origin emissions (1993 and 2010) | ↓5% | ↓14% |
| Change in UK only product emissions (1993 and 2010) | ↑3% | ↓5% |
| Change in overseas origin emissions (1993 and 2010) | ↑59% | ↑38% |
| Change in overseas product emissions (1993 and 2010) | ↑39% | ↑38% |

Table 3: Changes in emissions

## 2.4 Results comparison

As seen above, in the past five decades a number of MRIO models and databases to estimate a country's consumption emissions have become available. While they rely on the same modelling principles they utilise different economic, trade and environmental datasets; different methods of combining and balancing national IO tables into an integrated global model; and have different regional and sector breakdowns. As a result use of different models/databases will generate difference estimates of the UK's carbon footprint. The various peer-reviewed models are summarised in Table 1 (see section 2.1.3). **Error! Reference source not found.** shows the UK carbon footprint time series as reported by four global models (Eora, Exiopol, GTAP and WIOD), and two variants of Eora (CCC and DEFRA). Only one or two years of data are available from the Exiopol and GTAP models. In 2007, the latest year allowing comparison across the majority of models, the lowest reported UK consumption emissions (GTAP) are 72% below the highest reported emissions (Eora).

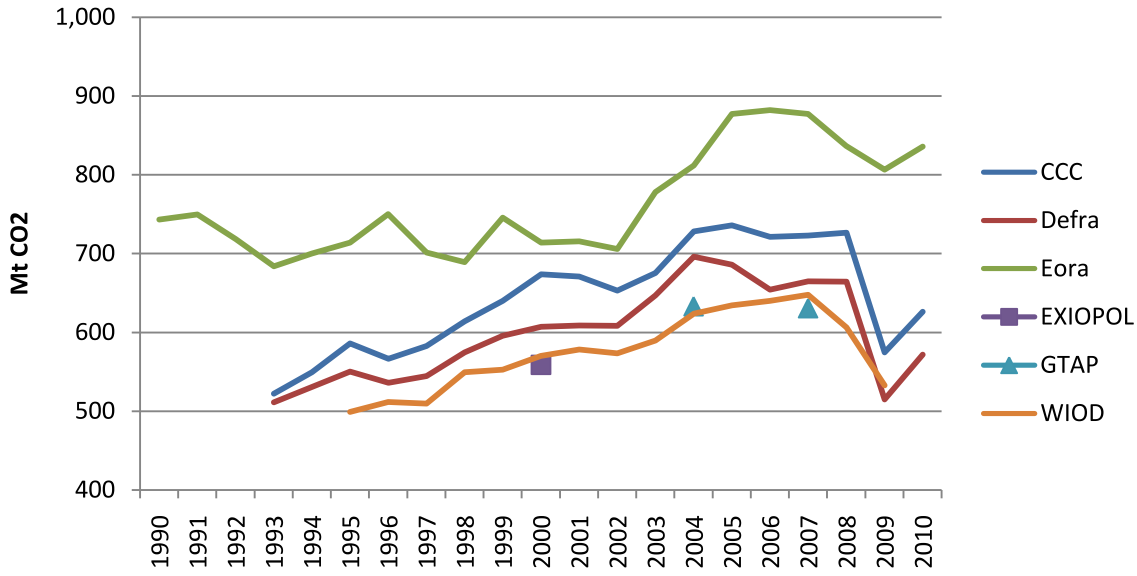


**Figure 3: UK consumption-based $CO_2$ estimates from alternative MRIO models**

The University of Leeds uses Eora data to develop estimates of UK consumption emissions for Defra, but results differ from the Eora model as Leeds integrates more detailed (unpublished) UK data with Eora data to generate a four region[6] model. The CCC requested more regional disaggregation (an eight-region versus four region model for Defra) and as a result CCC estimates are higher than Defra results[7]. This is because models which allocate emissions to greater numbers of regions and sectors tend to reveal higher emissions for the UK. These models are able to detect the impact of trade with developing nations whose impact ($CO_2$) per unit of output (£) tends to be higher than that assigned to a general Rest of World region[8]. For example GTAP analyses 127 regions totalling 7,239 sectors while Eora analysis 187 regions totalling 15,909 sectors.

This holds true when comparing the Eora model with the modified model used by the University of Leeds to develop the Defra and CCC estimates. Aggregating Eora's more detailed format (187 countries and heterogeneous sectors ranging from 26 to 515) to a UK-centric eight and four region model with 110 UK sectors and 26 harmonised rest of world sectors results in estimates of the UK's carbon footprint that is lower. Figure 4 compares emissions embodied in product groups for the UK in 2010 between the Defra and CCC models[9].

[6] UK, EU 27, China and Rest of World
[7] UK, OECD – Europe, OECD – other, China, India, Russia, Developing Asia, Rest of World
[8] The strength of this hypothesis is currently being tested (between University of Leeds and University of Sydney)
[9] This excludes household direct emissions resulting from on-site burning of fuel for heat and private travel

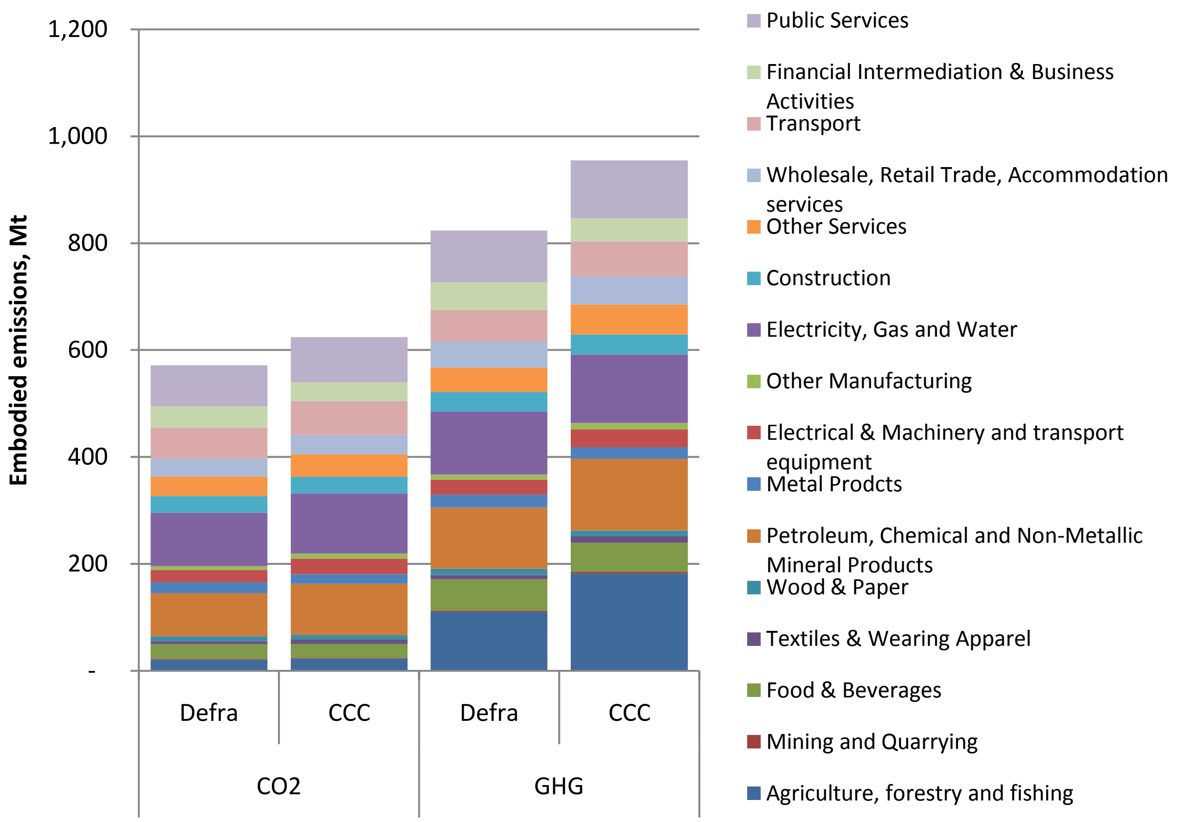


**Figure 4: UK consumption emissions by product for 2010 comparing the Defra and CCC models**

Overall emissions are 9% and 16% higher in CCC results for $CO_2$ and GHGs respectively; which varies between product groups. The CCC has a separate analysis of Russia, Developing Asia and India. The more detailed model is able to detect the impact of trade with these nations, whose impact per unit of output is higher than a generic rest of world sector, resulting in higher emissions embodied in imports. This is particularly noticeable for greenhouse gas emissions embodied in agricultural products. Figure 5 compares GHG emissions embodied in agricultural products consumed in the UK originating in the different regions.

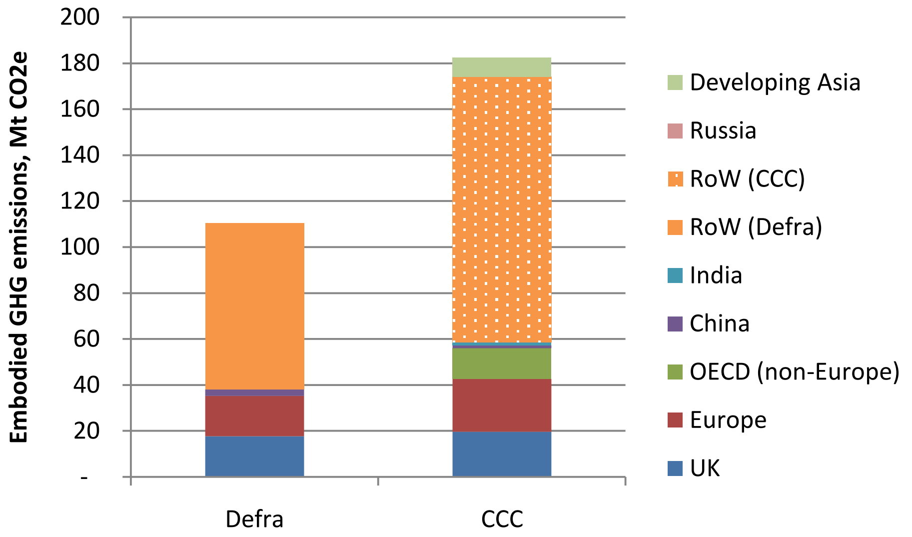


Figure 5: UK GHG consumption emissions for agricultural products for 2010 comparing the Defra and CCC models

The contribution from domestic and European industry is similar between Defra and the CCC model. However, where Defra has a single Rest of World region, the CCC disaggregates into five regions: OECD nations, Russia, India, Developing Asia and Rest of World. Excluding OECD (non-Europe), where the impact per unit of output for Agriculture is lower, the impact per unit of output for the remaining rest of world regions are much higher. The OECD nations' lower impact has a diluting effect in the Defra model. Agriculture is one of the few sectors where the majority of UK consumption is sourced from abroad and so this effect is most strongly seen for this product.

## 2.5 Uncertainty

An uncertainty analysis has not been conducted within the timescales of this project. However, the sources of uncertainty in MRIO models are discussed and references to other similar MRIO studies that undertake uncertainty calculations are provided where possible.

### 2.5.1 Sources of uncertainty

EE-MRIO analysis relies on secondary economic, environmental and trade data sources which add uncertainty to EE-MRIO analysis (Lenzen et al., 2010, Peters et al., 2012, Wiedmann et al., 2008). One source of uncertainty is the use of monetary data to represent physical commodity flows. Representing a quantity of a good by monetary data rather than using physical data such as weight assumes the same quantity of the commodity is represented by the same monetary amount regardless of which sector the commodity is bought by. For example, electricity prices will vary depending on the importing industry; however, the model assumes that every industry purchases electricity at the same price. Emissions are attached per pound of electricity purchased, and will be distributed through supply chains according to this homogenous price assumption. One production industry might have paid less for the same quantity of electricity as another. The emissions attributed to both should therefore in be the same, however, with IO assigning an emissions per pound spent, the industry which paid less will show as having less emissions from electricity embodied in their product.

Further uncertainties can be introduced after the source data has been collected and analysts start to assemble the information into an EE-MRIO table. There are many ways in which the data can be assembled and adjusted and each alteration to the original source data introduces further uncertainty. Economic data needs to be converted into a common currency and monetary transactions converted into basic prices. This requires price conversion statistics and taxes and subsidies to be re-distributed from a product to a value added sector. Where national data is missing, estimations are required such as the use of a representative average. Often further calculations are required to populate international trade data, the off-diagonal sectors of the table. MRIO tables must also adhere to a number of properties such as inputs must equal outputs and the sum of value added must equal the sum of the final demand. If these conditions are not met, then the table is subjected to a number of balancing iterations until a table is produced that satisfies these constraints. Balancing methods vary and there are numerous techniques for table construction which leads to uncertainty in the final result. Each stage of data processing takes it a step further from the original data source.

In addition, the aggregation of economic sectors introduces uncertainty. For example, Eora applies an average carbon intensity to the agricultural sector when calculating consumption emissions. This aggregated sector covers all agricultural activities including a wide range of crops, animals, practices and so forth. However, cattle farming are considerably more carbon intensive than other types of agriculture. The choice of aggregation can therefore lead to different impact results. Grouping data together that exhibit very different emission intensities will lead to calculations that use aggregated sectors containing more uncertainty than calculations that involve grouping more homogenous data. Issues of aggregation occur when MRIO models are constructed with a sector classification that is common to each country. The model selected is the Eora harmonised MRIO table and original data from national tables have been either aggregated or disaggregated to match the common classification.

### 2.5.2 Measuring uncertainty

As Lenzen et al. (2010) and Wiedmann (2009) note, there are actually very few examples of environmental MRIO studies where uncertainty analyses are undertaken. The table below describes examples of types of uncertainty analyses and summarises their findings.

| Study | Uncertainty methods used | MRIO data | Findings |
|---|---|---|---|
| Lenzen et al. (2010) and Wiedmann et al. (2008) | Uses Monte Carlo techniques to carry out a sensitivity analysis of the MRIO model. The method repeatedly simulates the MRIO model with slight perturbations to the model elements meaning the standard deviations of the emission multipliers and error propagations of the embedded emissions can be determined. | These studies use the 2008 version of the Defra UK MRIO model | The authors conclude there is an 89% probability that the UK's carbon footprint increased between 1994 and 2004 and that the relative standard error for consumer emissions lies within 3.3% for 1994 and 5.5% for 2004. |
| Wilting (2012) | Conducts a sensitivity analysis by allowing elements in the domestic and trade blocks of the MRIO table to vary by up to 10%. Uses Monte Carlo simulations to Investigate uncertainties for the total Dutch footprint and at sector and product level. | This study uses an aggregated version of GTAP version 6 to consider the Dutch carbon footprint for 2001. | The Dutch footprint has an uncertainty of around 4.6%, whereas uncertainties associated with the carbon emissions allocated to products ranged from 4% to 53%. Sectors with non-$CO_2$ GHGs had the highest uncertainties. |
| Weber & Matthews 2007 | Sensitivity analysis of estimated trade data to the US. The authors test the impact on the US footprint when a rest of world trade region takes multipliers of the most and least carbon intensive countries in the data set | This study measures the US footprint by using an MRIO model for the US, seven trade countries and the RoW | Choice of rest of world data can vary the US footprint by up to 20% |

An additional source of uncertainty described in the literature is the exchange rate methodology used to convert currencies into a common unit. The two main methods are market exchange rates (MER) and purchasing power parities (PPP). While both methods should give identical results for consumption emissions if used consistently (i.e. to convert both trade flows and emission intensities), the emissions estimate may vary where not. Therefore it is important to ensure a common method is used throughout the estimate to minimise estimation errors. The Eora model uses MERs.

Based on the findings above, we suggest that uncertainties in the total consumption based emissions calculation for the UK may be in the order of 5% however as Wilting (2012) shows, at the product level the uncertainty level increases. This 5% represents the uncertainty in the total UK consumption account as calculated by the Defra MRIO model. It does not indicate the uncertainty of model results calculated using different models, as seen in Figure 3. Comparing different models yields greater uncertainty due to the differing model structures and data sources used.

# 3 UK consumption emissions projections (2010 – 2050)

Future UK consumption emissions to 2050 (at five year intervals) under various demand and emissions reduction scenarios are explored. The scenario approach is consistent with the method used to estimate historic consumption-based emissions. Using the EE-MRIO scenario framework devised by the University of Leeds, the CCC developed scenarios reflecting different combinations of UK demand (including imports) and global production emissions intensities.

## 3.1 Scenario descriptions

Five scenarios exploring potential future UK consumption-based emission pathways were developed by the CCC constrained to two and four degree global temperature rise and with low, medium and high levels of import growth:

1. 2 degree future ($CO_2$)
2. 2 degree future without availability of carbon capture and storage technology ($CO_2$)
3. 2 degree future with overseas production intensities converging to UK intensities ($CO_2$)
4. 4 degree future ($CO_2$)
5. A 2 degree future including all GHGs

## 3.2 Scenario framework

Figure 6 illustrates the different stages of scenario generation. As described in the previous section Eora is the starting point for estimating historic UK consumption-based accounts. Annual IO data from Eora was provided in Excel sheets and decomposed into four variables: sector output; technical coefficients (or production recipe); final demand and production intensities (see Table 2). The computational requirements to calculate emission results is too big to be carried out in Excel therefore the input-output analysis is scripted in MatLab, which generates emission results matrices in Excel files.

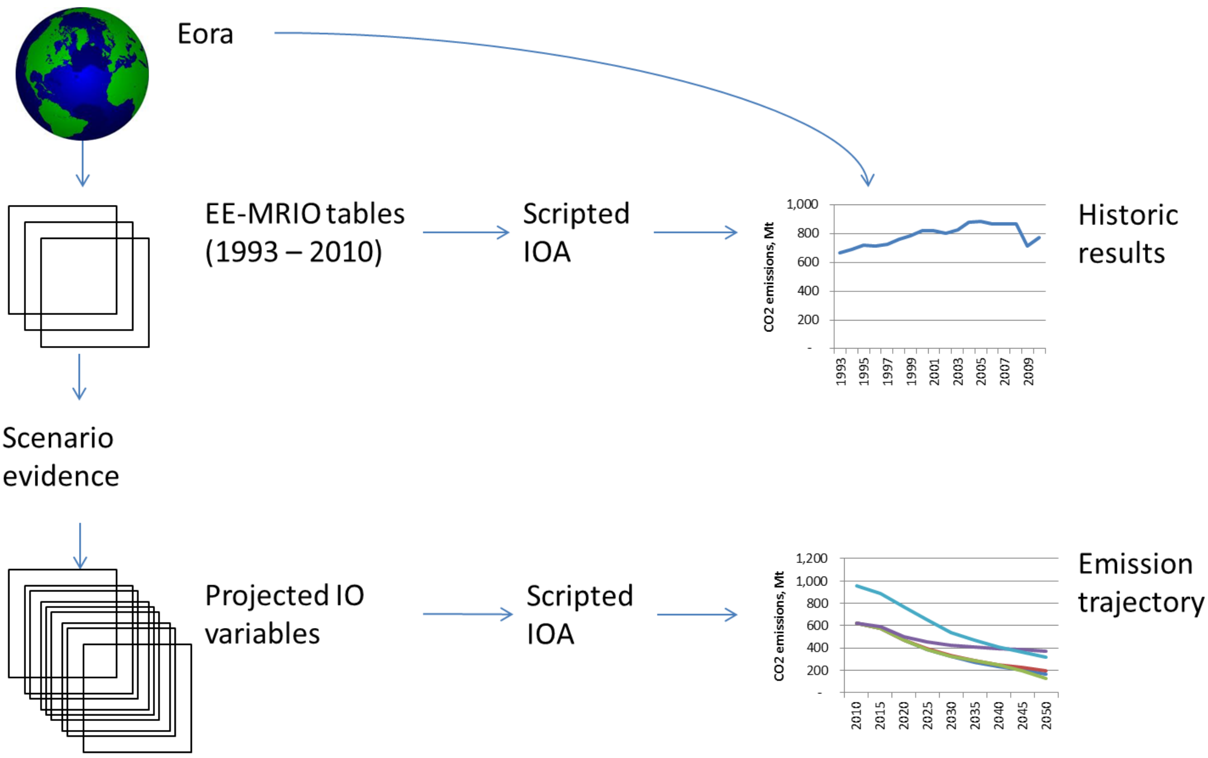


Figure 6: Scenario framework

The CCC projected future demand and emission intensities under constrained UK carbon budgets and 2050 target to reduce production emissions by 80% relative to 1990 levels. These were specified in five scenarios incorporating various pathways for global emissions reductions. A description of this approach and supporting data is provided in Appendix 3: Evidence base for scenarios (contributed by the CCC). The limits to production intensities within defined carbon budgets, projected demand growth rates and with a low, medium and high increasing reliance on imports were explored.

Table 4 summarises the level of detail and sources used. The column 'Constant' refers to whether the values used for the variable are the same in the different scenarios; the 'Regional and sector detail' indicates the level of aggregation of projections; the 'Source' denotes whether the variables are projected using the time series or an alternative source; and 'Sensitivity' indicates whether the variable is modelled at different levels within scenarios. Variables are projected at 5 year intervals as a growth rate from the 2010 baseline and input into Excel. The input-output calculations are performed in Matlab and emission results up to 2050 are generated for each scenario and its associated sensitivity runs (the level of reliance on imports).

| Variable | Constant | Region and sector detail | Source | Sensitivity |
|---|---|---|---|---|
| Sector output | No | Varies across countries but not across sectors within a country | UK: OBR projections; Rest of world: IMF, DECC, and DfT projections[10] | No |
| Technical coefficients | Yes | Global production structure remains constant at 2010 | 2010 EE-MRIO model[11] | No |
| Final demand for products | No | Varies by country and sector (Historic trends with gradual shift towards imports arising from emerging economies and away from advanced economies, gradual shifts away from demand for fossil fuels for energy production) | Import demand projected forward in line with historic GDP growth (with range 2.25%-3.25% per year); Domestic demand adjusted to maintain historic trade balances | Yes: each scenario is run at low, central and high rates of import demand |
| $CO_2$ and GHG sector emissions | No | Constrained to 2 degree and 4 degree global emission levels; varies by country and high level sectors | CCC analysis and IEA[12] | No |
| $CO_2$ and GHG intensity of production | No | Varies by country and high level sectors | Emissions divided by output | No |

Table 4: Summary of projection variables

## 3.3 Summary of results

Scenario results at 5 year intervals from 2010 to 2050 from an origin perspective have been provided to the CCC, summarised in Figure 7. Datasets are available in Excel.

[10] Department for Transport (2013) UK Aviation Forecasts, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/183931/aviation-forecasts.pdf

[11] Described in section 2

[12] CCC

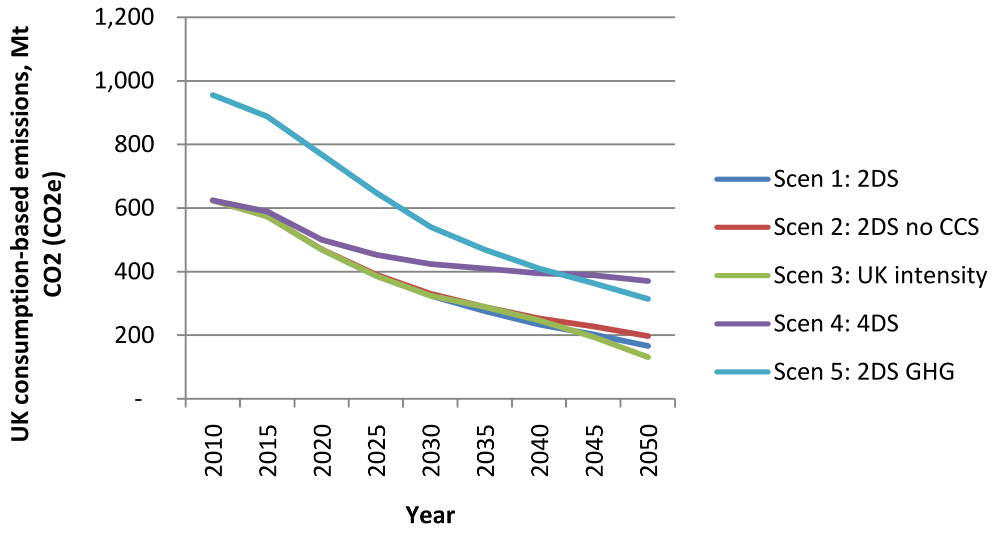


**Figure 7: Summary of scenario emission results 2010 - 2050**

Each scenario shows a pathway of declining UK consumption-based emissions. The highest emission reduction is achieved in a world where global production intensities converge to mirror UK sectoral production intensities, reaching 131 $MtCO_2$, almost a fifth of those in 2010. If global carbon budgets defined to remain within two degrees of climate change are achieved, consumption emissions in 2050 are anticipated to be 27% what they were in 2010, more than half (45%) that when budgets are weakened to a four degree future. The results suggest that without the availability of CCS technology there is an additional 31 Mt $CO_2$. For greenhouse gases, aligned with a two degree future, emissions in 2050 are estimated to reach a third what they were in 2010.

A sensitivity on Scenario 1 was explored with varying assumptions demand for domestic and imported products (see Appendix 3). Varying demand scenarios for imported goods and services did not result in significant changes in the UK's carbon footprint (see Figure 8), partially reflecting assumptions which ensure that imports and exports and broadly aligned over time – while any increase in imports would increase imported UK emissions, this also translates to decreased demand for UK produced goods and services and increased exports, effectively lowering the domestic contribution to the UK's carbon footprint. In the high imports scenario the average annual growth in demand for imported products is 3.25% compared to a 1.6% growth in demand for domestic products. In the low import demand scenario these figures become 2.25% and 2.2% respectively. As production emissions intensities across countries are broadly similar to the UK's under Scenario 1, even under a high import demand scenario, the UK's carbon footprint is only 6% higher than in the central demand scenario.

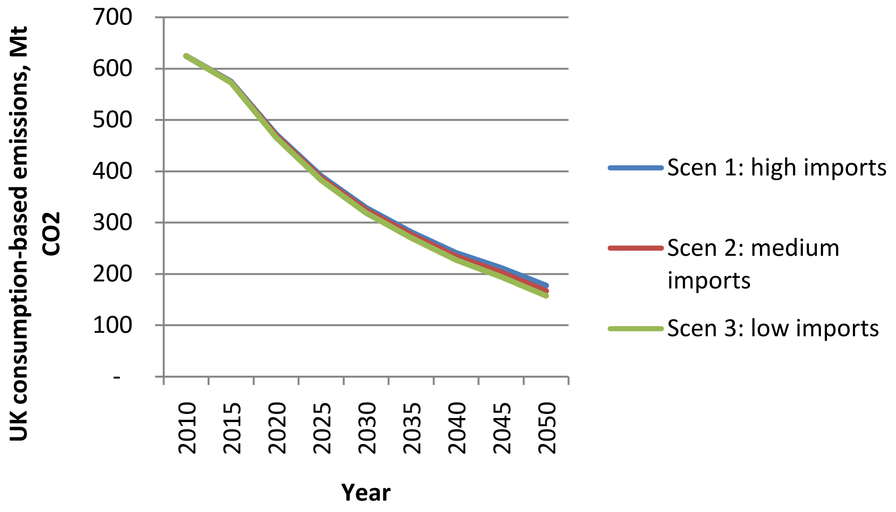


**Figure 8: Summary of scenario 1 emission results with different demand patterns, 2010 - 2050**

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# References

Barrett J., Peters G., Wiedmann T., Scott K., Lenzen M., Roelich K., Le Quere C. (2013) Consumption-based GHG emission accounting: a UK case study. *Climate Policy*, Vol.13, No 6, 1-19, http://dx.doi.org/10.1080/14693062.2013.788858

Davis, S. and Caldeira K. (2010) Consumption-based accounting of $CO_2$ emissions. *PNAS*, 2010: 1-6, doi: 10.1073/pnas.0906974107.

Department for Environment, Food and Rural Affairs (2012) *UK's Carbon Footprint – 1990 to 2010*, Statistical Release, https://www.gov.uk/government/publications/uks-carbon-footprint

Hertwich, E. G., & Peters, G. P. (2009) Carbon footprint of nations: a global, trade-linked analysis. *Environmental science & technology*, 43(16), 6414–20.

House of Commons Energy and Climate Change Select Committee (2012) *Consumption-based emission reporting: Government Response to the Committee's Twelfth Report of Session 2010-12*, The Stationary Office Limited.

Kanemoto, K., Lenzen, M., Peters, G. P., Moran, D., & Geschke, A. (2011) Frameworks for comparing emissions associated with production, consumption, and international trade. *Environmental science & technology*, 46 (1), 172–179, doi:10.1021/es202239t

Lenzen, M., Kanemoto, K., Moran, D., & Geschke, A. (2012a) Mapping the structure of the world economy. *Environmental science & technology*, 46(15), 8374–81, doi:10.1021/es300171x

Lenzen, M., Moran, D., Kanemoto, K., Foran, B., Lobefaro, L., & Geschke, A. (2012b) International trade drives biodiversity threats in developing nations. *Nature*, 486, 109–112, doi:10.1038/nature11145

Lenzen, M., Wood, R., & Wiedmann, T. (2010) Uncertainty Analysis for Multi-Region Input–Output Models – a Case Study of the UK's Carbon Footprint. *Economic Systems Research*, *22*(1), 43–63. doi:10.1080/09535311003661226

Miller, R. E., & Blair, P. D. (2009) *Input-output analysis : foundations and extensions*. Cambridge University Press.

Minx, J., Wiedmann, T., Wood, R., Peters, G. P., Lenzen, M., Owen, A., Scott, K., et al. (2009) Input – Output Analysis and Carbon Footprinting : an Overview of Applications. *Economic Systems*, 21(3), 187–216, doi:10.1080/09535310903541298

ONS (2009) *UK Standard Industrial Classification of Economic Activities 2007 (SIC 2007)*. A National Statistics publication

Peters G. and Hertwich E. (2008b) Post Kyoto Greenhouse Gas Inventories. Production vs consumption. *Climatic Change*, 86 (1-2), 51-66

Peters, G. P. (2008) From production-based to consumption-based national emission inventories. *Ecological Economics*, *65*(1), 13–23, doi:10.1016/j.ecolecon.2007.10.014

Peters, G. P., Andrew, R. M., & Lennox, J. (2011) Constructing an Environmentally-Extended Multi-Regional Input–Output Table Using the Gtap Database. *Economic Systems Research*, 23(2), 131–152, doi:10.1080/09535314.2011.563234

Peters, G. P., Davis, S. J., & Andrew, R. M. (2012) A synthesis of carbon in international trade. *Biogeosciences Discussions*, 9(3), 3949–4023, doi:10.5194/bgd-9-3949-2012

Peters, G., & Solli, C. (2010) *Global Carbon Footprints: Methods and import/export corrected results from the Nordic countries in global carbon footprint studies*. TemaNord 2010:592. Nordic Council of Ministers. Copenhagen, Denmark.

Reisinger, A., Meinshausen, M., Manning, M. and Bodeker, G. ( 2010) Uncertainties of global warming metrics: $CO_2$ and CH4, *Geophysical Research Letters*, 37(14), doi:10.1029/2010GL043803

Timmer, M., Erumban, A. A., Gouma, R., Los, B., & Temurshoev, U. (2012) The World Input - Output Database ( WIOD ): Contents , Sources and Methods. *World*, (April), 1–73.

Tukker, A., & Dietzenbacher, E. (2013) Global Multi-Regional Input-Output Frameworks : An Introduction and Outlook. *Economic Systems Research*, 25(1), 1–19.

Tukker, A., Poliakov, E., Heijungs, R., Hawkins, T. R., Neuwahl, F., Rueda-Cantuche, J. M., Giljum, S., et al. (2009) Towards a global multi-regional environmentally extended input–output database. *Ecological Economics*, 68(7), 1928–1937, doi:10.1016/j.ecolecon.2008.11.010

Weber, C. L. (2008) Uncertainties in Constructing Environmental Multiregional Input-Output Models. *16th International Input-Output Conference*.

Weber, C. L., & Matthews, H. S. (2007) Embodied Environmental Emissions in U.S. International Trade 1997-2004. *Environmental Science & Technology*, *41*, 4875–4881.

Wiedmann, T., H. Wilting, S. Lutter, V. Palm, S. Giljum, A. Wadeskog, and D. Nijdam. (2009a) *Development of a methodology for the assessment of global environmental impacts of traded goods and services*. Environment Agency publication SCHO1009BRAM-E-P, Environment Agency UK and SKEP Network, http://www.eipot.eu

Wiedmann, T. (2009) A review of recent multi-region input–output models used for consumption-based emission and resource accounting. *Ecological Economics*, 69(2), 211–222, doi:10.1016/j.ecolecon.2009.08.026

Wiedmann, T., Wilting, H. C., Lenzen, M., Lutter, S., & Palm, V. (2011) Quo Vadis MRIO? Methodological, data and institutional requirements for multi-region input–output analysis. *Ecological Economics*, 70(11), 1937–1945, doi:10.1016/j.ecolecon.2011.06.014

Wiedmann, T., Lenzen, M., & Wood, R. (2008) UNCERTAINTY ANALYSIS OF THE UK-MRIO MODEL. Report to the Department for Environment, Food and Rural Affairs. *Report to the Department for Environment, Food and Rural Affairs*.

Wiedmann, T., & Barrett, J. (2013) Policy-relevant applications of evironmentally extended MRIO databases - experiences from the UK. *Economic Systems Research*, 25(1), 143–156.

Wilting, H. C. (2012). Sensitivity and uncertainty analysis in MRIO modelling; some empirical results with regard to the Dutch carbon footprint. *Economic Systems Research*, 24(2), 141–171.

Wu, X. and Zhang, Z. (2005) Input–output analysis of the Chinese construction sector. *Construction Management and Economics*, 23(9), 905-912, doi:10.1080/01446190500183974

Zhou, X., & Kojima, S. (2009) How Does Trade Adjustment Influence National Inventory of Open Economies ? Accounting embodied carbon based on multi-region input-output model. *17th International Input-Output Conference*, 1–20.

# Appendix 1: EE-MRIO method

The structure of an EE-IOT is illustrated in Figure 9. Sectoral emissions released directly by sectors are appended to the table. Households also emit GHGs directly[13] that do not enter production activities and hence the IO calculations. They are added to the consumption-based emissions account post-IOA.

| | Purchases by intermediate sectors | Net final demand | Total output |
|---|---|---|---|
| Sales to Intermediate sectors | Z | Y | X |
| Value added | V | | |
| Total input | X | | |
| GHG emissions | F | F | |

**Figure 9: Basic structure of an EE-IOT**

The total output ($X_i$) of a particular sector can be expressed as:

$$X_{i=}z_{i1} + z_{i2} + \cdots + z_{ij} + y_i \qquad (1)$$

where $z_{ij}$ is intermediate demand and $y_i$ is the final demand for the Sector *i*. In this instance output is a measure of the sales of a sector. Alternatively expenditure on inputs equals money generated from sales. A technical coefficients matrix describes intermediate industry input requirements:

$$a_{ij} = \frac{z_{ij}}{X_j} \qquad (2)$$

Where $a_{ij}$ are direct input coefficients, $z_{ij}$ the input from Sector $i$ to Sector $j$ and $X_j$ is the total input to Sector *j*.

Substituting for (2) in equation (1) forms:

$$X_{i=}a_{i1}X_1 + a_{i2}X_2 + \cdots + a_{ij}X_i + y_i \qquad (3)$$

Which, if written in matrix notation is $X{=}AX + Y$. Solving for Y gives:

$$X = (I - A)^{-1}Y \qquad (4)$$

where $X$ and $Y$ are vectors of total output and final demand, respectively, $I$ is the identity matrix, and $A$ is the technical coefficient matrix. $(I\text{-}A)^{-1}$ is known as the Leontief inverse (further identified as $L$). It indicates the inter-industry requirements of the $i^{th}$ sector to deliver a unit of output to final demand.

$$X = LY \qquad (5)$$

[13] From the burning of fuels for heating and travel

A vector of $CO_2$ emissions $F$, shows the volume of emissions generated by industrial sectors. Direct emissions from households are added to the consumption-based account post-IOA. $F_x$ is the emissions per unit of output (the intensity) and multiplying both sides of (4) by $F_x$ gives:

$F_x X = F_x LY$ and simplifies to $F = F_x LY$ (6)

Consumption-based emissions are equivalent to pre-multiplying the Leontief inverse by emissions per unit of output and post-multiplying by final demand, in this case UK demand only. The model is demand driven and shows how a unit change in final demand $Y$, increases the emissions by all sectors to satisfy this change. It assumes a linear relationship between production and changes in final demand, meaning that if final demand for a product doubled, the input requirements and production emissions associated with producing that product would also double. The emissions associated with final demand spend on product $y_1$ is the sum of:

$F_{x1} L_{11} y_1 + F_{x2} L_{21} y_1 + \ldots + F_{xi} L_{i1} y_1$ (7)

The emissions of each sector required in the production of product $y_1$ are reallocated to the demand of this product, rather than the supply. This calculates the emissions associated with product consumption, also referred to as a Carbon or GHG Footprint. Environmental extensions are not limited to greenhouse gas emissions, and include land and resource consumption such as energy and water (Galli et al., 2011).

## Appendix 2: EORA sector classification

UK 110 sectors according to Standard Industrial Classification (2007). The 110 sectors were aggregated to higher level sectors for ease of comparison with CCC production sectors. This allocation is provided in the third column.

| No | Description | High level sector allocation (by CCC) |
|---|---|---|
| 1 | Products of agriculture, hunting and related services | Agriculture & forestry |
| 2 | Products of forestry, logging and related services | Agriculture & forestry |
| 3 | Fish and other fishing products; aquaculture products; support services to fishing | Agriculture & forestry |
| 4 | Coal and lignite | Industry |
| 5 | Crude petroleum and natural gas & metal ores | Industry |
| 6 | Other mining and quarrying products | Industry |
| 7 | Mining support services | Industry |
| 8 | Preserved meat and meat products | Industry |
| 9 | Processed and preserved fish, crustaceans, molluscs, fruit and vegetables | Industry |
| 10 | Vegetable and animal oils and fats | Industry |
| 11 | Dairy products | Industry |
| 12 | Grain mill products, starches and starch products | Industry |
| 13 | Bakery and farinaceous products | Industry |
| 14 | Other food products | Industry |
| 15 | Prepared animal feeds | Industry |
| 16 | Alcoholic beverages | Industry |
| 17 | Soft drinks | Industry |
| 18 | Tobacco products | Industry |
| 19 | Textiles | Industry |
| 20 | Wearing apparel | Industry |
| 21 | Leather and related products | Industry |
| 22 | Wood and of products of wood and cork, except furniture; articles of straw and plaiting materials | Industry |
| 23 | Paper and paper products | Industry |
| 24 | Printing and recording services | Industry |
| 25 | Coke and refined petroleum products | Industry |
| 26 | Paints, varnishes and similar coatings, printing ink and mastics | Industry |
| 27 | Soap and detergents, cleaning and polishing preparations, perfumes and toilet preparations | Industry |
| 28 | Other chemical products | Industry |
| 29 | Industrial gases, inorganics and fertilisers (all inorganic chemicals) - 20.11/13/15 | Industry |
| 30 | Petrochemicals - 20.14/16/17/60 | Industry |

| | | |
|---|---|---|
| 31 | Dyestuffs, agro-chemicals - 20.12/20 | Industry |
| 32 | Basic pharmaceutical products and pharmaceutical preparations | Industry |
| 33 | Rubber and plastic products | Industry |
| 34 | Manufacture of cement, lime, plaster and articles of concrete, cement and plaster | Industry |
| 35 | Glass, refractory, clay, other porcelain and ceramic, stone and abrasive products - 23.1-4/7-9 | Industry |
| 36 | Basic iron and steel | Industry |
| 37 | Other basic metals and casting | Industry |
| 38 | Weapons and ammunition | Industry |
| 39 | Fabricated metal products, excl. machinery and equipment and weapons & ammunition - 25.1-3/25.5-9 | Industry |
| 40 | Computer, electronic and optical products | Industry |
| 41 | Electrical equipment | Industry |
| 42 | Machinery and equipment n.e.c. | Industry |
| 43 | Motor vehicles, trailers and semi-trailers | Industry |
| 44 | Ships and boats | Industry |
| 45 | Air and spacecraft and related machinery | Industry |
| 46 | Other transport equipment - 30.2/4/9 | Industry |
| 47 | Furniture | Industry |
| 48 | Other manufactured goods | Industry |
| 49 | Repair and maintenance of ships and boats | Industry |
| 50 | Repair and maintenance of aircraft and spacecraft | Industry |
| 51 | Rest of repair; Installation - 33.11-14/17/19/20 | Industry |
| 52 | Electricity, transmission and distribution | Power |
| 53 | Gas; distribution of gaseous fuels through mains; steam and air conditioning supply | Power |
| 54 | Natural water; water treatment and supply services | Industry |
| 55 | Sewerage services; sewage sludge | Industry |
| 56 | Waste collection, treatment and disposal services; materials recovery services | Industry |
| 57 | Remediation services and other waste management services | Industry |
| 58 | Buildings and building construction works | Industry |
| 59 | Constructions and construction works for civil engineering | Industry |
| 60 | Specialised construction works | Industry |
| 61 | Wholesale and retail trade and repair services of motor vehicles and motorcycles | Services |
| 62 | Wholesale trade services, except of motor vehicles and motorcycles | Services |
| 63 | Retail trade services, except of motor vehicles and motorcycles | Services |
| 64 | Rail transport services | Transport |
| 65 | Land transport services and transport services via pipelines, excluding rail transport | Transport |
| 66 | Water transport services | Transport |
| 67 | Air transport services | Transport |
| 68 | Warehousing and support services for transportation | Services |
| 69 | Postal and courier services | Services |
| 70 | Accommodation services | Services |

| | | |
|---|---|---|
| 71 | Food and beverage serving services | Services |
| 72 | Publishing services | Services |
| 73 | Motion picture, video and TV programme production services, sound recording & music publishing | Services |
| 74 | Programming and broadcasting services | Services |
| 75 | Telecommunications services | Services |
| 76 | Computer programming, consultancy and related services | Services |
| 77 | Information services | Services |
| 78 | Financial services, except insurance and pension funding | Services |
| 79 | Insurance, reinsurance and pension funding services, except compulsory social security & Pension funding services | Services |
| 80 | Services auxiliary to financial services and insurance services | Services |
| 81 | Real estate services, excluding on a fee or contract basis and imputed rent | Services |
| 82 | Imputed rent services | Services |
| 83 | Real estate activities on a fee or contract basis | Services |
| 84 | Legal services | Services |
| 85 | Accounting, bookkeeping and auditing services; tax consulting services | Services |
| 86 | Services of head offices; management consulting services | Services |
| 87 | Architectural and engineering services; technical testing and analysis services | Services |
| 88 | Scientific research and development services | Services |
| 89 | Advertising and market research services | Services |
| 90 | Other professional, scientific and technical services | Services |
| 91 | Veterinary services | Services |
| 92 | Rental and leasing services | Services |
| 93 | Employment services | Services |
| 94 | Travel agency, tour operator and other reservation services and related services | Services |
| 95 | Security and investigation services | Services |
| 96 | Services to buildings and landscape | Services |
| 97 | Office administrative, office support and other business support services | Services |
| 98 | Public administration and defence services; compulsory social security services | Services |
| 99 | Education services | Services |
| 100 | Human health services | Services |
| 101 | Residential care services | Services |
| 102 | Social work services without accommodation | Services |
| 103 | Creative, arts and entertainment services | Services |
| 104 | Libraries, archives, museums and other cultural services | Services |
| 105 | Gambling and betting services | Services |
| 106 | Sports services and amusement and recreation services | Services |
| 107 | Services furnished by membership organisations | Services |
| 108 | Repair services of computers and personal and household goods | Services |
| 109 | Other personal services | Services |
| 110 | Services of households as employers of domestic personnel | Services |

Rest of world regions Eora 26 harmonised sector Classification. The 26 Eora sectors were aggregated to higher level sectors for ease of comparison with IEA production sectors. This allocation is provided in the third column.

| No | Eora sector description | High level sector allocation (by CCC) |
|---|---|---|
| 1 | Agriculture | Agriculture, non-private transport, non-res buildings, services |
| 2 | Fishing | Agriculture, non-private transport, non-res buildings, services |
| 3 | Mining and Quarrying | Industry |
| 4 | Food & Beverages | Industry |
| 5 | Textiles and Wearing Apparel | Industry |
| 6 | Wood and Paper | Industry |
| 7 | Petroleum, Chemical and Non-Metallic Mineral Products | Industry |
| 8 | Metal Products | Industry |
| 9 | Electrical and Machinery | Industry |
| 10 | Transport Equipment | Industry |
| 11 | Other Manufacturing | Industry |
| 12 | Recycling | Industry |
| 13 | Electricity, Gas and Water | Power |
| 14 | Construction | Industry |
| 15 | Maintenance and Repair | Industry |
| 16 | Wholesale Trade | Agriculture, non-private transport, non-res buildings, services |
| 17 | Retail Trade | Agriculture, non-private transport, non-res buildings, services |
| 18 | Hotels and Restaurants | Agriculture, non-private transport, non-res buildings, services |
| 19 | Transport | Agriculture, non-private transport, non-res buildings, services |
| 20 | Post and Telecommunications | Agriculture, non-private transport, non-res buildings, services |
| 21 | Financial Intermediation and Business Activities | Agriculture, non-private transport, non-res buildings, services |
| 22 | Public Administration | Agriculture, non-private transport, non-res buildings, services |
| 23 | Education, Health and Other Services | Agriculture, non-private transport, non-res buildings, services |
| 24 | Private Households | Agriculture, non-private transport, non-res buildings, services |
| 25 | Others | N/A |
| 26 | Re-export & Re-import | N/A |

# Appendix 3: Evidence base for scenarios (contributed by the CCC)

The CCC scenarios for future UK consumption emissions incorporate scenarios for UK production emissions together with scenarios for demand, imports and emissions intensity in other countries. These scenarios required making a number of assumptions regarding future emissions trajectories, economic output, and UK demand, which are described in detail below.

The University of Leeds provided the CCC with historic (1993-2010) datasets extracted from Eora[14], which are inputted into the EE-MRIO model to estimate current and historic UK consumption emissions. These datasets included historical trends for the UK (for 110 individual economic sectors) and for seven other world regions (for 26 individual sectors) for the following variables:

- Historic production emissions for both $CO_2$ and all greenhouse gases ($CO_2e$)
- Historic sectoral economic output
- Historic emissions intensities (production emissions divided by economic output)
- Final UK demand (in current £) for all goods and services both in the UK and regions assessed

Five scenarios explore the implications of a range of existing high-level global emissions pathways for the UK's consumption-based emissions trajectory. Historical data along with other historical trends and CCC/IEA long-term emissions pathways were used to project future levels of economic output, emissions intensity, and final demand. Developing these projections involved four key steps:

A. Aligning future emissions pathways with historic emissions data
B. Projecting future economic output by sector
C. Calculating future emissions intensities of production (in the UK and rest of the world)
D. Projecting future UK demand for imported and domestic goods and services

## A. Aligning future emissions pathways with historic emissions data

The CCC first aligned high level future UK and rest of the world emissions trajectories with historic emissions data from Eora's sector classification.

### i. UK production emissions to 2050

*ONS sectors*

Historic UK emissions data used for estimating the UK's carbon footprint in the Leeds EE-MRIO model are obtained from the Office for National Statistics Environmental Accounts[15] and are disaggregated to 110 economic sectors on the basis of SIC codes (see Appendix 2: EORA sector classification).

*CCC sectors and pathways to 2050 (production basis)*

CCC scenarios for meeting carbon budgets and the 2050 target in the Climate Change Act (to reduce 2050 production emissions by 80% on 1990 levels) examine emissions reductions pathways in the key emitting sectors of the UK's economy, including power generation, buildings and industry, surface transport, international aviation and shipping emissions), agriculture and waste.

[14] Eora World MRIO database (2012), http://www.worldmrio.com/
[15] ONS (2012) Environmental Accounts

In its International Aviation and Shipping advice published in 2012[16] the CCC identified a range of abatement options for reducing emissions across the key emitting sectors to achieve the 2050 target. These options reflected a combination of improved energy efficiency, behaviour change to reduce demand for emitting activities, and increasing use of low-carbon sources of energy supply in place of unabated fossil fuels. The scenarios also reflect the UK's expected growth in population from around 63 million in 2010 to 75 million in 2050 (+19 million).

The CCC developed deployment ranges for key abatement measures in each sector based on detailed modelling of technology costs, deployment constraints and interactions within the energy sectors. Deployment ranges were combined with sectoral deployment levels to create economy-wide scenarios. These identified how an 80% reduction target could be met, including when some barriers to deployment of technologies cannot be overcome (e.g. potential consumer resistance to uptake of heat pumps or electric vehicles), or in the absence of key technologies (e.g. CCS).

All scenarios meet the 2050 target but with different contributions from individual sectors. For the modelling of future UK consumption emissions, the "Barriers in Industry" production emissions scenario was selected. This scenario was chosen as it required maximum deployment of abatement in just one sector (surface transport). A sensitivity on this scenario, where carbon capture technology is not available, was also explored. In this scenario, additional renewable and nuclear capacity replaces CCS (at higher costs) and (higher cost) electrification of industry as well as full decarbonisation of surface transport is required in order to meet the 2050 target.

The 2012 advice did not model detailed emissions pathways between 2030 and 2050. For the Leeds modelling, the CCC applied a linear trend to estimate annual emissions reductions between 2030 and 2050 in 5-year intervals.

*Aligning CCC with ONS sectors*

The future emissions pathways for these key emitting sectors needed to be aligned with historic emissions data for the 110 ONS sectors. First, the ONS 110 sectors were aggregated to higher level sectors for ease of comparison with CCC production sectors (see Appendix 2: EORA sector classification for aggregation).

Next, the high level ONS sectors were aligned with the CCC sectors:

- For some sectors, aligning emissions was straightforward (e.g. CCC power sector emissions encompass ONS emissions allocated to SIC code 35 – "Electricity, transmission and distribution and Gas; distribution of gaseous fuels through mains; steam and air conditioning supply").
- Aligning emissions arising in the ONS "Services" sectors to CCC sectors was less straightforward. Discussions with ONS and Defra suggested that ONS "Services" emissions encompass mainly non-residential buildings and surface transport emissions arising from commercial and public sector activities. To understand the precise breakdown of Service sector emissions, energy use statistics by UK SIC codes[17] were analysed, which suggested that 20% of all surface transport emissions are allocated to the Services sector (e.g. are directly emitted by Services sectors).
- ONS Environmental Accounts emissions differentiate between direct household travel (e.g. emissions arising from personal car use by residents) and surface transport emissions occurring

[16] CCC (2012) *The 2050 target – achieving an 80% reduction including emissions from international aviation and shipping*, http://www.theccc.org.uk/publication/international-aviation-shipping-review/
[17] ONS (2013) Energy Use by Industry - Source and Fuel, 1990-2010

in the rest of the economy. CCC scenarios for future surface transport emissions do not make this distinction. Analysis of energy use statistics showed that 60% of UK transport emissions are related to private transport. This assumption was applied forward (i.e. 60% of surface transport emissions in the CCC scenarios were allocated to the ONS direct household travel sector).

- As a result, only 20% of surface transport emissions in the CCC's scenarios were assigned to the ONS transport sector (60% are assigned to private transport and 20% to Services).

Table A3.1 describes how CCC production emissions were allocated to the high level ONS sectors.

**Table A3.1 Alignment of CCC UK production emission sectors with ONS high level sectors**

| ONS high level sectors | CCC production emission sectors |
|---|---|
| Agriculture & forestry | Agriculture & forestry emissions |
| Industry | Industry emissions |
| Power | Power emissions |
| Services | 20% Surface transport emissions<br>All non-residential buildings emissions |
| Transport | 20% Surface transport emissions<br>All International aviation & shipping emissions |
| Direct household transport | 60% of Surface transport emissions |
| Direct household heat | Residential buildings emissions |

### ii. Rest of the world production emissions to 2050

The International Energy Agency (IEA) provided detailed emissions trajectories by sector and region from its 2012 *Energy Technology Perspectives* (ETP) publication, which explores global emission scenarios and strategies to achieve the objective of limiting the global average temperature rise to 2°C (2DS). It also explores less ambitious energy futures including a scenario where international actions do not go beyond the pledges made at the UN Climate Change Conference in Copenhagen in 2009. This scenario is projected to lead to a long-term temperature rise of 4°C (4DS):

The IEA ETP model explores pathways for reducing emissions in the following high-level sectors:

- Power generation
- Industry (and other transformation)
- Transport
- Residential and commercial buildings
- Energy-related emission from agriculture, fisheries, and other activities.

The ETP model covers $CO_2$ emissions only from 28 regions. The CCC requested that the IEA aggregate emissions data to the seven regions selected in the EE-MRIO , including OECD Europe (as a proxy for the European Union), rest of the OECD, China, India, the rest of developing Asia, Russia, and rest of the world). Table A3.2 details IEA emissions trajectories by sector and region for the 2DS scenario.

**Table A3.2 IEA two degree emissions scenario by region and sector (Mt $CO_2$)**

| | Scenario | 2009 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| OECD Europe | 2DS | 3,888 | 3,963 | 3,876 | 3,749 | 3,184 | 2,771 | 2,366 | 2,107 | 1,868 | 1,659 |
| All other OECD | 2DS | 8,549 | 8,745 | 8,842 | 8,621 | 7,530 | 6,139 | 5,021 | 4,232 | 3,622 | 3,146 |
| China | 2DS | 7,897 | 8,378 | 9,419 | 9,537 | 8,438 | 6,835 | 5,327 | 4,354 | 3,907 | 3,561 |
| India | 2DS | 1,727 | 1,795 | 2,278 | 2,338 | 2,127 | 1,985 | 1,972 | 1,978 | 1,996 | 1,913 |
| Rest of developing Asia | 2DS | 1,701 | 1,754 | 2,000 | 2,072 | 1,946 | 1,807 | 1,681 | 1,574 | 1,504 | 1,406 |
| Russia | 2DS | 1,709 | 1,701 | 1,622 | 1,506 | 1,334 | 1,169 | 1,017 | 885 | 764 | 657 |
| ROW | 2DS | 5,608 | 5,786 | 6,178 | 6,261 | 5,843 | 5,391 | 4,956 | 4,605 | 4,258 | 3,811 |
| **Total** | | **31,079** | **32,122** | **34,216** | **34,085** | **30,403** | **26,098** | **22,342** | **19,734** | **17,919** | **16,152** |

| | Scenario | 2009 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Power generation | 2DS | 11,827 | 12,048 | 13,298 | 12,766 | 10,062 | 7,183 | 4,836 | 3,418 | 2,868 | 2,351 |
| Industry | 2DS | 7,864 | 8,347 | 8,862 | 8,923 | 8,636 | 8,168 | 7,710 | 7,419 | 7,082 | 6,695 |
| Non-residential building | 2DS | 874 | 858 | 869 | 883 | 895 | 897 | 870 | 839 | 809 | 779 |
| Residential buildings | 2DS | 1,924 | 1,930 | 1,857 | 1,812 | 1,753 | 1,666 | 1,578 | 1,491 | 1,395 | 1,296 |
| Transport | 2DS | 6,422 | 6,756 | 6,907 | 7,339 | 6,926 | 6,385 | 5,889 | 5,460 | 5,014 | 4,676 |
| Other transformation | 2DS | 1,586 | 1,577 | 1,651 | 1,632 | 1,471 | 1,174 | 823 | 503 | 170 | - 202 |
| Agriculture, fisheries, otl | 2DS | 583 | 606 | 771 | 730 | 660 | 626 | 636 | 604 | 581 | 557 |
| **Total** | | **31,079** | **32,122** | **34,216** | **34,085** | **30,403** | **26,098** | **22,342** | **19,734** | **17,919** | **16,152** |

Source: IEA (2012) *Energy Technology Perspectives*

The next step aligned historic Eora sectoral emissions data with IEA sectoral emissions trajectories:

- First, UK $CO_2$ emissions data was subtracted from the IEA $CO_2$ emissions data set to better compare IEA emissions data with Eora rest of the world emissions data provided to the CCC.
- As in the UK analysis, aligning ONS emissions for the Service and Transport sector with IEA emissions pathways was less straightforward.
  - First, emissions released directly by households abroad (e.g. residential heating and private transport) were subtracted from IEA emissions pathways data as they are not part of intermediate production activities and therefore do not become embodied in UK imports.
  - IEA scenarios for buildings emissions distinguish between residential and non-residential emissions, so subtracting residential emissions was straightforward.
  - However, IEA transport sector emissions scenarios do not differentiate between household and non-household travel. Eora contains direct household emissions for all regions however these are not split by heating and travel, but rather aligned with EDGAR emissions for the residential sector. This split was interpolated by examining the proportion of IEA residential building emissions as a proportion of total Eora direct household emissions data (i.e. including residential buildings and transport).
- Having re-aligned IEA emissions data to the Eora high level sectors, emissions data for 2010 between the two datasets were compared. In power and industry sectors, emissions data were found to be similar in IEA and Eora databases (+/10% difference). Agriculture and forestry, services, and transport sector emissions data were quite different therefore these IEA sectors were aggregated to one sector where they better aligned with Eora data (5% difference).

Table A3.3 below compares emissions data between Eora and IEA.

Taking the high level CCC domestic production sectors and the three IEA sectors (power, industry and a combined sector of agriculture, transport, and services) the CCC used proportional analysis to model detailed sectoral emissions trajectories using CCC/IEA emissions trajectories out to 2050. For example, if emission from textiles production represented 3% of total Chinese industry emissions in

2010, it was assumed that Chinese textiles emissions would continue to represent 3% of total emissions under the IEA's decarbonisation pathways for Chinese industrial emissions.

**Table A3.3 Comparison of 2010 global $CO_2$ emissions (excluding UK) in IEA and Eora databases**

| $MtCO_2$ | IEA | Eora | % difference |
|---|---|---|---|
| Power | 12,048 | 12,783 | 6% |
| Industry | 9,811 | 8,613 | -12% |
| Agriculture, non-private transport, non-res buildings, services | 8,095 | 8,515 | 5% |

### iii. Emissions scenarios

The above steps were repeated for **five** scenarios incorporating various emissions pathways in the UK and rest of the world. As IEA covers reductions in energy-related $CO_2$ emissions only, most scenarios focused on estimating the UK's carbon footprint for $CO_2$ emissions only. A final scenario (Scenario 5) includes non-$CO_2$ emissions. These scenarios are described below:

1. **2 degree future ($CO_2$):** The UK reduces its emissions to meet its 2050 target compatible with the 2 degree climate objective ("Barriers in industry" scenario described above). Rest of the world emissions follow the IEA's 2DS emissions scenario.

2. **2 degree future without availability of CCS technology ($CO_2$):** The UK meets its 2050 target but without the availability of CCS (thus requiring more deployment of renewable and nuclear, electrification in industry, and full decarbonisation of transport). Rest of the world emissions fall in line with the IEA's 2DS scenario but without the availability of CCS (thus global emissions are higher than the 2DS scenario).

3. **2 degree future with overseas production intensities converging to UK intensities ($CO_2$)**: Rest of the world emissions intensities fall in line with the UK's (reflecting a 2 degree "Barriers in industry" scenario) starting in 2030.

4. **4 degree future ($CO_2$):** The UK meets its 2050 target under a "Barriers in industry" scenario but rest of the world emissions fall in line with the IEA's 4DS scenario.

5. **2 degree future including all GHGs:** As the UK's 2050 target is based on all GHGs, a scenario for non-$CO_2$ emissions reductions - based on climate modelling work described in the CCC's 2008 report on setting 2050 target[18] - was explored:

   - This modelling explored several pathways for reductions in all greenhouse gases
   - We used a 2DS scenario consistent with IEA, where non-$CO_2$ emissions are around 7.6 $GtCO_2e$ in 2050
   - Eora emissions data for $CO_2$ were subtracted from all $CO_2e$ data to determine non-$CO_2$ emissions for each sector and region in 2010 (totalling around 12.8 $GtCO_2e$).

[18] CCC and Met Office Hadley Centre analysis for CCC (2008), Building a low-carbon economy – the UK's contribution to tackling climate change, Chapter 1 Technical Appendix: Projecting global emissions, concentrations, and temperatures.

– Using proportional analysis, non-$CO_2$ emissions in each sector by region were reduced in line with global non-$CO_2$ emissions pathways (less UK non-$CO_2$ emissions).

As a result, detailed emissions trajectories for each scenario for 110 UK sectors and 26 sectors in each of the seven trading regions were developed (between 2010 and 2050).

## B. Projecting future economic output by sector

Having modelled detailed emissions pathways for each sector in step A, the next step was to project economic output for all regions and sectors. Office for Budget Responsibility (OBR) projections were used to project UK economic output for the whole economy and IMF and other sources were used to project economic output in the seven trading regions (Table A3.4).

As for emissions data, proportional analysis was used to project economic growth by sector, such that a given sector was assumed to account for the same proportion of total economic output in 2010 as in 2050. These assumptions therefore do not account for structural changes in the economy.

**Table A3.4 CCC assumptions for annual growth in regional economic output**

| | 2011-15 | 2016-20 | 2021-25 | 2026-30 | 2031-35 | 2036-40 | 2041-50 |
|---|---|---|---|---|---|---|---|
| Rest of OECD Europe | 1.7% | 1.9% | 2.8% | 1.9% | 1.4% | 1.2% | 1.5% |
| Rest of world | 4.9% | 3.7% | 3.8% | 3.3% | 2.9% | 3.0% | 3.9% |
| China | 8.5% | 10.2% | 8.0% | 5.6% | 4.7% | 3.9% | 2.8% |
| India | 6.2% | 9.3% | 8.8% | 7.5% | 8.1% | 7.5% | 5.5% |
| United Kingdom | 1.3% | 1.9% | 2.7% | 2.0% | 1.5% | 1.1% | 1.4% |
| Russia | 3.9% | 4.4% | 3.1% | 4.6% | 6.9% | 6.6% | 3.6% |
| Rest of dev. Asia | 7.2% | 6.7% | 6.0% | 4.0% | 2.9% | 2.5% | 3.3% |
| Rest of OECD | 2.9% | 2.5% | 2.6% | 2.2% | 2.0% | 1.8% | 2.0% |

Source: OBR (2012); Department for Transport (2013) obtained from a combination of IMF projections and assumptions used by DECC, https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/183931/aviation-forecasts.pdf

## C. Calculating future emissions intensities of production

Taking together projections for emissions and economic output by sector (110 for the UK and 26 for all other regions), we estimated emissions intensities out to 2050 (sectoral emissions divided by sectoral economic output).

## D. Projecting future UK demand for imported and domestic goods and services

### i. Final demand

To account for sensitivity in consumption-based emissions resulting from trade patterns, growing demand is met by three levels of demand between domestic and imported products. These assumptions are summarised in Table A3.5.

**Table A3.5 CCC assumptions for growth in imports and domestic demand**

| Scenario | Demand (annual growth, 2010-2050) Imports | Domestic demand | Source/Notes |
|---|---|---|---|
| Low imports | 2.25% | 2.2% | Import growth in line with average long-run UK GDP growth; UK demand for domestic goods/service adjusted such that trade balance similar to current levels (deficit less than 10%). |
| Central imports | 2.75% | 1.9% | Import growth halfway between low/high import growth scenario, reflecting increase in import share of GDP to ~40% in 2050; domestic demand growth adjusted to maintain trade balance. |
| High imports | 3.25% | 1.6% | Import growth in line with historic rate of import growth from 1975-2011. This rate may not be sustainable in future as it reflects a period of strong growth in trade and would imply an increase in imports share of GDP to 50% in 2050 (and therefore is applied in the high demand scenario). |

### ii. Import penetration by region

As UK imports have gradually shifted away from the rest of Europe towards emerging economies, we assumed that UK import demand continues to shift towards emerging economies, although at less than recent rates, such that by 2050, 50% of UK imports are from emerging economies, including China and India. Table A3.4 provides more detail of our assumptions.

**Table A3.4**

**UK import demand share (historic and CCC projections)**

| | | 1993 | 1995 | 2000 | 2005 | 2010 | 2015 | 2020 | 2025 | 2030 | 2035 | 2040 | 2045 | 2050 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Emerging | Rest of developing Asia | 4% | 4% | 4% | 4% | 8% | 9% | 10% | 12% | 13% | 14% | 15% | 17% | 18% |
| Advanced | Rest of OECD Europe | 66% | 63% | 64% | 59% | 47% | 45% | 43% | 41% | 40% | 38% | 36% | 34% | 33% |
| Emerging | India | 0% | 0% | 1% | 1% | 1% | 1% | 1% | 2% | 2% | 2% | 2% | 3% | 3% |
| Advanced | Rest of OECD | 16% | 18% | 17% | 17% | 25% | 24% | 23% | 22% | 21% | 20% | 19% | 18% | 17% |
| Emerging | Rest of world | 11% | 9% | 11% | 12% | 11% | 11% | 10% | 10% | 10% | 10% | 10% | 10% | 10% |
| Emerging | China | 2% | 4% | 2% | 5% | 7% | 8% | 10% | 11% | 12% | 14% | 15% | 16% | 18% |
| Emerging | Russia | 1% | 2% | 2% | 3% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% | 2% |
| | | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |
| | Emerging | 18% | 19% | 19% | 24% | 29% | 31% | 34% | 36% | 39% | 42% | 45% | 47% | 50% |
| | Advanced | 82% | 81% | 81% | 76% | 71% | 69% | 66% | 64% | 61% | 58% | 55% | 53% | 50% |
| | | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% | 100% |

### iii. Shift in demand away from fossil fuels

As the UK moves to a low-carbon economy, demand for fossil fuels and associated products is likely to decrease and move towards other goods and services. To explore this future, the scenarios incorporate a shift away from fossil fuels sectors and towards all other economic sectors (on an equal basis). Exploring this shift for imported goods and services was complicated by the fact that final demand for fossil fuels data from Eora is only available in the higher level economic sector **“Petroleum, chemicals and non-metallic minerals"** which covers a broad set of sub-sectors including fossil fuels (both crude and refined), petrochemicals/petrochemical products, other chemical products such as pharmaceuticals, and minerals such as cement, ceramics, glass and lime.

To understand the breakdown of imports for fossil fuels for energy use, HMRC highly disaggregated trade data was examined. HMRC data showed that around 50-60% of imports in the aggregated category are related to fossil fuels, so this share was applied forward for future demand. While UK demand for other products within the sector (chemicals, non-metallic mineral products, petrochemicals) was forecast to increase at the projected rates (see "Final demand" above), demand for fossil fuels for energy use gradually declines over time.