UK Consumption Emissions by Sector and Origin

Sustainability Research Institute, University of Leeds and Stockholm Environment Institute, University of York

A research report completed for the Department for Environment, Food and Rural Affairs

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Final Report to the Department for Environment, Food and Rural Affairs

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Glossary

CDIAC	Carbon Dioxide Information Analysis Centre
CO2e	Carbon dioxide equivalent
Defra	Department for Environment, Food and Rural Affairs
GTAP	Global Trade Assessment Programme
IO	Input Output
MRIO	Multi-Regional Input Output
OPEN-EU	Open Planet Economy Europe
ROW	Rest of World
OECD	Organisation for Economic Cooperation and Development
UNFCCC	United Nations Framework Convention on Climate Change
USEPA	US Environmental Protection Agency

Executive Summary

1. This report provides an analysis of where Greenhouse Gas emissions associated with UK consumption occur by both sector and country. To undertake this task a “Multi-Regional Environmentally extended input-output analysis” (MREEIOA) is employed to allocate environmental pressures (e.g. emissions of greenhouse gases) associated with production and supply chain processes to groups of finished products by means of inter-industry economic transactions. The majority of the data is derived from the “Global Trade Analysis Project” and forms part of the outputs from a European 7th Framework project entitled, “OPEN-EU”.

2. The UK’s full supply chain emissions for 2004 from a consumption perspective are 853Mt CO2e. This does not include direct emissions from households as a result of burning fuel for heating and private car use. These account for a further 161Mt CO2e bringing the total emissions to 1014 Mt CO2e. This figure is consistent with other models that have divided the rest of the world into fewer regions (Wiedmann and Barrett, 2011), demonstrating consistency and agreement across the various models.

3. Of the 853 Mt CO2e, 89% of these emissions were associated with household consumption and the remainder related to public administration and defence. Of the 726 Mt CO2e associated with household consumption, 45% of emissions are from consumption satisfied by UK production. Therefore, 55% of CO2e emissions to provide UK households with goods and services occur outside the UK. The variation between products is substantial with some products having 94% of their “carbon footprint” inside the UK and other only having “17”%.

4. Of the 853 Mt CO2e, 15 product groups account for more than 75% of total emissions. Over 55% of the emissions associated with these products occur overseas. Electricity is the most significant product, where 94% of the emissions occur inside the UK. Excluding electricity, the emissions associated with the other key products have a greater proportion of emissions occurring overseas (over 61%). In some cases such as electronic equipment and clothing, over 80% of the emissions occur outside the UK.

5. Only a fifth of UK’s emissions embodied in imports come from the European Union. 78% of emissions occur outside the European Union. The highest proportion of emissions comes from Asia, accounting for 36% of the total. Other regions of significance are North America (12%) and the rest of Europe (10%). Together, these four regions account for 80% of imported emissions.

6. From a country perspective, 15 countries / world regions (out of a total of 113) account for nearly 70% of the total emissions associated with imports. They account for a total of 267 million tonnes of CO2e emissions. In terms of comparison, this is equivalent to all the UK electricity emission and household gas use. The country with the highest level of emissions

to satisfy UK consumption is China, by quite some margin. Over 81Mt CO2e occur in China related to UK consumption. This is nearly twice as large as the next country, the USA with emissions of 44 Mt CO2e. The next two countries are Russia and South Africa, demonstrating that countries with the most significant emissions occur outside the European Union.

7. Of the 81Mt CO2e associated with China, 43% of the emissions are associated with two products, these being electronic equipment and textiles. Other products of significance include vehicle and transport equipment, services and construction. The majority of the embodied carbon is from products or intermediate materials as opposed to the importing of raw materials.

8. With a specific profile on textiles, China is the largest provider of finished textiles and clothing products, supplying around 13% of all UK imports, followed by Italy (9%) and Southeast Asia (9%). Further emissions are associated with the import of intermediate products where the final assembly is within Europe. In terms of the emissions from all textiles, the majority of UK emissions, more than two thirds, are generated in other regions of the world. A significant portion of these take place in China, which is the biggest exporter of textiles and clothing (finished and intermediate products) to the UK. To be precise, around 27% of all emissions from textiles & clothing have their source in that particular country. In the case of leather products, China accounts for almost 45% of emissions associated with leather for UK consumption.

9. The application of this data is widespread. In particular, it could be used to provide greater detail on assigning responsibility as part of international negotiations. The data demonstrates which sectors have the highest carbon intensity down the supply chain of all UK products, providing valuable information on where the need for clean technology is most pressing. Additionally, the data has been used for maximum effect by the Carbon Trust to understand the scale and issues surrounding carbon leakage in the UK.

10. Additional applications relate strongly to informing the numerous initiatives related to sustainable production and consumption. It is clear that a demand side perspective for some products could deliver greater carbon reduction potential, hence the importance of product roadmaps currently being developed by Defra. Products that are both high in terms of emissions with the majority of the emissions occurring overseas include electronic equipment, textile and clothing, motor vehicles and construction equipment.

11. Finally, detailed supply chain data can be made available through these models allowing industry to fully appreciate the complex of their supply chains.

1 Introduction

This report provides an analysis of where Greenhouse Gas emissions associated with UK consumption occur by both sector and country. The analysis is provided for 2004 as this is the last complete year where a full global database is available. The analysis adds to other studies undertaken for Defra on the consumer emissions associated with the UK (Wiedmann et al, 2008, Minx et al, 2009, Wiedmann and Barrett, 2010).

Through these previous studies, the UK Government is fully aware of the fact that consumer emissions in the UK are higher than territorial emissions. Consumer emissions account for the full lifecycle emissions associated with all the products consumed by UK residents, while territorial emissions are the GHG emissions emitted within the territory of the UK. With the UK becoming increasingly reliant on imported products it is not surprising than consumer emissions have continued to rise in the UK while territorial emissions are falling.

Previous analysis of consumer emissions has been limited in terms of providing insights into where they occurred (i.e. which country and sector). The first study by Wiedmann et al divided the “Rest of the World” (ROW) into three world regions (Wiedmann et al, 2008). Further studies have been commissioned to provide the UK with an annual consumer emissions indicator. This approach considers emissions between the UK and the rest of the world and the associated carbon trade balance, therefore adopting a two region approach.

This analysis provides depth in the understanding in terms of country and sector of emissions for the UK. To undertake this task a “Multi-Regional Environmentally extended input-output analysis” (MREEIOA) is employed to allocate environmental pressures (e.g. emissions of greenhouse gases) associated with production and supply chain processes to groups of finished products by means of inter-industry economic transactions. The main data sources are sectoral macro-economic and environmental accounts of each country combined with national input-output tables.

The MREEIOA model traces the embedded Greenhouse Gas Emissions of 57 product groups for 2004 across 113 countries and 57 sectors (6441 different sectors in total). This report provides an understanding of the model, the results and discusses their application to UK policy.

The data was obtained from a number of sources, but primarily built on the model currently under development for a European 7th Framework research project entitled “One Planet Economy Network” (OPEN-EU). The project is being coordinated by WWF-UK and the modelling to deliver a software tool for the project is being undertaken by NTNU and SEI.

2 Methods and approach

2.1 History of MRIO Models

The MRIO models link environmental pressures, such as Greenhouse Gas Emissions, with final consumption through understanding global supply chains. In short, the model links production to consumption by a detailed understanding of the integration between both sectors and countries. MRIO models are now recognised as one of the leading, if not only, approach to undertake such a task (Peter, 2010, Wiedmann, 2009, Minx et al, 2009). MRIO models are extremely data intensive thus limiting the number of data sources used to construct such models. One of the key data requirements are national input-output tables. While many countries produce such tables there are gaps, and the classifications and years are inconsistent. Therefore, for MRIO models to reflect a global picture, a consistent database provided by Purdew University is often employed, called “Global Trade Analysis Project” (GTAP). Alternatively data provided by the OECD is applied however the global coverage of this data is limited.

A more detailed description of the history of MRIO modelling can be found in Wiedmann (2009).

2.2 Methodology

The standard Input-Output analysis considers that the output (*X*) of sector “*i*” is given by:

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

where each x_{ij} represents the contributions from the “*i-th*” sector to “*j-th*” sector or industry in an economy, and where y_i stands for final demand. In other words, the total output of a particular sector is determined by its intermediate and final demand.

If each x_{ij} is divided by the total output of its corresponding sector:

$$a_{ij}=\frac{x_{ij}}{X_i} \qquad (2)$$

then, after rearranging (2), equation (1) can be reformulated as:

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

This last equation, in turn, can be expressed in matrix notation as $X=AX+Y$, and after solving for *X*, it becomes:

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

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, which shows the inter-industry requirements. On the other hand, the first term at the right hand of the equation deserves special attention. $(I-A)^{-1}$ 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.

Under a Multi-Region Input-Output (MRIO) framework, *A* has to account not only for domestically produced goods and services within the different regions, but also for the trade that takes place between them. In this sense, the sectoral requirements of region "*m*" are decomposed into a domestic component —which represents inter-industry relationships within the region— and another one that represents imports —which show the inter-industry relationships with other sectors located in the "*n-th*" region.

$$A_m = A_m^D + \sum A_n^I \qquad (5)$$

Hence, *A* becomes a square composite matrix formed by a number of blocks. The diagonal blocks (i.e. A_{mn}^D, where *m*=*n*) represent domestic IO matrices, which show the inter-linkages between sectors located within regions. Conversely, the off-diagonal blocks (i.e. A_{mn}^I, where *m*≠*n*) represent the sectoral requirements of region "*m*" from other sectors located in region "*n*". These are known as the import matrices.

$$A = \begin{Bmatrix} A_{11}^D & A_{12}^I & \cdots & A_{1n}^I \\ A_{21}^I & A_{22}^D & \cdots & A_{2n}^I \\ \vdots & \vdots & \ddots & \vdots \\ A_{m1}^I & A_{m2}^I & \cdots & A_{mn}^D \end{Bmatrix} \qquad (6)$$

Similarly, *X* and *Y* must include total output and final demand, respectively, of all sectors located in all regions. Regarding *Y*, it incorporates all the components of final demand (i.e. private and public consumption, gross capital formation and change in stocks) of domestically produced goods and services (Y^D) within region "*m*", as well as of imported products and services (Y^I) from region "*n*" to be consumed in "*m*". Moreover, goods and services produced domestically (*E*), but consumed in region "*n*" (i.e. exports) are equally considered to be a part of *Y*.

$$X = \begin{Bmatrix} X_1 \\ X_2 \\ \vdots \\ X_m \end{Bmatrix} \quad \text{and} \quad Y = \begin{Bmatrix} Y_1 + \sum E_{1n} \\ Y_2 + \sum E_{2n} \\ \vdots \\ Y_m + \sum E_{mn} \end{Bmatrix} \qquad (7)$$

In this sense, in an open economy equation (4) can be rewritten as:

$$X = (A^D + A^I)\, X + Y^D + Y^{I+} + E - M \qquad (8)$$

And since total imports (*M*) are equal to imports to intermediate demand (A^I) plus imports to final consumption (Y^I),

$$M = A^I\, X + Y^I \qquad (9)$$

then, by substituting (9) in (8), exactly the same form of equation (4) is obtained once again. This implies that it can be used to determine the amount of output (*X*) from any arbitrary demand.

In the context of an Multi-Regional Environmentally Extended Input-Output (MREEIO) model, environmental impacts are included as an extra vector. This report focuses specifically on GHG emissions, which are assumed to be a function of output. If the emissions (*g*) generated by sector "*i*" are divided by the corresponding output (X_i), then a row vector of direct intensities (*G*) are obtained, just as is expressed by equation (10):

$$G = \frac{g_i}{X_i} \qquad (10)$$

In order to calculate the amount of emissions that would result from a certain level of output, *G* —known as the direct intensity multipliers— is post-multiplied by *X*. So by substituting this last variable according to equation (4), the direct emissions (F^d) are determined by:

$$F^d=\hat{G}LY \qquad (11)$$

where the symbol "^" stands for a diagonal vector. *G* provides a set of weights to the *L* matrix, forming the total intensity multipliers (*GL*). Thus, when this new matrix ($\hat{G}L$) is post-multiplied by *Y*, then direct emissions are obtained.

Another approach is to post-multiply *GL* by $\hat{Y}$, which allows determining the indirect emissions (F^i) originated from a given level of final demand.

$$F^i=GL\hat{Y} \qquad (12)$$

Both approaches yield the same amount of total emissions. However, they differ in terms of the entities to which they are allocated (Munksgaard and Pedersen, 2001; Gallego and Lenzen, 2005; Lenzen et al., 2007; Peters, 2008). In the first one, these are assigned to the sectors (industries) where the emissions were generated during production. Conversely, in the second one, these are allocated to the final consumers —which can be households, firms or the government— in terms of their final demand.

2.3 Data Sources

A Multi-Regional Environmentally Extended Input-Output model requires a substantial amount of data. Domestic IO tables are required for each region, as well as bilateral trade data and environmental impact variables. Fortunately, the Global Trade Analysis Project (GTAP), which involves a network of researchers who conduct global economic analyses —by using computable general equilibrium models—, has made all this data available.

The MREEIO model used in this report features data for the year 2004 extracted from the GTAP version 7 dataset (the latest available), which includes 113 regions and 57 sectors. This means that the technical coefficients matrix (*A*) has a dimension of 6441 rows by 6441 columns. In addition to this matrix, there is another one for final demand, which is constituted by four categories for each region (households, government, capital formation and variation in stocks). It forms a matrix with a dimension of 6441 rows by 452 columns.

Accompanying all these matrices, there is also a vector of environmental extensions, consisting of total annual GHG emissions for all the 113x57 region-sectors of GTAP 7. CO_2 emissions were calculated according to the Tier 1 method suggested in the revised 1996 IPCC guidelines (Lee, 2008), and by using energy statistics published by the International Energy Agency (IEA). Under the IPCC accounting rules, mitigation only applies to "greenhouse gas emissions and removals taking place within national territory and offshore areas over which the country has jurisdiction" (taken from Peters et al, 2011). In this sense, emissions are derived from six energy sources or carriers: coal, crude oil, natural gas, petroleum products, electricity and gas distribution. In turn, non-CO_2 data (CH_4, N_2O, and fluorinated gases) were obtained from the US Environmental Protection Agency (USEPA) and calculated by applying growth rates based on near-term projections to 2001 emissions data from GTAP 6. Thus, these figures can vary from the emissions reported by different countries in 2004 (Rose et al., 2010). It is worth mentioning, however, that CO_2 emissions generated from land change and non-CO_2 emissions from biomass are missing from this dataset. Additionally, emissions associated with processing, such as cement production are also excluded. The UK Environmental Accounts suggest that these process emissions account for around 2% of total UK emissions.

2.4 Uncertainties

There are a number of uncertainties associated to the GTAP database and to the construction of MRIO models in general. These are related to a number of issues, like manipulation due to calibration, balancing and harmonisation, use of different time periods, currencies, country classifications and levels of disaggregation, inflation, data errors, among others (Lenzen, 2001; Lenzen et al., 2004; Peters, 2007; Weber, 2008; Lenzen et al., 2010).

According to Peters (2007), the biggest uncertainty might be the one related to its manipulation. GTAP data is collected from voluntary submissions by individuals or organisations at an international scale, and these receive in return the right to use the dataset. Thus, the data is presented in different country classifications and levels of aggregation. Walmsley and Lakatos (2008) have claimed that of all the contributed tables, 58 did not contain all 57 sectors, so disaggregation was required. Moreover, data generally corresponds to different years. IO tables for some countries, like Cyprus and Malta, date from 1986, while Hong Kong's is from 1988. Actually, only a fraction of the entire set of domestic IO tables corresponds to 2004. Furthermore, the data is often expressed in national currencies. For these reasons, after receiving the data from its original sources, GTAP undertakes a process of harmonisation. The data is initially transformed in order to comply with GTAP classification. It is subsequently valuated by taking into account currency conversions and inflation, so all tables are expressed in a common unit in 2004 prices. Then it is further "calibrated" and "balanced", making it suitable to be used in a computable general equilibrium model. The precise details of these harmonisation, calibration and balancing processes are not transparent enough, which affect data consistency and generate a degree of uncertainty that is hard to estimate.

Giljum et al. (2008) believe that GTAP data is not sufficiently harmonised. Hence, they prefer to use other sources, such as the OECD, who supplies better harmonised international IO tables and bilateral trade data. The drawback is that domestic IO tables from only OECD countries plus 11 non-member countries are available. Moreover, the organisation does not supply bilateral trade data for the latter group of countries. In this sense, Giljum's MRIO model just takes into account the trade that occurs between OECD members, while the rest of the countries seem not trade between them. This makes it a semi-unidirectional trade MRIO model. Consequently, while it may be more robust in terms of harmonisation, it lacks the ability to take into account the complete effects obtained from a full multilateral model.

Relating to MRIO models in general, Weber (2008) has analysed the most common error types associated with environmental MRIO models compared to the traditional single-region ones. By using IO data from the United States and several of its largest trading partners, he determined that aggregation and concordance to a common sectoral classification, the treatment of the rest-of-world (ROW) region, and monetary exchange rate issues represent the greatest uncertainties. In the particular case of the GTAP EE-MRIO model that is used to produce the results for this report, these problems seem to be also present at a certain extent. Some of these have already been mentioned, but it is worthy to highlight the ROW issue. Although it does not include a ROW region as such, it does possess 18 aggregate regions that comprise 116 nations in total. Due to the reduced size of their economies or the lack of data at a national level, these were aggregated instead of being presented individually. This aggregation, according to Lenzen (2004) and Weber (2008), is likely to result in some errors.

Some other issues further contribute to increase the level of uncertainty that is present in any model of this kind. In general terms, raw macroeconomic and energy data, as is generated by national sources, is already associated with a series of errors. These are seldom estimated by governmental offices of statistics at a national scale, so it is difficult to determine their magnitude. Moreover, data from different sources often varies due to differing definitions or methodologies for data collection. For example, GTAP CO_2 data is calculated by using IEA energy statistics. However, it may vary from 10% to 20% at a national level —and maybe even more at a sectoral level— when compared to other sources (Minx, et al., 2008), such as the Carbon Dioxide Information Analysis Centre (CDIAC). Particularly, significant variations have been found in the case of the United States, China and the EU. In this same respect, Lenzen et al. (2010), while undertaking an uncertainty analysis of the UK's carbon footprint by using an MRIO model, estimated an 89% probability that the footprint might have been significantly larger than originally calculated due to errors related to the carbon multipliers.

In summary, it is almost impossible to know how big the uncertainties are. But, in spite of all these issues, some authors think that the advantages of MRIO models outweigh these problems (Weber, 2008). And regarding GTAP, it still constitutes one of the most reputable sources and its data is currently being used in numerous studies.

3 Results

3.1 Structure of the Results

The analysis of the results have been organised by posing a number of relevant questions related to where and in which sectors UK consumer emissions occur. The analysis provides over 415 million data points therefore making it impossible to display all the data.

3.2 What are the consumer emissions in the UK?

The UK's full supply chain emissions from consumption are 853Mt CO2e. This does not include direct emissions from households as a result of burning fuel for heating and private car use. These accounted for a further 161Mt CO2e bringing the total emissions to 1014 Mt CO2e. This figure is generated by the 113 region model described above. For comparison, Wiedmann and Barrett (2011) have produced a time series of the UK's carbon footprint between 1990 and 2008 using a two-region model (UK and "Rest of World"). This model is used to generate the official indicator for the UK Government on consumer emissions. For comparison, in 2004, the UK's carbon footprint according to this model was 1059 Mt CO2e (Wiedmann and Barrett, 2011). The small variation of 4% adds legitimacy to both models.

Figure 1 below provides a high level breakdown of this total in three categories. These being:

- Household Supply Chain Emissions – CO2e emissions embedded throughout the whole supply chain in products purchased by UK households for one year (in this case 2004).
- UK Government Supply Chain Emissions – CO2e emissions embedded throughout the whole supply chain in products purchased by the UK Government for one year (2004).
- Direct Emissions from Households – CO2e emissions associated with the direct emissions of UK households mainly including gas for heat and vehicle fuel.

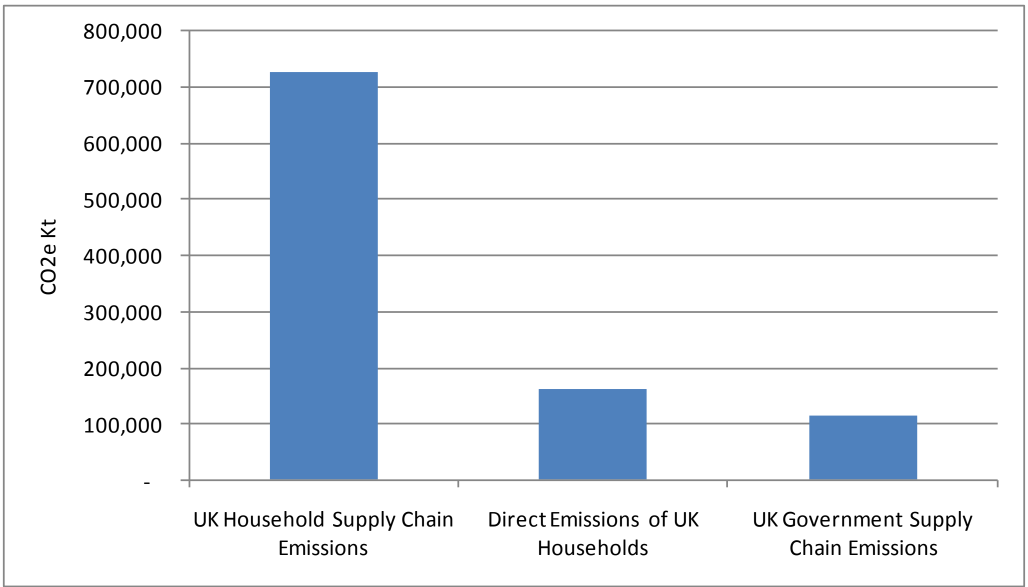

Figure 1: High Level Breakdown of UK Consumer CO2e Emissions (2004)

Both directly and indirectly, UK households are responsible for 89% of the UK's consumer emissions, with UK Government expenditure accounting for 11%. This is consistent with the recent Defra study undertaken by Wiedmann and Barrett (2010) where between 1990 and 2008 UK Government consistently accounted for about 10% of total consumer emissions. In terms of the split between direct and indirect household emissions, indirect (supply chain emissions) account for 82% of total emissions.

The following analysis concentrates on evaluating this 82% and the previously mentioned report already covers UK Government emissions in considerable detail (Wiedmann and Barrett, 2010).

3.3 Which products have the highest carbon footprint consumed by UK households?

The 57 product categories in the model have been aggregated into 14 high level categories below. Figure 2 provides the results.

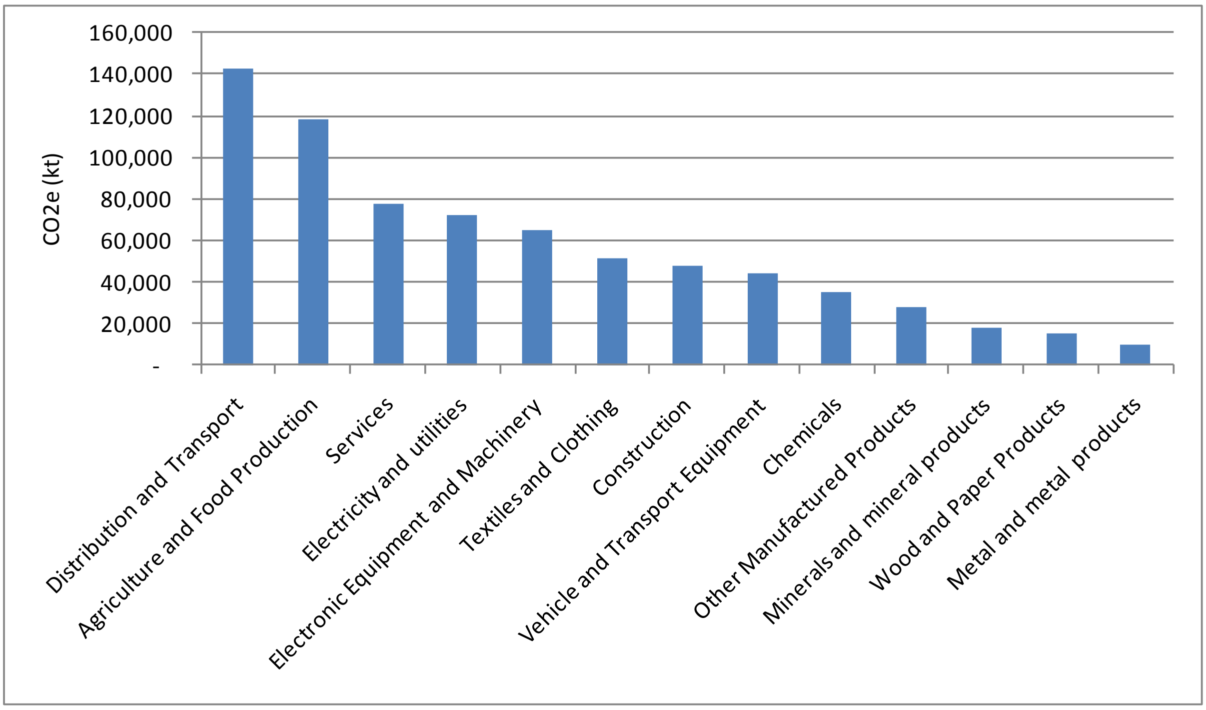

Figure 2: UK Household Indirect Emissions by high level product groups

Distribution of products along with household travel accounts for 20% of the total UK household emissions. As mentioned, this does not include direct household of which car fuel accounts for an additional 68,669 Kt CO2e. This is closely followed by agricultural and food products, accounting for 16% of indirect households CO2e emissions. The indirect emissions related to services are also high. This is consistent with findings from Minx et al (2009) who demonstrated the increasing reliance on services and the continual rise in emissions in this sector. In fact, emissions from services are higher than the emissions from electricity use by households.

In terms of the more disaggregated results, figure 3 provides the CO2e emissions for the 15 products that account for more than 75% of total emissions.

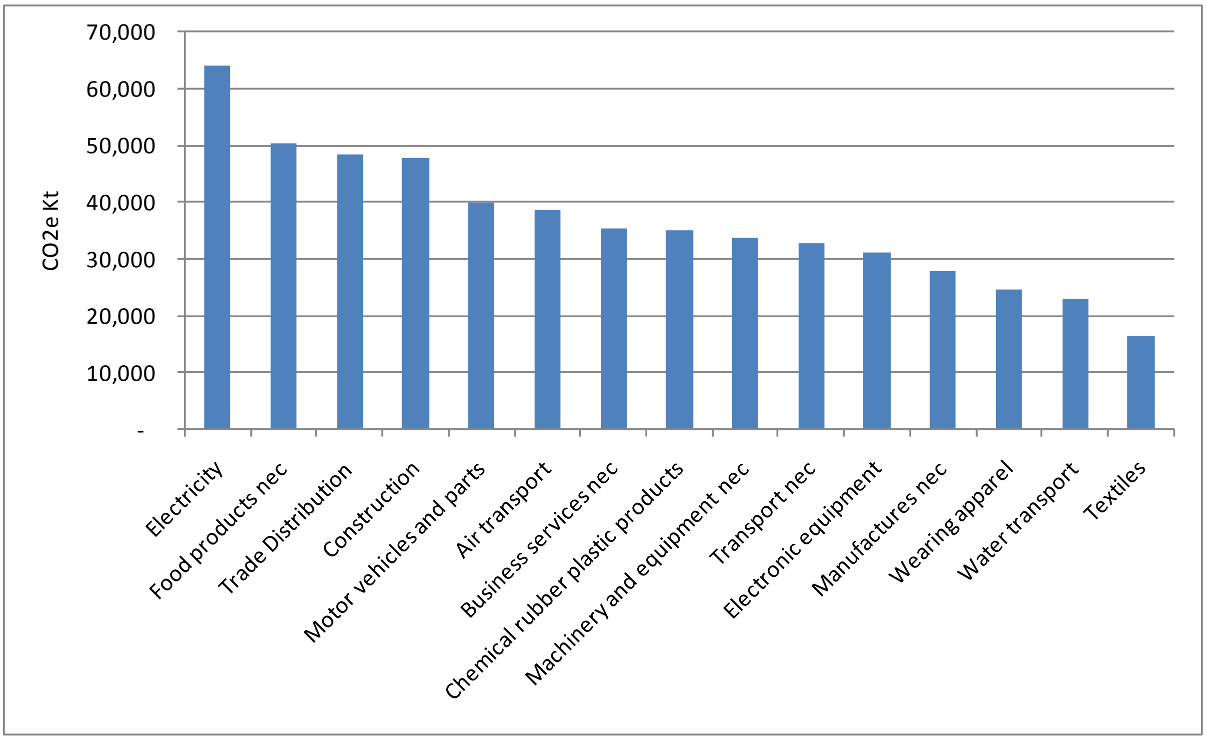

Figure 3: 15 Top 15 products with highest CO2e emissions

Electricity has the greatest impact, followed by food products not classified elsewhere. This mainly refers to packaged and manufactured food products. Trade distribution refers to transport requirements in distributing products to households, followed by construction.

The analysis below gives an indication of where the emissions occur to supply these key products to UK households.

3.4 Which products embedded carbon is emitted outside the UK?

Of this 725.8 Mt CO2e, 45% of emissions are from consumption satisfied by UK production. Therefore, 55% of CO2e emissions to provide UK households with goods and services occur outside the UK. The variation between products is substantial in terms of this proportion.

Figure 4 shows the proportion of the 14 high level product groups in terms of territorial and overseas CO2e emissions.

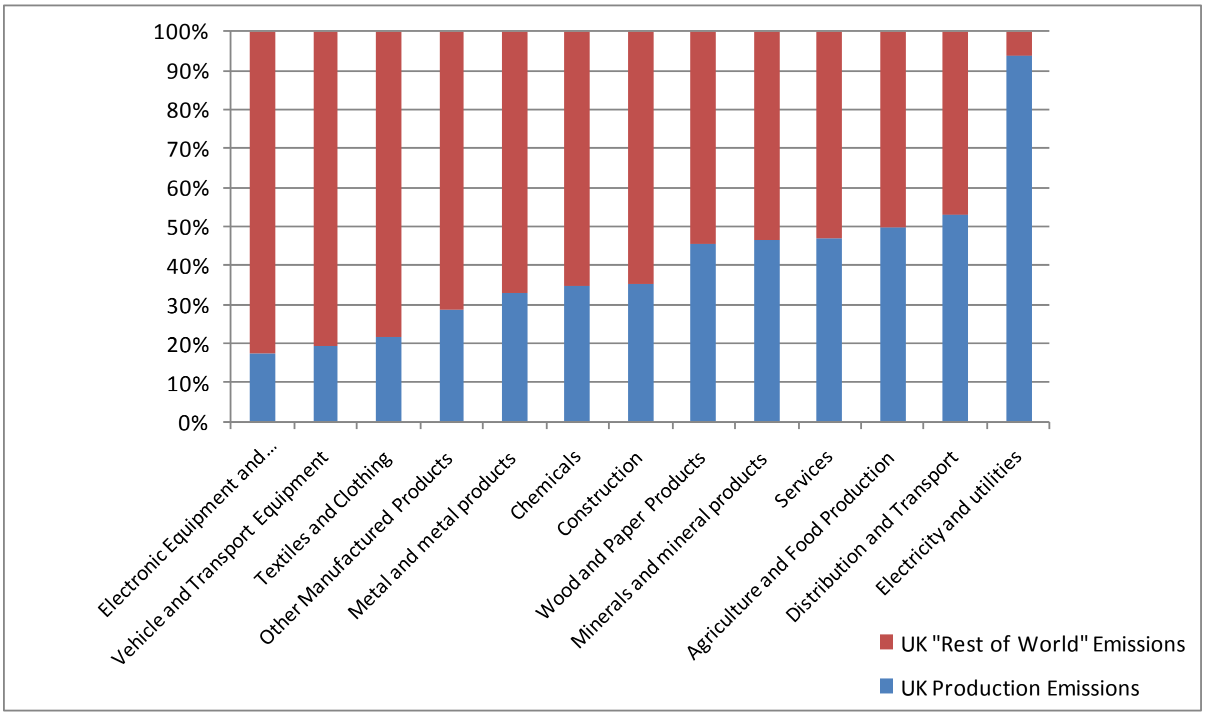

Figure 4: Proportion of UK consumer emissions occurring inside and outside the UK

The emissions throughout the supply chains related to the 14 product groups shows large variation in where the emissions occur. For electricity, 94% of the emissions occur in the UK and for electronic equipment only 17% occur in the UK. A similar situation occurs for vehicles, where 81% of emissions are emitted outside the UK to satisfy UK consumption. The other product group to resemble a similar pattern is textiles (79% of emissions occurring overseas).

Clearly the inefficiency in the distribution of electricity combined with energy security issues means it is a very different product from the others. With electricity excluded, 60% of UK consumer emissions occur outside the UK.

Figure 5 shows the proportions for 15 products that account for over 75% of total consumer emissions.

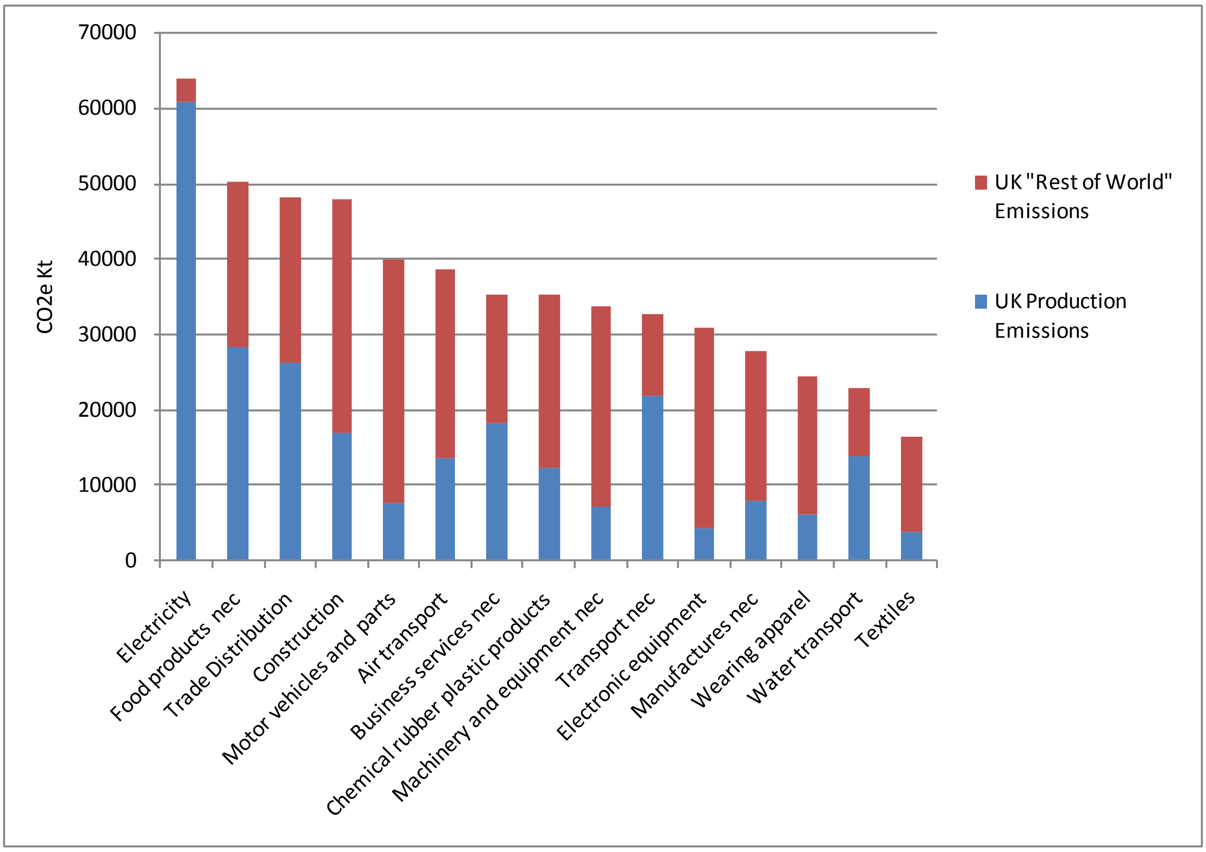

Figure 5: Proportion of UK Household Products with emissions occurring inside and outside the UK

It could be argued that territorial CO2e emissions related to providing UK households with products could be reduced through either production or consumption side changes. Significant improvements in the carbon intensity of UK industry could deliver large reductions in these emissions. However, options related products produced outside the UK are significantly limited. In these cases, consumption side changes become one of the only options available. Figure 6 documents the 15 products that have the highest Co2e emissions outside the UK.

3.5 Where are the CO2e emissions from imports emitted related to UK consumption?

The following analysis identifies the location by country of the CO2e emissions required to satisfy UK consumption for 2004. This does not mean that the UK directly imports from every country where the emissions occur, but somewhere down the supply chain to import all the products consumed in the UK, emissions would have indirectly occurred in every country.

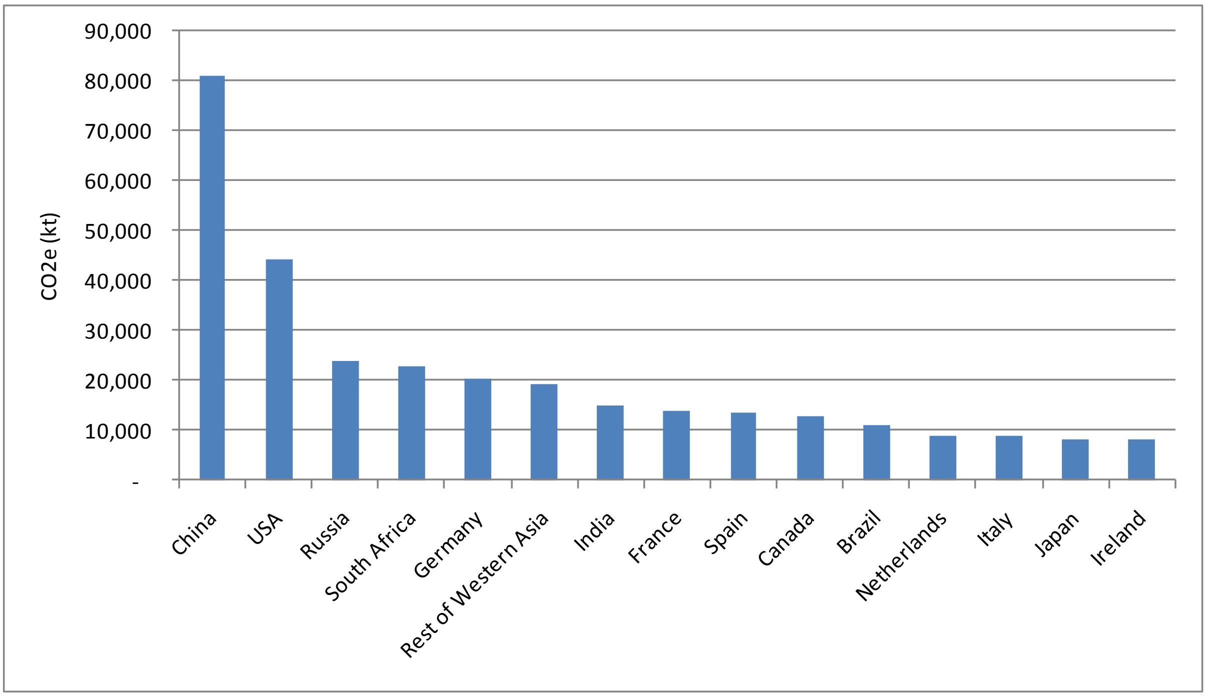

Figure 6: Country of origin for CO2e emission emitted to satisfy UK consumption for 2004

The 15 countries / world regions (out of a total of 113) account for nearly 70% of the total emissions associated with imports. They account for a total of 267 million tonnes of CO2e emissions. In terms of comparison, this is equivalent to all the UK electricity emissions and household gas use.

The emissions that occur in China alone are higher than all the direct emissions of UK households (this including gas and car fuel). In other words, the scale of these emissions is far from trivial. Historically, a greater proportion of these emissions would have occurred in the UK, when imports from China were lower and domestic production considerably higher. In 1990 for example, our two-region model suggest that 65% of the emissions from UK consumed goods and services occurred in the UK. By 2008, this has reduced to 45%, a dramatic shift in a very short timescale.

Figure 7 provides the results by different world regions.

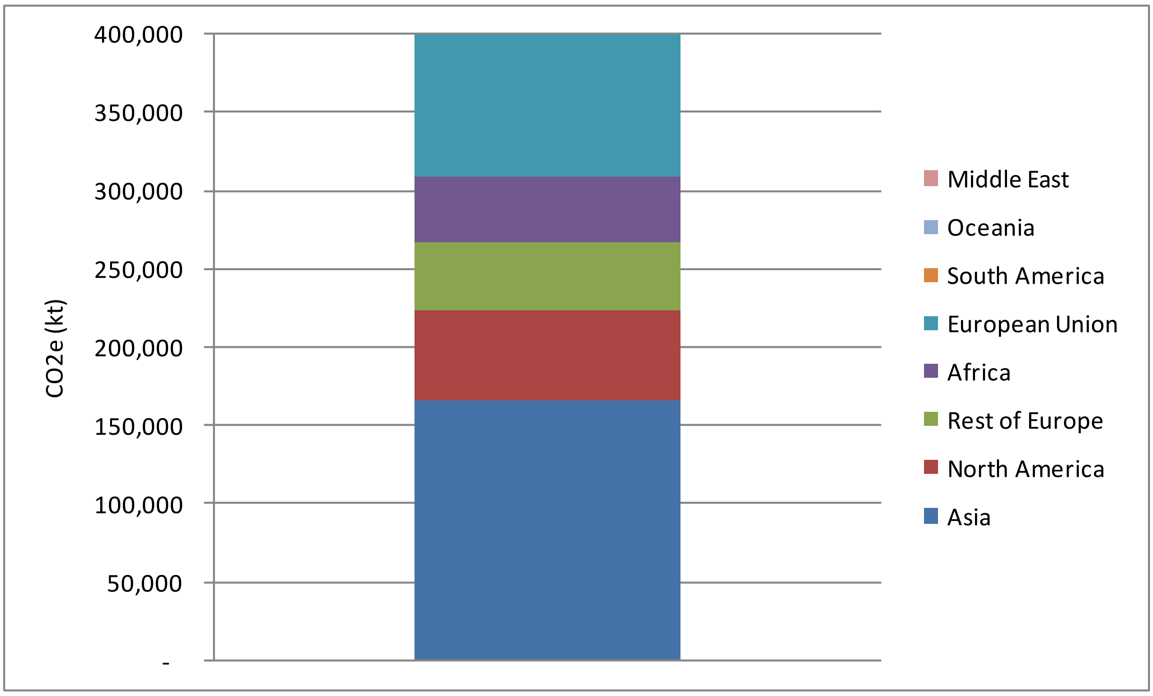

Figure 7: CO_2e Emissions by World Regions

Only a fifth of UK's emissions embodied in imports come from the European Union. This is very important, as these emissions could potentially be captured under a joint European agreement on emission reduction. However, 78% of emissions occur outside the European Union. The highest proportion of emissions comes from Asia, accounting for 36% of the total. Other regions of significance are North America (12%) and the rest of Europe (10%). Together, these four regions account for 80% of emissions.

3.6 In which sectors in China do emissions occur to provide UK households with goods and services?

With over 81 million of CO_2e emissions embodied in UK consumption occurring in China, a more detailed analysis of China has been provided. Figure 8 provides an analysis of the products that China's emissions are associated with. Over 43% of the emissions are associated with two products, these being electronic equipment and textiles.

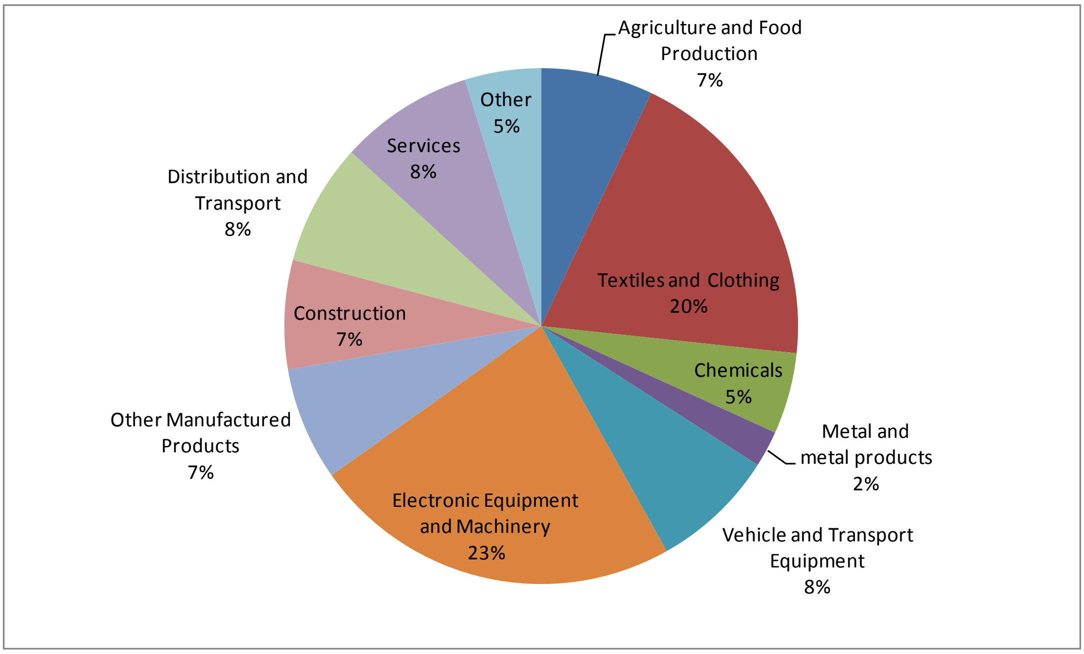

Figure 8: CO2e emissions from products emitted in China (2004)

Figure 9 shows which sectors the CO2e emissions occurred to provide each of the product groups.

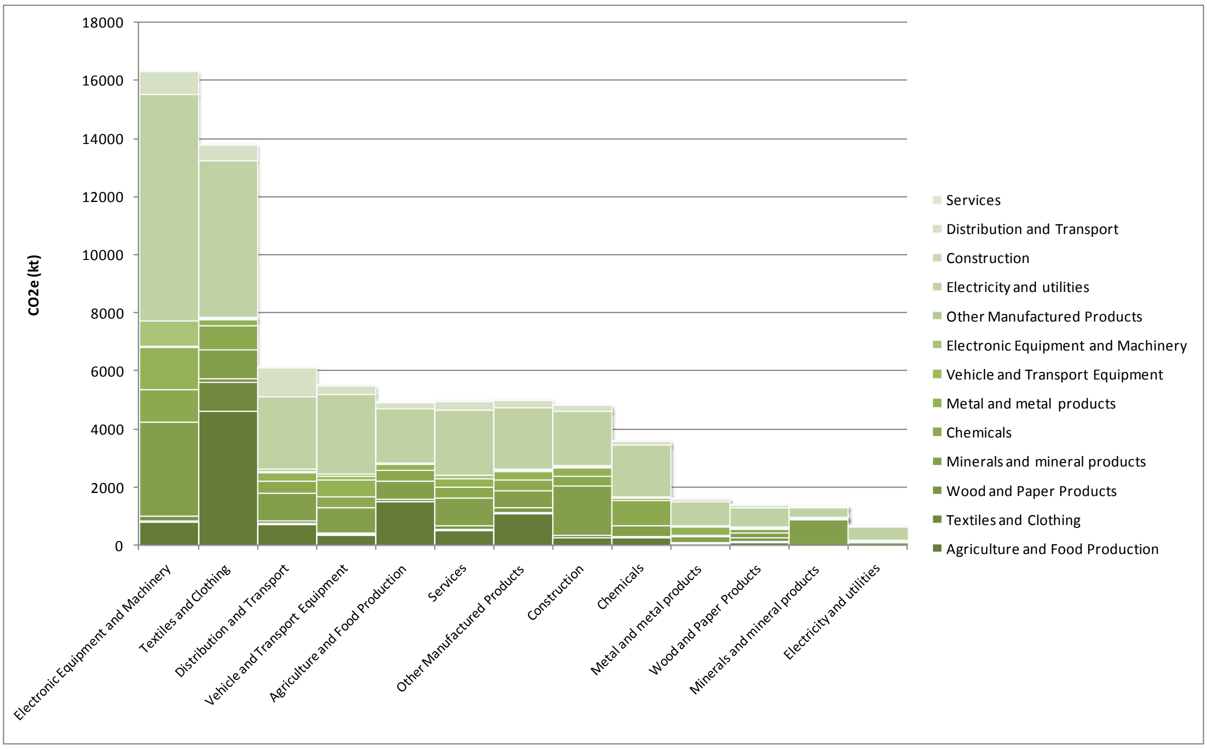

Figure 9: China's CO2e emissions by product and sector of origin.

Of the 81 Mt CO2e, over 30 Mt CO2e are emitted in the electricity sector in China to provide the UK with its goods and services. This is nearly 40% of the total emissions. The carbon intensity of China's electricity is almost double that of the UK's, meaning considerably higher emissions to provide the same product.

3.7 Case Study – CO2e emissions associated with textiles

The following section analyses UK emissions related to the textile and clothing industries, which encompass the manufacture of textiles and man-made fibres, wearing apparel and leather products.

In order to satisfy final demand by households, government and firms in the UK, finished goods are imported from diverse regions around the world. As can be seen in figure 10, China is the largest provider of textiles and clothing products, supplying around 13% of all imports, followed by Italy (9%) and Southeast Asia (9%).

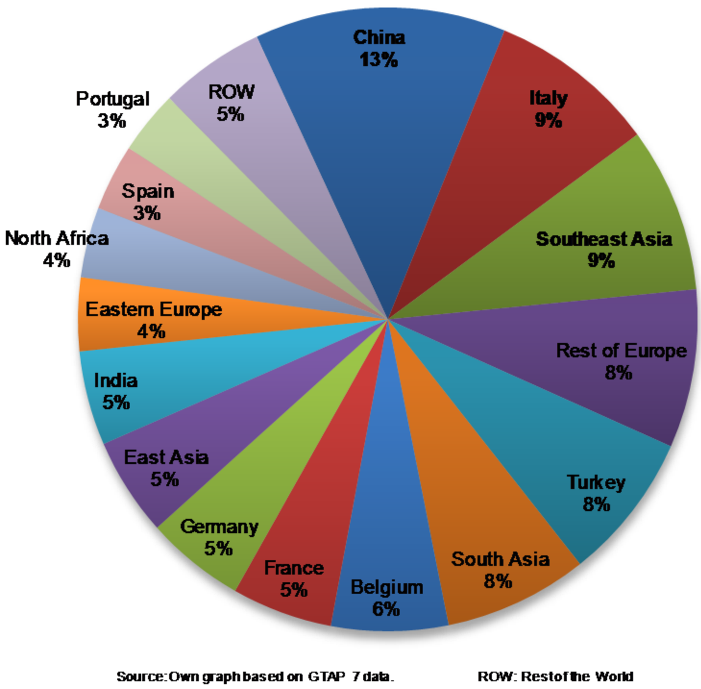

Figure 10: UK Imports of finished goods (textiles) according to origin

The UK also imports intermediate goods that are used to manufacture textiles and clothing within the country. Figure 11 shows the amount of intermediate products (in percentage terms) that these industries import from other nations and regions around the world. In this case, China is not the larger supplier of intermediate goods. These mainly come from EU member countries, especially from Italy (9%), Ireland (8%), France (7%), Belgium (5%) and Germany (5%). The USA (8%) also represents an important supplier, along with West Asia (5%).

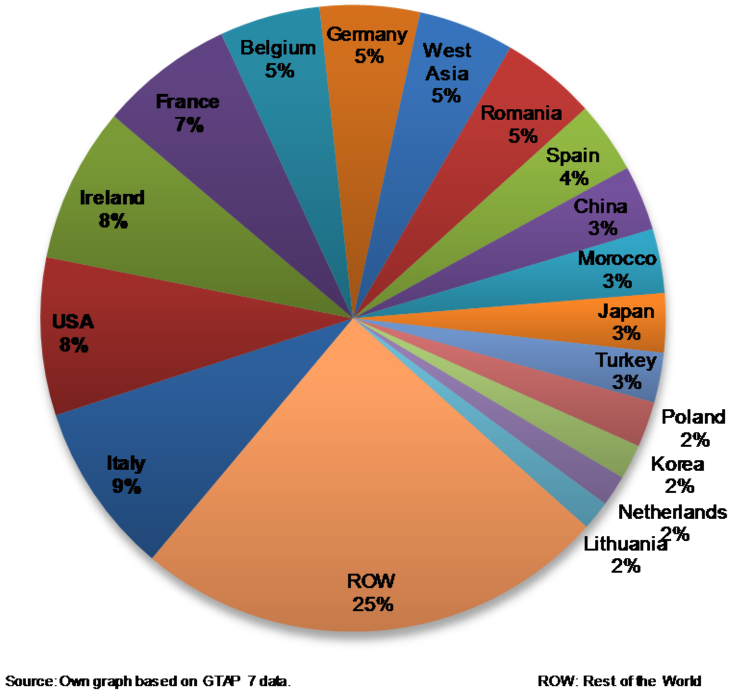

Figure 11: UK Imports of intermediate goods (textiles) according to origin

Due to the structure of final demand related to these industries in the UK, the territorial emissions that occur within the country are significantly low. As can be seen in figure 12, the majority of UK emissions —more than two thirds— are generated in other regions of the world. A significant portion of these take place in China, which is the biggest exporter of textiles and clothing (finished and intermediate products) to the UK. To be precise, around 27% of all the emissions have their source in that particular country. In the case of leather products, China accounts for almost 45% of emissions. This indicates that Chinese industries are very carbon-intensive. On the other hand, almost half of the emissions correspond to the rest of the world (ROW).

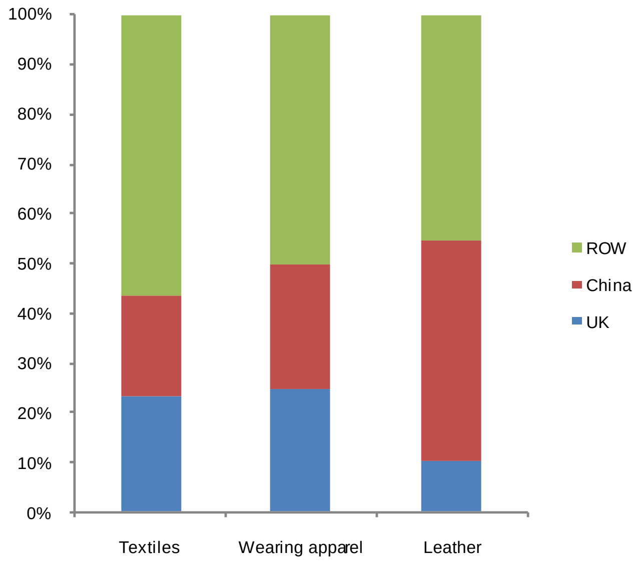

Figure 12: Percentage of consumption emissions related to textiles, wearing apparel and leather products according to source (2004)

By analysing the source of these emissions in more detail in each of these three regions (UK, China and the rest of the world), it can be seen that the larger portions correspond to the electricity sectors (see figure 13). The transport sector has an important contribution in the UK, as well as in the ROW. On the other hand, the livestock sector (bovine, cattle, sheep and others) contributes importantly in China.

Table 1 shows the highest emitting sectors. Nearly 10% of emissions are related to the electricity sector in China. In other words, the textiles and clothing industries in that country are dependent on “dirtily” produced electricity. This is followed by the transport sector in the UK, which is required to ship all the imported products. As has been said, the livestock sector in China comes next, accounting for around 4.5% of the emissions. The remaining sectors are listed next (the last 44 sectors, labelled “others”, were aggregated due to their small contributions).

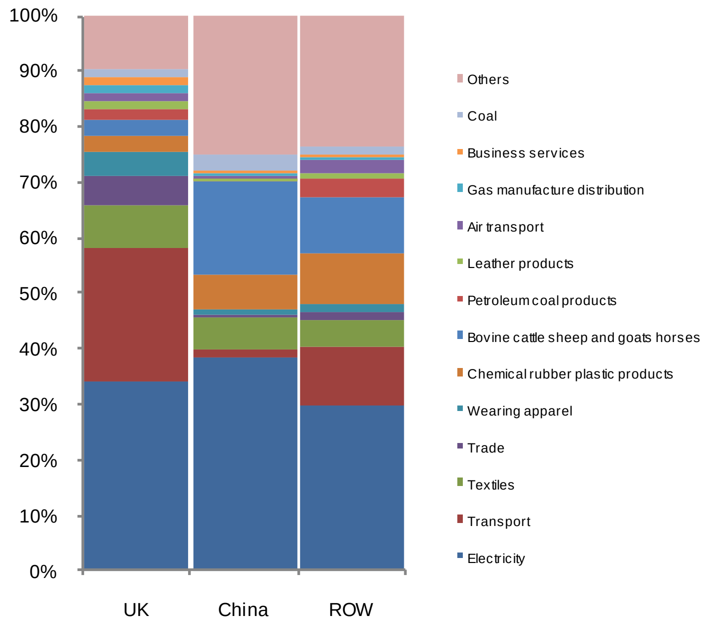

Figure 13: Sources of emissions related to textiles, wearing apparel and leather products according to sector and region of source

Sector (country)	% of emissions
Electricity (China)	10.40%
Transport (UK)	5.11%
Bovine cattle, sheep, goats, horses (China)	4.64%
Textiles (UK)	1.69%
Chemical rubber plastic products (China)	1.67%
Plant-based fibers (China)	1.42%
Trade (UK)	1.12%
Wearing apparel (UK)	0.94%
Mineral products (China)	0.91%
Paddy rice (China)	0.88%
Coal (China)	0.84%
Animal products (China)	0.71%
Vegetables fruit nuts (China)	0.63%
Others	69.05%

Table 1 Percentage of emissions according to highest emitting sectors

4 Applications of Results to Policy

Data of such complexity and depth have considerable applications, some of which have already been realised.

4.1 International negotiations

One of the key barriers related to the progress in international climate change negotiations relates to the interpretation of "common but differentiated responsibilities " (CBDR) as outlined in the United Nations Framework Convention on Climate Change (UNFCCC). The interpretation of CBDR to date has meant territorial emission reduction targets for developed countries only. However, a lack of targets in some of the largest economies in the world, such as China and India is not consistent with the need for deep emission cuts to avoid dangerous climate change.

The MRIO model provides sound empirical evidence on the final destination of the products and their associated emissions. Evidence of this nature helps to provide information that could inform negotiations related to the allocation of responsibility. Additionally, this information can help focus attention of which sectors in which countries have the greatest potential for climate change mitigation.

4.2 Carbon leakage

Data from MRIO models has already been used to understand the carbon emissions associated with carbon leakage. There is a significant concern related to competiveness issues when one region, such as the European Union, places a price on carbon and other regions do not, suggesting that imports to the European Union would then be cheaper without this additional cost. MRIO models can be used to identify the scale of this issue and a recent report by the Carbon Trust has fully documented the level of carbon leakage from the UK using an MRIO model. The full report is available from:

http://www.carbontrust.co.uk/SiteCollectionDocuments/carbon_news/Tackling%20Carbon%20Leakage.pdf

One of the key issues raised by MRIO data is not just the imports of intermediate products such as steel but the steel embedded within products. This demonstrates the complexity of information needed to ascertain the scale of carbon leakage as it does not simply relate to raw materials such as steel and aluminium.

4.3 Prioritisation of products

It is clear that the CO_2e emissions associated with some products could be reduced through improvements in the carbon intensity of UK production. Electricity has to be the best example of this, as 94% of the emissions occur within the boundary of the UK. However, with other products it is very difficult to see how the UK can influence the carbon intensity of production when over 80% of the emissions occur in numerous other countries. There is the additional challenge that the majority of these emissions do not occur inside the European Union, ruling out the opportunity for EU level agreements on emission reduction.

With the absence of a global agreement on climate change mitigation, the UK can still influence the emissions associated with products consumed in the UK and produced elsewhere. A recent report commissioned by WRAP (Barrett and Scott, 2011) demonstrated a wide range of demand side strategies that could be effective in terms of emission reduction. These included identifying the optimal use of products by households, ensuring that the product is used for its full lifetime. Also the benefits of “closing the loop” for materials and products to ensure that maximum options for repair and recycling could deliver savings.

It is clear that a demand side perspective for some products could deliver greater carbon reduction potential, hence the importance of product roadmaps currently being developed by Defra. Products that are both high in terms of emissions with the majority of the emissions occurring overseas include electronic equipment, textile and clothing, motor vehicles and construction equipment.

4.4 Analysis of supply chains

With additional analysis, a complete and comprehensive supply chain of each of the product groups by country and sector is possible. Companies have already been using data of this type to fully appreciate the complexity of their supply chain. Methods such as structural path analysis provide a picture of both the production layers and associated emissions of products (Wiedmann, Lenzen and Barrett, 2009).

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