LUND UNIVERSITY
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CO_2 Emissions Embodied in International Trade of the UK, 1995-2009: A Multi-Region Input–Output Analysis

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Abstract

In a globalized world with increasing international trade, it is highly important to accurately determine environmental impacts resulting from pollution embodied in trade. This study examines carbon dioxide (CO_2) emissions embodied in international trade of the United Kingdom from a consumption perspective, rather than the more conventional production side, during the period 1995-2009. The analysis is based on Multi-Region Input Output (MRIO) model covering 35 sectors and 41 countries. The results show that during the entire study period CO_2 emissions associated with UK imports from abroad were greater than CO_2 emissions associated with UK exports. The balance of emissions embodied in trade has grown from -48 $MtCO_2$ in 1995 to -110 $MtCO_2$ in 2009. The share of imports from non-Annex B countries have risen by more than 10% since 1995 and accounted to 35% (57% when RoW is considered as non-Annex B region) of all imports in 2009. The results of this study also show that on average 68% of emissions embodied in UK imports originate from energy intensive manufacturing sectors and additional 8% from energy intensive non-manufacturing sectors. In contrast to production based emissions, consumption based accounts clearly show that global CO_2 emissions associated with UK consumption have not declined over time but actually increased.

Key words: Multi-region input-output, Embodied Pollution, CO_2, Carbon leakage, Trade, UK.

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Contents

List of Figures

List of Tables

Chapter 1

Introduction

The expansion of globalization over the last few decades has generated a significant growth in economic activities around the globe. International trade compared to gross domestic product (GDP), population and carbon dioxide emissions has grown more rapidly than ever before. Today, exports of goods and services are about 50 times larger than they were in the 1970s (Kanemoto and Murray, 2013). Increasing global trade and, as a result, increasingly internationalized production chains have changed our production and consumption patterns completely, and lead to a separation of the locations of production and consumption of goods and services.

Many of today's goods and services are no longer produced within the borders of a single country. For instance, most of the electronic products are labeled as "assembled in China", whereas their key components are often produced in other parts of the world. In addition, a closer look at the production process also reveals that many businesses in developed countries are purchasing goods and services from developing countries, which may lead to the relocation of energy use and pollution to developing countries.

The transfer of carbon from developed to developing countries through trade is a substantial and growing problem. Shifting of carbon between regions was not formally addressed in the initial Kyoto Protocol discussions, as it was anticipated to be a minor issue, or one to be addressed later. However, recent studies show that it is not minor, and that up to 30% of global emissions are linked to production for export (Kanemoto et al., 2014).

China has argued that responsibility for emissions should lie not just with the producer but also with the final consumers of goods (BBC, 2009). This is because they produce goods that are consumed by other countries, but carbon emissions are charged to their national accounts. Many believe that this keeps developing countries from reaching reduction targets because countries like e.g. China and India, have experienced rapid economic growth largely associated with increase in exports, which of course significantly contribute to an increase in their territorial carbon emissions.

The measurement of emissions in the Kyoto Protocol follows the territorial (or production) accounting principle. This method attributes all emissions generated from production activities within a country's territory to that country's total emissions. With regard to international trade, this method includes the emissions released within a country for production of exports. However, the major drawback of this method is that it does not take into account emissions embodied in imports and thus creates incentives for displacement of emissions abroad.

The consumption-based accounting method has been suggested as an alternative way to more fairly allocate responsibility between the emitters and final consumers. This approach adjusts conventional production-based emission inventories by subtracting export-related and adding import-related emissions. Although, so far, this method has not had any substantial implications for international climate negotiations, a number of statistical offices and government organizations have started to calculate consumption-based emissions, mainly in Europe, Australia and Canada (Barrett et al., 2013).

A crucial question is whether economic consumption patterns are becoming less polluting over time or, whether the apparent environmental improvements in developed countries are simply illusions, produced by shifting global trade flows. A country may clean up its own backyard, while throwing the garbage to their neighbors. Naturally, if de-carbonization in developed countries is simply a result of relocating energy intensive production to the developing world, then reduction in global emission would not exist.

In this general context the UK economy deserves particular attention. According to territorial accounting figures the UK was amongst the first countries to fulfill its Kyoto Protocol commitments and reduce GHG emissions by 12.5 % already in 1999. There are a number of factors that contributed to the rapid fall in UK emissions since 1990, but two stand out the most: the increasing changes in the fuel mix used for power generation and reduction in activity of energy intensive-industries since the 1970s/1980s. It can be argued that the emission reductions delivered by the so-called "dash for gas" were real because of lower carbon output of natural gas relative to coal. Whereas the gains from de-industrialization are less concrete, simply because there may not have been real saving of GHG emissions at the global level but just displacement of resources from the UK to overseas.

1.1 Objective of the Study

The principal objective of this study is to examine CO_2 emissions embodied in international trade of the UK from a consumption perspective, rather than the more conventional production side, during the period 1995-2009. The research question is whether the significant reduction in UK emissions since 1990 is due to a real shift in consumption or simply a matter of displacement of industrial production? The scope of this problem warrants more detailed questions that target specific aspects studied in this thesis, such as: (i) What shares of CO_2 emissions are linked to production for export and how much is embodied in imported goods? (ii) Which countries are the main destinations for exports and which ones are the main sources of the imports? (iii) What are the main CO_2 emission importing and exporting sectors?

1.2 Method and Sample

This study applies multi-region input output (MRIO) analysis, in order to trace carbon dioxide emission flows in trade of the UK. This is one of the most popular tools used by researchers to evaluate the impact of trade on environmental issues such as CO_2 emissions. There are several different MRIO models. This study relies on the methodology developed by Peters (2008b), which allow the distinction between trade for final consumption/use and intermediate demand.

Data for this study comes from recently constructed World Input-Output Database (WIOD). This is the first database that provides detailed annual time-series on trade and greenhouse gas (GHG) emissions for the period from 1995 to 2009/2011. The WIOD uses 35 product groups and 41 countries/regions including 27 EU and 13 other major advanced and emerging economies, plus a region called "Rest of the World".

1.3 Outline of the Thesis

Chapter 2 provides an overview and discussion of the main theories and hypotheses related to the investigation of emissions embodied in international trade, Chapter 3 provides country background and overview of energy sector together with historical context. Chapter 4 looks at the main studies conducted in the field. Chapter 5 and 6 describe in detail, the data and methodology used in the study. Chapter 7 presents the results. In chapter 8 the obtained results are discussed and various implications are considered. Finally, in chapter 9, an overview of the whole study is presented and conclusions with suggestions for further research are put forward.

1.4 Supporting Information and Technical Details

This thesis is written in LaTeX with the help of LyX editor. All of the calculations are performed using Matlab and Python programming languages. Most of the figures and diagrams are presented in vector graphics, which allows to view figures in detail (zoomed in) without any loss of quality. A complete set of results and code syntax can be provided on request. It is also important to note that because of challenges associated with displaying results in black and white, all graphs and tables of this thesis are designed to be viewed in color.

It is possible to browse the PDF version of the report as hypertext. Headings in the table of contents, literature, chapter, figure and table references in the text are all clickable links. After clicking, to return to previous position press Alt + left arrow (cmd + [on Mac OS). To go forwards again, press Alt + right arrow (cmd +] on Mac OS).

Chapter 2

Theory and Hypotheses

2.1 Theoretical Context

Globalization of economic activities together with increasing environmental pressures have generated a heated debate on the links between economic growth, international trade and the environment, particularly in the context of developed and developing countries (Mehra and Satya, 2008).

At the early stages of environmental movement, most of the debate was centered on limited and nonrenewable resource availability. Already in the 1970s some scientists began to question how natural resource availability could be compatible with further economic development. The environmentalists argued that global ecological constraints (related to resource use and emissions) would have a significant influence on economic development (Meadows et al., 1972). While more optimistic neoclassical economists suggested that limits to growth due to resource availability were not an issue because these limits could be overcome by technological progress (Beckerman, 1974)

A decade later the issues associated with growing environmental problems e.g. global warming have shifted the debate from natural resource availability towards the relationship between economic growth and environmental degradation. Additionally, the events stemming from economic growth were suggested as a way out of poverty, social depravation and also environmental degradation, particularly for the developing countries. This resulted in even greater interest in the relationship between economic growth and environmental degradation.

In the 1990s the relationship between economic growth and environmental degradation was put to empirical tests (Stern, 2004). Most of the literature sought to test the so-called Environmental Kuznets Curve (EKC) hypothesis, which posits that an inverted U shape relationship exists between the level of pollution and economic growth. The general idea behind EKC is that when a country develops, the pollution level in that country increases up to a certain point, after which environmental degradation starts to decrease. The decreasing point of EKC is often explained by the shift towards cleaner technologies, more responsible use of available resources and a decoupling between economic activity and environmental degradation.

One important factor often missing in the explanation of EKC is the international trade. A relevant question associated with economic growth, environmental degradation and trade is to what extent the more developed countries actually develop as a result of transferring their environmental problems to less developed countries (Taylor and Copeland, 1994). Any evidence of such transfer would indicate that the cleaner environment often used to characterize developed countries may be a consequence of moving their problems to less developed countries (Jiborn and Kander, 2014). In the literature, such a process has been termed as the displacement hypothesis (Lucas et al., 1992). It implies that when countries develop, other less developed countries take over their energy intensive production associated with high pollution and export the products back to the developed countries in exchange for cleaner products. These shifts may occur due to varying reasons, including lower labor costs, better know how and worker skills or lack of environmental regulation (Lucas et al., 1992).

Another stricter version of the displacement hypothesis is called the pollution haven hypothesis. This implies that companies or industries in developing countries with tight environmental regulations will relocate their production to countries where environmental costs are lower (Neumayer, 2001). In fact this hypothesis is best seen in the context of the comparative advantage theory: when environmental costs begin to matter for some industries/companies in some countries other countries should gain comparative advantage in those industries/companies, if their environmental costs are lower (Eskeland and Harrison, 2003).

If a large proportion of displacement from developed to developing countries takes place, then it could be an explanation for the decreasing EKC curve in developing countries (Stern, 2004). One way to empirically investigate the international trade flows is to use the so-called consumption-based approach, which takes into account emissions embodied in the import of goods and services from other countries. Large share of emissions embodied in imports from developing countries would indicate that environmental improvement in the developed world is actually an illusion, implying that it is difficult to achieve further economic growth without the increasing stress on the environment.

All this being mentioned two different explanations could be given for prevailing and further interrelationship of economic growth, environmental pollution and international trade. One proposition is that while we live in a service economy, our goods are being produced elsewhere (Hermele, 2002). If this statement is correct then it gives a very dim picture about further economic development, because it implies that developing countries would not be able to move into lighter and less polluting industries such as services or pharmaceuticals.

On the other hand according to Kander et al. (2013) it is also possible that there is a logical sequence of events: at first when a country industrializes, it requires a lot of energy intensive production and this rapid capital accumulation results in high emissions. Later when a country enters a mature stage, its industrial requirements decline and it requires much lower inputs of energy to produce the same amount of output. This stage may also be accompanied by the consumption of less environmentally damaging goods and a shift towards a less polluting structure of the economy. As a matter of fact the energy history of Europe seems to support the latter idea of a logical sequence of events or development stages (Kander et al., 2013).

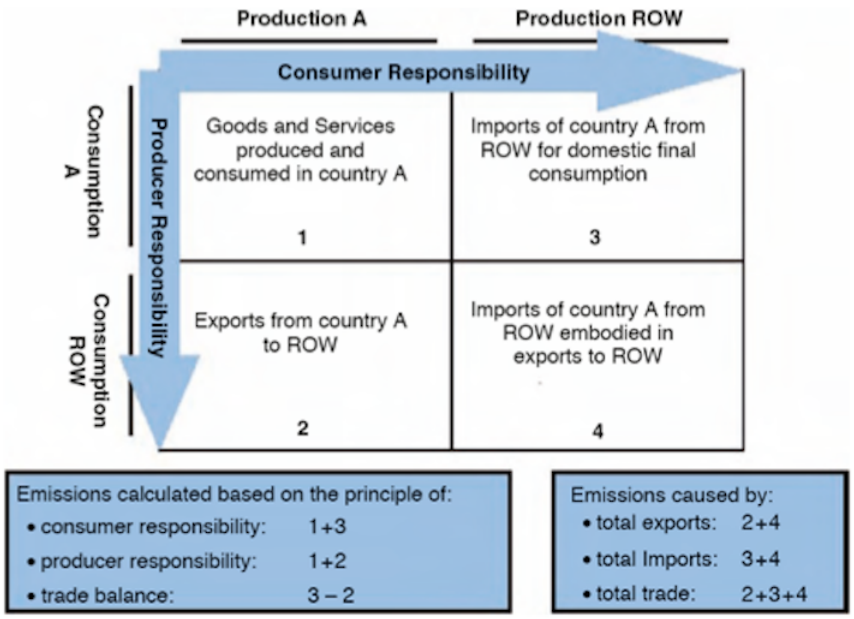
Given the complex interplay of these factors, it is not surprising that theoretical and empirical studies have not reached a consensus on the effect of economic development, free trade and the environment. In order to give a better understanding of this interplay the main associated theories and hypothesis briefly mentioned in the text above are reviewed and discussed in the sections below

2.2 Consumer vs Producer Responsibility

Under the United National Framework Convention of Climate Change (UNFCCC), countries are required to submit National Emission Inventories (NEI) that measure a country's greenhouse gases (GHG) emissions in a given year, to provide a benchmark for a country's emission reductions (Peters, 2008b). These measures are then used to evaluate various international policies as for example the Kyoto protocol, and/or regional policies, such as the EU Emissions Trading Scheme (ETS).

Two approaches are commonly used to calculate GHG emissions. These are known as the production-based (also known as territorial-based) approach and the consumption-based approach. Currently under the UNFCCC NEI, the reporting of GHG is based on territorial accounting, i.e. production based. According to the production-based accounting (PBA) principle, the producer is responsible for the GHG emissions from the production of energy, goods and services taking place within the national territory of the country. This is shown in figure 2.1, where the producer's responsibility consists of goods and services produced and consumed in country A, plus the exports from country A to the Rest of World (RoW). The main critique of the production-based approach is that there is no distinction between production for domestic use and exports. In other words GHG emissions from the production of goods and services that are exported to other countries are treated in the same way as the domestic GHG emissions. Such an accounting principle also creates a possibility of carbon leakage through imports from developing (non-Annex B) countries to developed ones (Annex B)[1]. This will be discussed in more detail in section §2.4 of this chapter.

Figure 2.1: Producer vs Consumer Responsibility



Source: Suh (2009)

On the other hand, according to the consumption-based accounting (CBA) principle, the consumer is responsible for GHG emissions that come from the production of energy, goods, and services. Under this principle emissions are allocated to the final user of goods and services, which means that imports are also taken into account. This is also shown in figure 2.1, where consumer's responsibility consists of goods and services produced and consumed in country A, plus imports from the RoW to country A for domestic and final consumption. The major advantage of this method is that it removes territorial boundaries and takes into account international trade by considering the global GHG emissions which give more options for mitigating emissions and naturally encourages cleaner production (Peters, 2008b). However, a consumption-based approach also has some drawbacks, one of which is a more complex and data intensive calculations of emissions, which require additional assumptions and thus increase uncertainty. In addition, consumption based accounting requires political decision making to extend outside the boundaries of the political administered region where the consumption occurred, which in many cases might be problematic and require significant international cooperation.

[1] Annex B are the countries included in to the Kyoto Protocol that have agreed to a target for their GHG emissions. Non-Annex B are the countries not included in Annex B of the Kyoto Protocol.

The difference between production emissions and consumption emissions represents the trade balance, or the net effect of emissions embodied in trade (BEET) (Davis and Caldeira, 2010). It is equal to emissions embodied in exports (EEE), minus emissions embodied in imports (EEI). A positive difference implies that a country is a net exporter of emissions and a negative result indicates a net importer of emissions. It is also important to note that the total emissions on a global level do not change when different accounting principles are used, only the allocation of emissions responsibility among countries will differ.

Several further adjustments were suggested to overcome the shortcomings associated with consumption and production based approaches. Lenzen et al. (2007) have argued that production and consumption accounting principles represent two extremes and suggested a shared responsibility between the producer and consumer.

Jiborn and Kander (2014) suggested to adjust consumption-based emissions with "NEGA-emissions", which is defined as a measure of the global emissions that are avoided due to export from countries with relatively low carbon technologies (e.g., Sweden). Cleaner countries, when calculated with the consumption-based approach do not get any credit for their low carbon technologies in their export sector, but are burdened with all of the responsibility of its imports from high-carbon countries. Complementing consumption-based accounting with NEGA credits and debit emissions allows for countries to be fully responsible for the level and composition of their consumption and at the same time to credit countries for improving the productivity of their exports.

However, in this thesis the above-mentioned adjustment is not made when calculating CO_2 emissions embodied in trade, mainly because both shared consumer/producer responsibility and NEGA emission adjustments are still in the process of development.

2.3 Displacement and Pollution Heaven Hypotheses

As mentioned before the displacement and pollution haven hypotheses are often used to explain the changes in trade patterns associated with economic growth and the environment. In fact, these two hypotheses have their cloned counterparts known, as "strong carbon leakage" equivalent to the pollution haven hypothesis and "weak carbon leakage" meaning the same as the displacement hypothesis. The main difference between these two hypotheses is the time during which they were introduced and the countries that they represent. Pollution haven (see e.g., Birdsall and Wheeler, 1993) and displacement hypothesis (see e.g., Lucas et al., 1992) were discussed in the early 1990s, while the term carbon leakage came to light during the signing of the Kyoto Protocol Convention (see e.g., Goldemberg et al., 1996). In later years, Peters (2008a) redefined the initial version of the term carbon leakage into its "strong" and "weak" subdivisions. These subdivisions are now commonly used in studies investigating carbon embodied in trade. Below more details are given for the term carbon leakage and its two subdivisions.

2.4 Carbon Leakage

As noted in the previous section one of the main shortcomings of the production-based approach is that it allows for the possibility of carbon leakage. This term is usually used to label studies that examine whether a participating country's emissions under certain climate policies (e.g., Kyoto Protocol or EU ETS) are being reduced by an increase in imports from non-participating countries. The rationale is that under tight emission constraints, some production will relocate to regions with less stringent emission constraints or no constrains at all. The definition of carbon leakage in the related literature exists in two forms: "strong" and "weak". Both of these address different but related problems.

First, the "strong" definition refers to a rather narrow view of the term carbon leakage given by the IPCC. This is defined as "The part of emissions reductions in Annex B countries that may be offset by an increase of the emissions in the non-constrained countries above their baseline levels. This can occur through (1) relocation of energy-intensive production in non-constrained regions… "(IPCC, 2007). It is important to note that under such a definition, only relocation of industries is considered. This implies that certain industries must physically close down in a country with tight emission constraints and reopen in a non-constrained region. The carbon leakage in this case would be represented by the net change in emissions. The measurement of such leakage is highly complex because one has to establish the counterfactual, i.e., what would have happened in the absence of a policy action. This also explains why there was a rather limited number of studies (see e.g., Babiker, 2005) that have attempted to model possible outcomes.

Furthermore, the strong definition is also restricted to energy intensive industries. While these industries are important, they are not the only source of global emissions. In general, these industries are more pollution intensive in relative terms, but in absolute terms it is manufacturing production that dominates (Peters, 2008b). For example, Weber et al. (2008) show that Chinese exports are primarily driven by emissions from textiles, chemicals, electronics and manufactured products.

A weaker but more frequently used alternative definition of carbon leakage considers total pollution embodied in trade i.e. not only changes specifically induced due to climate policy. Subsequently "weak carbon leakage" is defined as "the emissions embodied in the imports of goods and services from non-Annex B to Annex B countries. Under this wider definition, it is no longer necessary for a company to physically close down its operations in Annex B country and relocate to non-Annex B country. Instead it is only necessary for expanded production to occur in non-Annex B countries.

One can argue that it is not important what causes the changes in trade and emission when only certain countries are participating in climate policy action and commit to reduce emissions. Instead the fact that emissions might be growing unchecked in Annex B countries is of much bigger importance. For instance, it is very unlikely that emissions embodied in exports of non-Annex B country occur as a result of climate policies in the participating country, this is because pollution abatement costs form only a small fraction of the total costs of a firm, often less than 4 percent and thus are unlikely to affect the decision to relocate (Kearsley and Riddel, 2010). Nevertheless these exports from non-Annex B country to Annex B still have a significant impact on global emissions and can only be captured by a weak carbon leakage method.

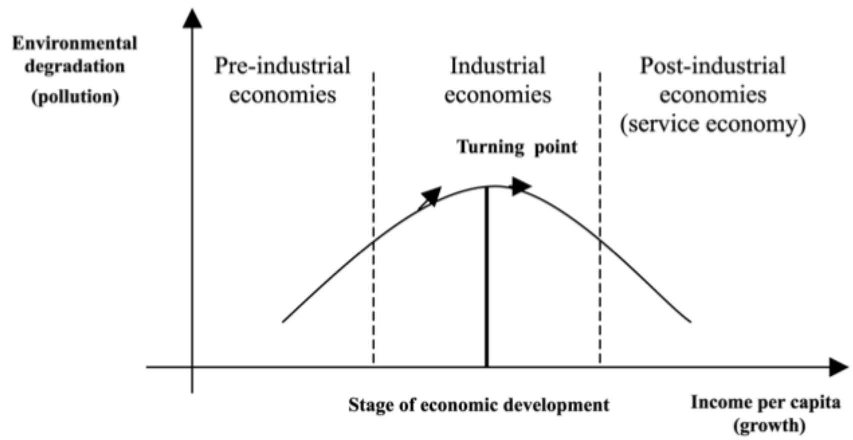
It is also important to note that one of the main reasons why carbon leakage occurs in the first place is the limited number of countries that participates in climate policy action. A solution to reduce carbon leakage may be to use a consumption-based instead of production based approach for calculating emissions. This method allows account for the carbon leakage associated with imports from non-participating countries. However, the shortcoming is that carbon leakage, might shift to exports from participating countries to non-participating

2.5 Environmental Kuznets Curve

As mentioned in section §2.1 the relationship between economic growth and environmental degradation is often tested under the so-called Environmental Kuznets Curve hypothesis. This name has its origins in early income inequality study by Kuznets (1955) who suggested that economic inequality increases over time and then after a threshold becomes more equal as per capita income increases. This relationship became known as the Kuznets Curve. In the Environmental analogy income inequality is simply replaced by environmental degradation.

The debate on the EKC started in the early 1990s when Grossman and Krueger (1991) suggested that an inverted U shape relationship exists between the level of pollution and economic growth (it is important to note that the actual term EKC was not yet used at this time, but the proposed inverted-U relationship later became known as EKC). This relationship is shown graphically in figure 2.2. Starting from the low base, the pollutant per capita and income per capita increase together until a certain point of income is reached, at which growth of the pollutant flattens and reverses. This implies that once a certain level of income has been reached, further growth can be achieved without a proportional increase in emissions (Grubb et al., 2006). The fundamental idea of EKC is that we can simply grow out of any limitations associated with natural resource use or environmental degradation (Rothman, 1998).

Figure 2.2: Environmental Kuznets Curve



Source: Panayotou (1993)

There are several theoretical explanations for the EKC pattern. The first and probably the most common are the stages of economic development. Panayotou (1993) suggest that environmental degradation tends to increase when the structure of the economy changes from rural to urban and from agricultural to industrial, mainly because of the increasing production and consumption growth. But it starts to decline with the shift from the energy intensive heavy industries to service economy with more technology intensive industries. A second explanation is associated with technological progress. It implies that as countries become wealthier the dirty and polluting technologies are substituted with the cleaner and more efficient ones, which in turn improves the environmental quality (Galeotti and Lanza, 2005). A third explanation suggests that environmental quality is a normal or even a luxury good. In other words the income elasticity of demand for environmental quality is greater than zero (normal good), or most likely even greater than one (luxury good) (Beckerman, 1992). This implies that as the average income per capita increases, individuals become more environmentally aware and thus the demand for better environmental quality goes up as well. Increase in demand induces further economy wide structural changes. It is very likely that environmental awareness leads to a shift in production and technologies towards less-polluting and more friendly activities (Grossman and Krueger, 1991, 1995), as well as to the introduction of enhanced environmental legislation and environmental policies (e.g., stricter regulations).

Another factor that is often omitted, but is crucial in explaining the EKC pattern is international trade. The factors discussed in the previous paragraph suggest that a

U-shaped EKC may exist because of the shift from heavy intensive industrial processes to lighter ones with more technology intensive industries. However, it is very likely that these structural changes from heavy industries to services in the developed countries may also be a result of the less developed regions specializing in the extraction of natural resources and the production of labor and pollution intensive goods (Stern, 1998). Thus the apparent reduction of air pollution and improvement in environmental performance of developed countries may be due to the fact that most of the pollution and energy intensive products are now being imported from abroad (Cole and Elliott, 2005). In the literature, the aforementioned pollution haven and carbon leakage hypotheses are usually used to explain these changes in trade patterns.

Most of the studies examining the EKC use various econometric techniques to test the causal relationship between different indicators of environmental degradation (e.g., CO_2, sulfur dioxide etc.) and income per capita as well as other explanatory variables (Stern, 2004). However, in this thesis such econometric tests are not performed simply because they require a longer evaluation time (at least 40 years) while the period examined in this thesis only covers 19 years. Nevertheless, we will calculate consumption-based emissions in order to examine the role of trade and to see whether the UK has managed to achieve higher income levels, while decreasing its environmental pressures. By using this approach, we take into account all environmental impact caused by the UKs consumption, which includes domestic production as well as the production required abroad to satisfy final demand in the UK.

2.6 Testable Hypotheses

Following previously mentioned theory and findings in the literature we specify several testable hypotheses.

Hypothesis I

The UK imports more CO_2 emissions from abroad than it exports, i.e. The Balance of Emissions Embodied in Trade (BEET) by Country is negative.

Hypothesis II

The UK imports more CO_2 emissions from non-Annex B countries than from Annex B, in other words the UK imports more CO_2 emissions from developing countries than from developed.

Hypothesis III

The UK imports more CO_2 emissions from energy intensive industries, than it exports. i.e. The Balance of Emissions Embodied in Trade (BEET) by Sector is negative.

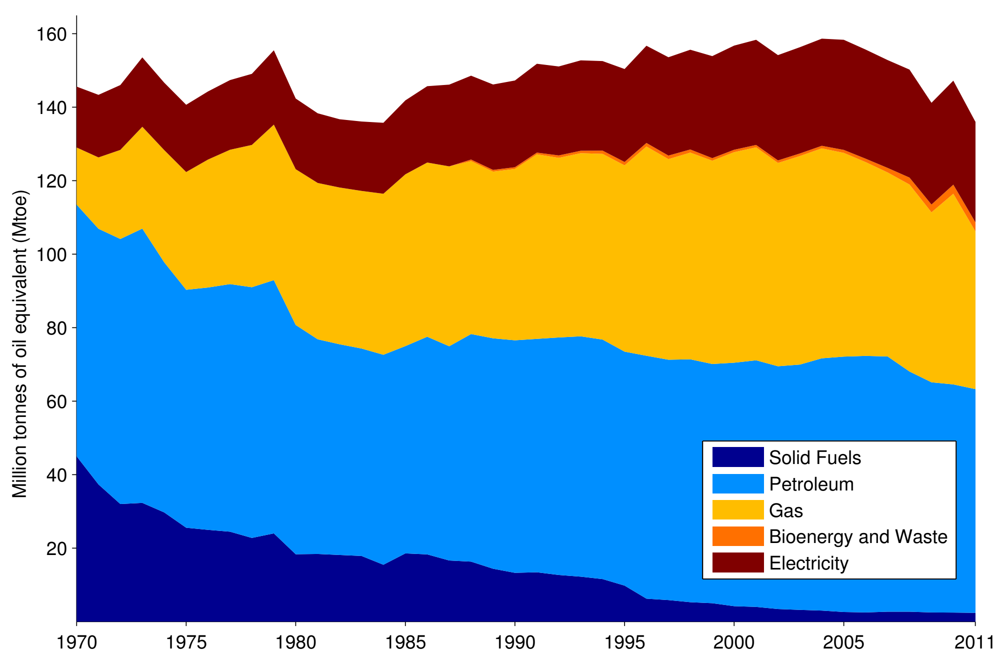
Chapter 3

The UK Background

3.1 Overview of Energy Sector

Since industrialization, the UK has been heavily dependent on fossil fuels for the bulk of its energy supply. This is still the case today, but the change is apparent (see figure 3.1). The overall fuel mix in the UK has changed from solid fuels accounting for 46.1 Mtoe in 1990 to only 2.4 Mtoe in 2011, mainly replaced by gas which grew from 14.4 Mtoe in 1970 to 43 Mtoe in 2011 (DECC, 2012).

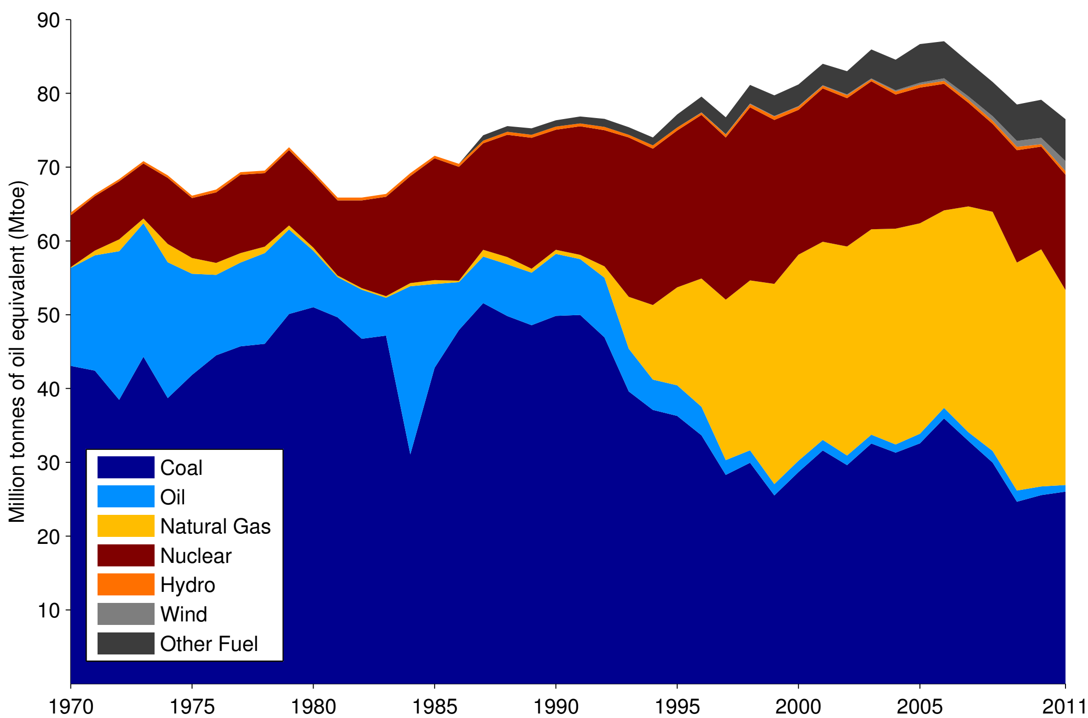
Figure 3.1: UK Final Energy Consumption by Fuel, 1970-2011



Source: DECC (2012). Author's Construction.

In fact the UK has been the first country in the world to liberalize its energy markets through the privatization of state owned companies, which led to the creation of competition among the successor companies, and the opening of the gas and electricity markets (IEA, 2008). In the 1970s before the privatization, most of the electricity in the UK came from coal, oil and nuclear powered power plants (see figure 3.2). Whilst after the reform in the 1980s and 1990s, natural gas took on an increasingly important role within the energy mix of the country. In the 1990s, the replacement of older and less-efficient coal-fired power plants, with efficient combined cycle gas turbine stations led to further improvements in the UK's energy mix, so that today, 36% of all electricity generated is from gas, 39% from coal and 19% from nuclear sources.

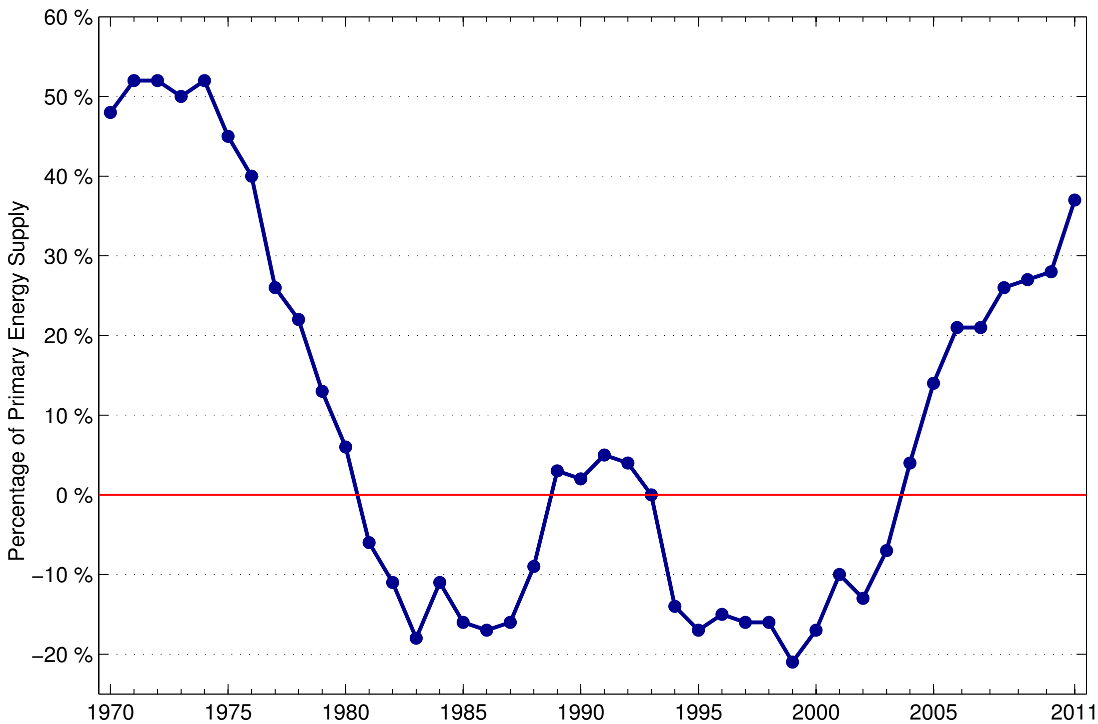
Figure 3.2: Breakdown of Sources of Electricity, 1970-2011



Source: DECC (2012). Author's Construction.

In the 1970s the UK was a net importer of primary energy. Since the early 1980s the UK has been self-reliant for all its energy demands and because of significant oil and gas production in the North Sea, it was regarded as a net energy exporter of energy (DECC, 2013). However, since 2004, the situation in the energy field has changed and the UK returned to being a net importer of fuel. In 2011, 37% of energy used in the UK was imported from overseas (see figure 3.3). Most of the imports came in the form of coal, solid fuels, crude oil, electricity and gas. Despite the large share of imports, the UK had the seventh lowest level of import dependency in the EU, behind, Estonia, Romania, Czech Republic, Netherlands Poland and Denmark (DECC, 2013).

Figure 3.3: UK Net Direct Energy Imports and Exports, 1970-2011



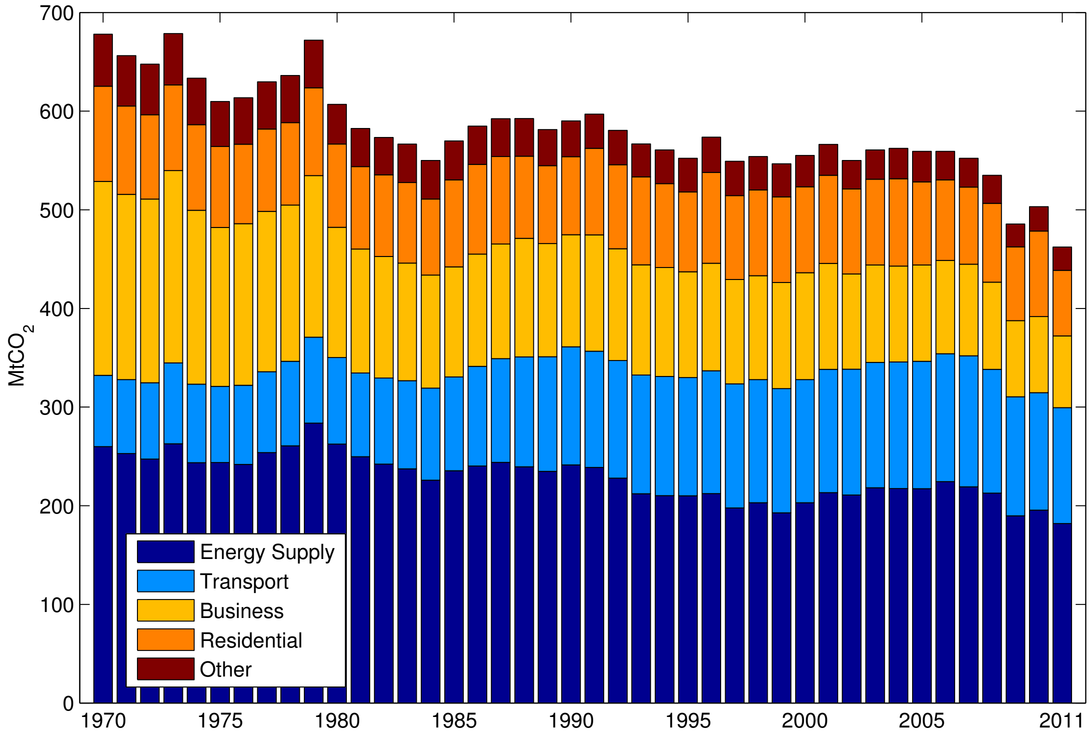
Source: DECC (2013). Author's Construction.

3.2 Greenhouse Gas Emissions

The UK has measured and reported its emissions of greenhouse gases (GHG) since 1988. Ever since the measurement began, the UK was amongst the first countries to fulfill the Kyoto protocol commitments and reduced the levels of their GHGs by 12.5% below the base year levels 1990 and 2008/2012 (based on the production accounting figures).

The basket of GHGs covered by Kyoto Protocol consists of six gases, namely: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). Due to the data availability this study only considers CO_2, which is the most important of the GHGs. According to the latest figures in the UK, carbon dioxide accounts for 82% of all GHGs (DECC, 2013).

Figure 3.4: CO_2 Emissions by Source, 1970-2011



Source: DECC (2013). Author's Construction.

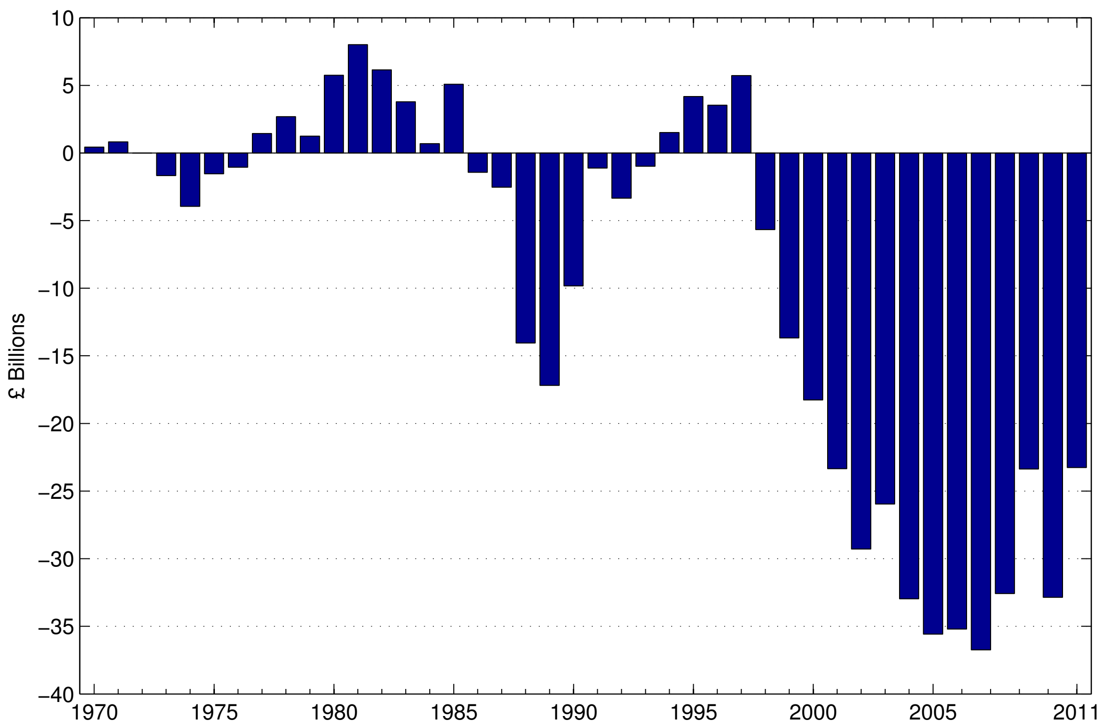
Carbon dioxide emissions by source are presented in figure 3.4. In 2011, an estimated 39% (182 Mt) of CO_2 emissions were from the energy supply sector, 25% (117 Mt) from transport, 14% (66.5 Mt) from the residential sector and 16% (73 Mt) from business. Yearly fluctuations that can be seen in figure 3.4 are usually explained by weather changes (e.g., cold winter requires longer heating period and thus more energy) and energy exports/imports.

Between 1990 and 2011 the aggregate levels of CO_2 emissions have declined by about 24% from 591 $MtCO_2$ to 454 $MtCO_2$. Most of this decrease can be attributed to the energy supply sector, where CO_2 emissions have declined by about 26% since 1990s. There was also a significant 34% decrease of emissions in the business sector. However since the business sector share (16%) towards overall level of CO_2 emissions is smaller, its contribution towards decrease was also smaller when compared to the energy sector. Contributions from other sectors towards the decline of CO_2 emissions were significantly smaller. Emissions from the transport sector were only 2% (3 Mt) lower in 2011 than they were in 1990. It should be noted that there was a general increase in transport sector emissions throughout the period up until 2007, and only since then they started to show a moderate decline, whereas, emissions in the residential sector were estimated to be around 3% lower in 2011 than they were 1990.

3.3 UK Balance of Trade

UK balance of trade (in goods and services) for the period from 1971 to 2011 is presented in figure 3.5. From the beginning of the period up until 1985 the UK balance of trade was mainly in surplus (except 1973 to 1976) the peak of £8 billion was reached in 1981 (ONS, 2012). From 1985 onwards (excluding 1994 to 1997) the Balance of Trade was in deficit. The UK reported its largest deficit of £37.6 billion in 2007 at the beginning of the global economic slowdown. Since 1985 the annual Balance of Trade in goods and services deficit has averaged at about -£15.4 billion.

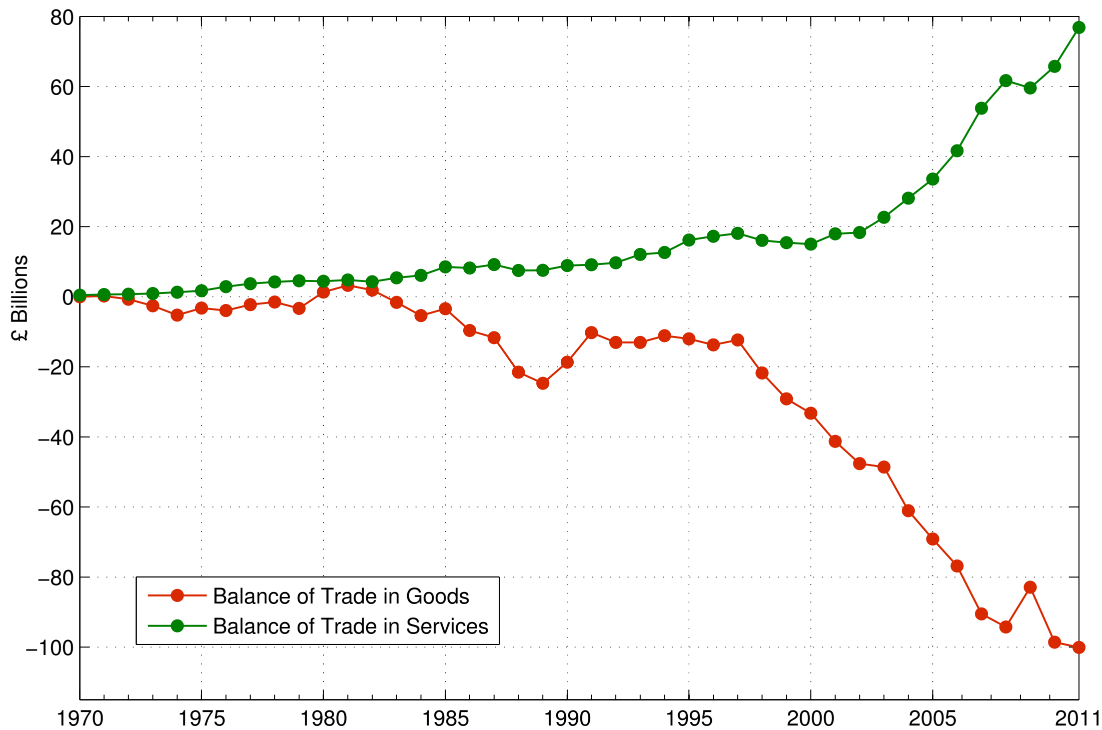
Figure 3.5: UK Balance of Trade, 1970-2011



Source: ONS (2012). Author's Construction.

Although the UK has shown a deficit in balance of traded goods and services since 1983, it is evident that the some of these annual deficits were worse during the late 1980s and more recently in 2005-2007. This is not surprising, as during these two periods, the UK economy was either booming (late 1980s) or at least doing very well (prior to recession). According to economic theory during the times of economic boom, the balance of trade should worsen (Barro, 1997). Ceteris paribus, the value of imports should rise as a result of the increase in real income. The UK government reports that UK citizens have a high marginal propensity to import, thus when real income increases, the demand for imports should increase more than proportionally. Similar can be said about the times of economic recession, during which one can expect the balance of trade to improve.

Figure 3.6: UK Balance of Trade in Goods and Services, 1970-2011



Source: ONS (2012). Author's Construction.

The balance of trade for goods and services is shown separately in figure 3.6. From 1971 to 2011, the balance of trade in goods has declined rather sharply, the only years in which there was a surplus were 1971, 1980, 1981 and 1982. The annual average balance of trade in goods was estimated to be about -£27 billion and the largest deficit of -£100 billion recorded in 2011. In contrast, the balance of trade in services has shown a significant increase in surplus since the 1970s. In 2011, this surplus was the highest over the period, standing at a record £76.4 billion with the annual average of about £17.5 billion (ONS, 2012).

The UK persistently has a surplus in its trade in services because of a few particular elements of the service sector. Mainly, this is due to the strength of its financial services sector. A significant proportion of the inflow of money into the UK comes from things like banking, insurance and management.

The UK's main trading partners in goods and services in 2011 are shown in table 3.1. According to the latest figure, the UK export of goods and services amounted to about 30% (£493 billion) of UK GDP. About 47.5% of total goods and services were exported to EU countries and the remaining 52.5% to the rest of the world. The US was the UK's single largest destination of exports, accounting for about 16.2% of total exports, followed by Germany (8.9%), the Netherlands (6.9%) and France (6.5%). Exports to the BRIC countries added together accounted for 6.5% of all exports.

On the other hand total imports of goods and services from the EU accounted for about 51%. Germany was the UK's single largest source of imports, accounting for 11.5%, followed by the US (9.4%), France (6.4%) and China (6.3%). Imports from the BRIC countries together accounted for about 10% of all imports.

Table 3.1: The UK's main Trading Partners in Goods and Services, 2011

Exports of Goods and Services			Imports of Goods and Services		
	£ million	% of World		£ million	% of World
World	492,646		*World*	516,609	
EU27	233,801	47.5%	*EU27*	261,378	51%
Germany	43,901	8.9%	Germany	59,563	12%
Netherlands	34,075	6.9%	France	33,170	6%
France	32,035	6.5%	Netherlands	32,774	6%
Ireland	27,409	5.6%	Belgium	21,521	4%
Belgium	19,047	3.9%	Spain	21,435	4%
Italy	15,607	3.2%	Italy	18,465	4%
Spain	15,283	3.1%	Ireland	17,297	3%
Sweden	9,564	1.9%	Sweden	9,672	2%
Denmark	5,935	1.2%	Poland	8,610	2%
Poland	5,755	1.2%	Denmark	7,394	1%
Rest of EU 27	25,190	5.1%	*Rest of EU 27*	38,871	8%
Rest of the world	258,845	52.5%	*Rest of the World*	255,231	49%
EFTA	21,408	4.3%	EFTA	37,357	7%
US	79,888	16.2%	US	48,639	9%
China	12,530	2.5%	China	32,775	6%
India	8,332	1.7%	India	8,544	2%
Russia	7,286	1.5%	Russia	8,520	2%
Brazil	3,695	0.8%	Brazil	3,106	1%

Note: EFTA - European Free Trade Association (Iceland, Liechtenstein, Norway and Switzerland).
Source: (ONS, 2012)

3.4 UK Climate Policies

Many multi-region input output (MRIO) studies bring policy importance to the forefront of the research. However, not many studies explain the policy measures prevalent in the country in particular when it comes to single country studies. The UK has one of the most advanced climate change legislations in the world for reducing GHGs. The legislation consists of two international and domestic policy measures, namely: the Kyoto protocol agreement and the UK 2008 Climate Change Act (Fankhauser et al., 2009).

The Kyoto Protocol is a legally binding agreement between signed-up countries to meet their emissions reduction targets of all GHGs in two commitment periods. The first commitment period applies to emission between 2008 and 2012 and the second to emissions for the period 2013-2020. In the first period the UK, as a signatory, agreed to reduce its GHGs by an average of 12.5% measured relative to 1990 levels. Although compared with other countries, this was a very ambitious target, the UK as noted previously was amongst the first countries to fulfill their Kyoto protocol commitments and reduce GHGs below the base year level. In the second Kyoto period the UK, committed to reduce its GHG emissions by at least 20% (the same target exists for all EU-27 countries) by 2020 compared to 1990 levels. Based on the latest emissions data, the UK 2012 emissions stand approximately 25% below the 1990 level target, and therefore meet the target of cutting emissions by 20% by 2020 (DECC, 2014).

For the UK to be at the forefront of developing low carbon economy, it has also set itself domestic targets to reduce GHG emissions by 2050. This was mainly stimulated by The 2008 Climate Change Act, which established a framework to develop an economically credible emissions reduction path. The act obliges the UK to reduce its GHGs by at least 80% below 1990 levels by mid-century. Although policymakers around the globe have endorsed such long-term goals, the UK is the first country so far to put this commitment into law. The key institutional innovation of the Climate Change Act is the introduction of five-year carbon budgets. The carbon budget places a restriction on the total amount of GHGs the UK can emit over a 5-year period. Under the system of carbon budgets, every tonne of GHGs emitted between now and by 2050 will count. Where emissions rise in one sector, the UK will have to achieve a corresponding fall in another sector, or purchase offset credits from the EU Emissions Trading System (EU ETS). Four carbon budgets have been set in place so far, the latest (forth) legislated carbon budget commits the UK to 50% reduction in GHGs emissions (relative to 1990 levels) for the period of 2023 to 2027. The most recent projections show that the UK is on track to meet its carbon budget targets (DECC, 2014).

3.5 The UK Emissions Pattern Since 1970

There are several factors that contributed to the fall in UK emissions since 1990 (and from 1970). However, two factors stand out the most: the increasing changes in the fuel mix used for power generation and the reduction in activity of energy intensive-industries since the 1970s/1980s.

As noted in section §3.1, the UK energy industry underwent a radical transformation in 1990, which lead to a significant shift of electricity generation from coal-fired power to natural gas. The "dash for gas" was primarily driven by economic reasons, namely cheaper wholesale gas prices and improved technology. The decrease in CO_2 emissions from the energy supply sector came from a combination of changes in the fuel mix and the greater efficiency of modern combined cycle natural gas power stations. Although it is difficult to access which one of these had a greater impact, it is very likely that the majority of the saving between 1990 and 2013 came from fuel switching from coal to gas for electricity generation(DECC, 2013). In addition to gains from electricity generation, industry and transport have also taken advantage of the dash-for-gas.

Another major effect that contributed to the fall in UK emissions is de-industrialization, which came at the end of the 1970s together with the second OPEC oil Shock. Rising oil prices accompanied with rising inflation (peaked at about 22%), resulted in a sharp increase in the interest rate (to 17% at peak). Although the effect of a higher interest rate was strongly deflationary, its impact on exchange rates was accompanied by a sharp rise in the British Pound sterling (Helm et al., 2007). As a result, there was a loss of international competitiveness and a decline in manufacturing output by around 25% in the 1970s, especially in internationally competitive industries like, steel and chemicals. The manufacturing output stabilized during later years and since 1993 its fall was only marginal.

This break of historical trajectory and shift towards a service-based economy has led to a decline in energy intensity and CO_2 emissions from a domestic perspective. However, the critical question is not whether the production in the UK was decarbonized, but whether its consumption of GHGs fell or whether it was replaced by imports from abroad. In fact the CO_2 savings that came from the switch between coal and gas were real, because of a lower carbon output of natural gas relative to coal, whereas the gains from deindustrialization are less concrete, there may not have been real saving at a global level, just displacement of resources from the UK to overseas. This is one of the main questions that this thesis is seeking to answer.

Chapter 4

Literature Review

Growing concerns about climate change and the increasing importance of international trade has led to a significant interest in consumption-based emissions and resource accounting. To date, a respectable number of studies have been undertaken worldwide in order to quantitatively examine emissions embodied in the international trade of different countries and world regions. Single region input-output (SRIO) and increasingly multi-region input-output (MRIO) models are used to assess environmental impacts of internationally traded goods and services. This section provides a brief overview of SRIO studies followed by a more in-depth examination of the developments in MRIO field and the UK specific studies.

4.1 Single-Region Input-Output Models

The interest in emissions embodied in international trade is not new. Early versions of single-region input-output studies date back to the 1970s (e.g., Walter, 1973). A fair number of studies has been carried out since those early days, with significant differences in terms of scope, technique, dataset and assumptions.

In an early study on international trade flows, Wyckoff and Roop (1994) estimates the amount of carbon embodied in the imports of 21 different groups of manufactured goods to six of the largest OECD countries - Canada, France, Germany, Japan, the UK and the USA - in order to determine whether or not the imports of carbon rich products is a significant problem worth addressing. The study is based on input-output tables for these countries and bilateral trade flow data. Their results suggest that a significant amount, about 13 % of these countries' total CO_2 emissions are embodied in imports of manufactured goods. Relying solely on standard measures of domestic carbon emissions such as territorial based accounts is not effective and might be misleading, thus new mechanisms should be devised.

In addition to calculating emissions, Wyckoff and Roop (1994) also perform a test for the importance of sectorial aggregation. The results of their original 33-sector model are compared to the aggregated 6-sector model. Their results reveal that carbon emissions embodied in imports of manufactured products are about 30% lower when calculated by a 6-sector model than when calculated using a disaggregated, 33 sector model.

Munksgaard and Pedersen (2001) demonstrate differences in Denmark's CO_2 emissions based on two accounting principles: a production vs consumption principle. By taking the difference between total CO_2 emissions estimated on the basis of two alternative methods, they develop the concept of a "CO_2 trade balance". Their results indicate that from 1989 to 1994 the CO_2 trade balance in Denmark has changed significantly, from a surplus of 0.5 million tonnes in 1987 it turned into a deficit of 7 million tonnes in 1994. This implies that it has become more difficult to reach national emissions targets because an increasing share of Danish territorial emissions is caused by foreign demand.

A study by Sánchez and Duarte (2004) analyzes the sectorial impacts that Spanish international trade has on the levels of CO_2 emissions. A 18-sector SRIO model is used to distinguish between the direct and indirect CO_2 emissions generated in Spain (domestic and exported) and abroad (i.e., imported emissions). The emission coefficients are based on the domestic technology assumption, which implies that imported goods are produced with the same technology as the one in Spain. The results indicate that Spain imports about the same amount of CO_2 emissions as it exports, i.e. its CO_2 trade balance is close to zero. Most of the imports come from construction, transport material, food and other services. While exports of embodied CO_2 emissions are mainly concentrated in the basic sectors of the Spanish economy i.e. transport, material, mining and energy, non-metallic industries, chemicals and metals.

More recently a number of studies have attempted to evaluate carbon dioxide emissions embodied in the international trade of China. This interest has been driven by a significant growth in China's CO_2 emissions, which have almost doubled within a very short period of time from 2002 to 2007, making China one of the world's biggest emitters. Weber et al. (2008) applies a SRIO model to estimate the CO_2 emissions emitted in the production of exports in China from 1987 to 2005. The authors find that in 2005, around 30% of Chinese emissions (1670 $MtCO_2$) were due to exports, and this proportion has risen significantly over time from 12% (230 $MtCO_2$) in 1987 to 21% (760 $MtCO_2$) in 2002. They also find that China avoids large amounts of emissions by importing products from abroad. In fact their estimates show that every year China imports more emissions than it exports, making it a net importer of emissions. However, import figures might be biased because authors apply China's carbon intensity, which is significantly higher than that of other countries.

In contrast, Lin and Sun (2010) using a similar approach, show that in 2005 about

3350 million tons CO_2 emissions were embodied in China's exports and the emissions avoided by imports amounted to 2300 million tons, making China a net exporter of emissions. The difference between the two studies can be explained by the different treatment of re-exported emissions, which represent the emissions that are imported but later exported. Weber et al. (2008) excludes the re-exported emission component, which leads to an underestimation of emissions embodied in Chinas exports, while Lin and Sun (2010) accounts for it and provides a more realistic estimate. Most of the other studies (e.g., Yan and Yang, 2010) support the findings that China is a net exporter of emissions, but to varying degrees. Differences in results are not small in magnitude and even territorial (production based emissions) are often different reflecting the different scope of emissions taken into account, as well as the different sources of data. China is not the exception and other studies dealing with different countries also report varying levels of production-based emissions. This will be shown and discussed in more detail in section 4.3.2.

There are many more interesting SRIO studies that investigate GHG emissions as well as other environmental impacts (e.g. water use, energy use etc.) embodied in international trade. A broader review of these SRIO studies can be found in Wiedmann et al. (2007), Wiedmann (2009) and Sato (2013).

4.2 Multi-Region Input–Output Models

Not all multi-region input-output approaches have the same mathematical form and modeling framework. There are essentially two types of MRIO models that can be distinguished in the literature. In the first model, national input-output tables are exogenously linked with bilateral trade data for different countries and the embodied emissions in this case are estimated for each country separately Wiedmann et al. (2007). The other model known as a the true or full multi-region model combine domestic technical coefficient matrices with trade flow matrices between multiple countries into one large coefficient matrix. This allows the tracking of international trade supply chains between all trading partners, as well as the feedback effects Wiedmann et al. (2011). In this paper the term MRIO is used to represent all international input-output models with more than one region.

Although the first international multi-region input-output studies were already conducted in the 1990s (e.g., Tiwaree and Imura, 1994; Proops et al., 1999), it was not until the mid-2000s that the first consistent theoretical framework for MRIO analysis with the purpose of calculating emissions embodied in trade was introduced. Ahmad and Wyckoff (2003) were amongst the first to present a framework for calculating carbon emissions embodied in internationally traded goods based on input-output and trade modelling. Their calculations of carbon emissions for 24 countries (responsible for 80% of global CO_2 emissions) are based on national input-output tables covering 17 sectors and bilateral trade data for 41 countries. The result is that carbon emissions generated to satisfy domestic consumption in OECD countries in 1995 were 5% (or 0.5 Gt) higher than emissions related to production. Most of these excess emissions can be allocated to a few importing countries, mainly the US, Japan, Germany, France and Italy. In fact the US alone contributed to nearly half of the total carbon emissions embodied in imported goods. The largest share of emissions embodied in exports to OECD countries came from China and to a lesser extent from Russia.

Lenzen et al. (2004) and Peters and Hertwich (2004) develop a consistent theoretical framework for MRIO models to calculate pollution embodied in trade. The two approaches are very similar, the only difference is that Lenzen et al. (2004) uses supply and use tables, whereas Peters and Hertwich (2004) base their calculations on symmetric input-output tables. Both research groups calculate emissions embodied in trade for a number of different countries.

Lenzen et al. (2004) calculate CO_2 emissions embodied in multi-directional trade between Denmark, Germany, Norway, Sweden and the rest of the world. Assuming different scenarios the authors demonstrate the difference in the results when different technology assumptions are used to account for traded goods.

In the case of Denmark, 18.9 Mt of CO_2 emissions embodied in imports resulting from a single-region model (assuming DTA, i.e. all imports are produced with Danish technology) turn into 38.4 Mt of imported CO_2 emissions when multidirectional trade with specific production technology for each individual country is considered. This also changes the Danish trade balance, turning it from an 11 $MtCO_2$ trade surplus to 0.3 $MtCO_2$ deficit, when multidirectional trade is considered. Lenzen et al. (2004) show that the level of sector aggregation can have a significant effect on overall results and thus suggest that the most possible detail of sector disaggregation should be used.

Peters and Hertwich (2006) follow a slightly different approach, based on symmetric input-output tables analyzing pollution embodied in Norwegian trade. Their results indicate that in 2000 CO_2 emissions embodied in imports amount to 67% of Norway's domestic emissions, and about half of this pollution originates in developing countries, while exports amount to 69% of domestic emissions. The results also indicate that the carbon leakage from non-Annex I[2] countries was at least 30%. In addition, the study also shows that if imports were calculated assuming DTA (i.e., Norwegian technology) this would lead to underestimation of emissions by a factor of 2.5.

The creation and publication of complete MRIO databases such as GTAP, EX-

[2]Non-Annex I is essentially the same as non-Annex B, the only difference between the Annex I and Annex B countries, is that Turkey and Belarus are not Annex B countries.

IOPOL, WIOD and EORA has led to a significant increase in studies that attempt to estimate embodied carbon in trade for multiple countries. Peters (2008b) played a central role in constructing a full, multidirectional MRIO model, based on the GTAP database with 87 regions and 57 sectors. Based on this model Peters and Hertwich (2008a) calculated CO_2 emissions embodied in international trade among 87 countries for the year 2001. Their results suggest that there are over 5.3 Gt of CO_2 emissions embodied in global trade and countries with binding emissions commitments in the Kyoto Protocol are found to be the net importers of emissions.

Nakano et al. (2009) present a study of consumption-based CO_2 emissions for OECD countries in the year 2000. The results of this study show that consumption based emissions are 16.1% higher than production-based emissions and the results for seven OECD countries (Austria, France, Luxemburg, Portugal, Sweden, Switzerland, and the UK) show at least 30% higher consumption based emissions. An overall net trade deficit of CO_2 emissions are observed in 21 OECD countries. A study also shows that while a third (860 MtCO_2) of the global increase in production-based emissions took place within the non-OECD economies between 1990 and 2000, more than half of the consumption-based emission (1550 MtCO_2) can be attributed to consumption in OECD countries.

Using a similar approach Davis and Caldeira (2010) calculate emissions embodied in trade for 113 countries/ regions and 57 industry sectors for 2004. Their estimates indicate that 23% of global CO_2 emissions (6.2 Gt) can be attributed to international trade, mainly between the exports from China and other emerging markets and the consumers in developed countries. For some wealthy countries like Switzerland, Sweden, Austria, France and the UK more than 30% of consumption based emissions (on a per capita basis) can be attributed to imports. These consumption-based calculations demonstrate the possibility of international carbon leakage from developed to developing countries.

A more recent study by Boitier (2012) makes use of the WIOD database to calculate GHG emissions for 41 countries from 1995 to 2009. One of the main findings coming from this research is that the world can be split into two regions; CO_2 consumers (developed countries) and CO_2 producers (developing countries). The results of this study also indicate that the consumption-based emissions are increasing over time in the EU-27 countries. In 1995 CO_2 emissions calculated with the consumption-based approach were 11% higher when compared to emissions calculated with the production-based approach. Throughout the years this CO_2 surplus grew and in 2008 it amounted to 24%.

The MRIO model has also been used to investigate pollution embodied in trade for individual countries. For instance, Kanemoto and Tonooka (2009) employ MRIO model covering 26 countries and the RoW to estimate CO_2 emissions embodied in Japan's trade for the years 1995, 2000 and 2005. They report that emissions embodied in imports to Japan have grown significantly, from 276 $MtCO_2$ (22% of territorial emissions) in 1995 to 403 $MtCO_2$ in 2005 (30%), while emissions embodied in exports grew from 12% to 22% during the same period. The authors also demonstrate how sensitive the measurement of embodied emissions in trade can be to different assumptions about the exchange rate mechanisms (PPP and MER). When PPP is used to convert input-output tables to Japanese yen, the volume of emissions imported to Japan drops by half. This leads to a shift from Japans negative trade balance (imports more) of emissions embodied in trade to a positive balance (exports more).

4.3 Specific UK Studies

4.3.1 Single-Region Input-Output Models

During the last decade several studies have attempted to investigate emissions embodied in trade of the UK for various time periods and environmental indicators. A brief review of studies mainly dealing with the calculation of carbon dioxide emissions is presented this section.

One of the early attempts to quantify the carbon footprint of traded products between the UK and other countries is presented by the Carbon-Trust (2006). This study makes use of the 1995 Input-output Analytical Tables based on 122 industrial commodity categories to construct a two-region model incorporating trade between the UK and the rest of the world. The results show that UK consumption based emissions are 165.4 $MtCO_2$, this is 11.7 $MtCO_2$ greater that the emissions calculated using the production approach. It implies that the carbon associated with UK imports from abroad is greater than the carbon associated with UK exports. This difference can be attributed to the development of the UK service based economy and relocation of the carbon intensive industries such as manufacturing to overseas. It is also important to note that the trade effect might be underestimated because of the use of the domestic technology assumption.

Using a similar single-region input-output model, Druckman et al. (2008) calculates consumption based carbon dioxide emissions from energy use in the UK between 1990 (the Kyoto base year) and the year 2004 and compares this against the production perspective. The results from their two region input-output model suggest that any progress towards the UK's CO_2 reduction targets visible under a production perspective disappears entirely when viewed from a consumption perspective. Emissions have increased by 8% between 1992 and 2004. This rise in consumption-based emissions is explained by the increasing exports of more carbon intensive industries and imports of more consumer goods. Unsurprisingly the robustness of consumption-based estimates relies heavily on the accuracy of underlying economic and environmental datasets as well as assumptions about imports.

Druckman and Jackson (2009) in a study of CO_2 emissions that arise from production of goods and services to satisfy UK household demand, observe a similar trend. In this study (different from their previous attempt) the authors relax the domestic technology assumption by using a quasi-multi region input-output model and different carbon dioxide intensity coefficients of imported goods. Their results show that according to the consumption perspective carbon dioxide emissions attributable to households increased by around 14% between 1990 (660 $MtCO_2$) and 2004 (752 $MtCO_2$), whereas the carbon trade balance grew from 5% to 19% over the same time period. Further investigation into the carbon footprint of different segments of the UK population reveals, recreation and leisure are responsible for about 25% of total CO_2 emissions in 2004

4.3.2 Multi-Region Input–Output Models

This section provides a non-exhaustive list of studies that have attempted to calculate carbon dioxide emissions embodied in UK's international trade using MRIO models. The results stemming from these studies are presented in table 1, which also includes the results for the UK from several multiple country studies.

Wiedmann et al. (2010) construct a time series of balanced input-output tables for the period 1992 to 2004 to calculate national carbon footprints for the UK. Their UK-MRIO model covers 123 sectors for the UK and 30 sectors for the three world regions covering the global economy (OECD-Europe, other OECD and non-OECD countries). Carbon dioxide emissions calculated from the consumer perspective are significantly higher than producer emissions for all years considered in the study. Total consumer CO_2 emission increased from 653 Mt of CO_2 in 1995 to 730 Mt of CO_2 in 2004, whereas producer emissions during the same period increased from 594 Mt to 531 Mt of CO_2. Emissions embodied in imports (EEI) were found to be higher than emissions embodied in exports (EEE) during the entire study period. Both increased over time but EEI grew much faster (by 60% between 1992 and 2004) than EEE (by 28%). The balance of emissions embodied in trade (BEET), accounted for –59 Mt of CO_2 in 1995 ($\pm$ 10% of producer emissions) and in 2004 it was -99 Mt ($\pm$ 16% of PE). This clear trend of increasing in BEET deficit implied that more and more emissions have been imported to the UK, rather than exported from the UK.

Minx et al. (2009) using the UK-MRIO model developed by Wiedmann et al. (2010)[3] perform a structural decomposition analysis to understand the changes in the UK's pro-

[3] The model was already developed in 2008, and Minx et al. used it in 2009.

duction and consumption carbon emissions between 1992 and 2004. The study highlights that although the UK's territorial carbon dioxide emissions have declined between 1992 and 2004, consumer emissions have grown significantly over the same time frame. The overall increase in both accounts is mainly attributed to the rising levels of final consumption in the UK, which resulted in an increase of carbon dioxide emissions of 203 Mt for producer emissions and 249 Mt for consumer emissions between 1992 and 2004 respectively. The remaining fifth of these increases could be attributed to the changing socio-demographic forces in the UK, mainly declining household size (from 2.5 persons per household to 2.3) and growing population (from 57.6 to 59.8 million). Interestingly reduction of carbon emissions coming from technological progress in the UK and abroad, as well as shift towards greener consumption patterns were not large enough to off-set the rising levels of CO emissions from final consumption growth. Analysis also showed that the transition towards service economy did not make the UK less dependent on the manufactured products, but rather resulted in the increase of these products from elsewhere in the world.

The Carbon-Trust (2011), using similar methodology to previously mentioned studies estimate that consumption emissions are about 34% higher than production emissions for the year 2004. About 60% of consumption emissions occur in the UK, a further 12% comes from European (EU ETS) countries, and the remaining 38% occur in the rest of the world. Emissions embodied in imports into the UK come from a wide range of goods and commodities, with chemicals and rubber, machinery, air transport operations and minerals constituting one third of all imports. Overall around two thirds of all imports arrive as finished products. This reflects the UK's position as a consumer, rather than producer of final goods.

There exist several other research groups (Barrett et al., 2011; Barrett et al., 2013; Scott et al., 2013) that have attempted to calculate CO_2 or CO_2 equivalent emissions for the UK since the early 1990s to recent years. Although the results from different studies have some variation in the final estimates, they all show similar trends: emissions from a production perspective have declined over time, while consumption based emissions have increased. The difference found in these studies can arise due to the use of different definitions, data sources, methods and assumptions. These uncertainties are explained in more detail in section §6.8. However, it is important to note that it is not the aim of this study to fully understand these differences, instead the intention is to provide more evidence in support of the trends from different studies.

Table 4.1: Comparison of CO_2 emissions Embodied in UK Trade

Reference	Data year	Producer	Consumer	EEE	EEI	BEET %
Ahmad and Wyckoff (2003)	1995	536	549	110	123	-2%
Boitier (2012)	1995	590	641	133	184	-9%
Minx et al (2009)*	1995	593	620			-5%
Nakano et al (2009)	1995	533	623	290	222	-17%
Wiedmann et al (2008)*	1995	593	652	222	281	-10%
Boitier (2012)	2000	602	721	138	256	-20%
Minx et al (2009)*	2000	609	683			-12%
Nakano et al (2009)	2000	526	722	385	317	-37%
Wiedmann et al (2008)*	2000	609	681	218	290	-12%
Minx et al (2009)*	2001	625	731			-17%
Peters & Hertwich (2008)	2001	619	721	132	234	-16%
Wiedmann et al (2008)*	2001	625	732	229	336	-17%
Minx et al (2009)*	2002	610	729			-20%
Wiedmann et al (2008)*	2002	610	730	222	343	-20%
Minx et al (2009)*	2003	625	721			-15%
Wiedmann et al (2008)*	2003	625	764	242	380	-22%
Carbon Trust (2011)*	2004	632	845	125	338	-34%
Davis and Caldiera (2010)	2004	555	808	95	253	-46%
Minx et al (2009)*	2004	631	733			-16%
Wiedmann et al (2008)*	2004	631	762	242	374	-21%
Boitier (2012)	2005	621.6	787	152	318	-27%
Nakano et al (2009)	2005	488	549	59	121	-13%
Boitier (2012)	2009	559	672	133	246	-20%

Note: * Denotes UK-specific study. EEE - Emissions Embodied in Exports; EEI - Emissions Embodied in Imports; BEET is expressed as a percentage of the production-based emissions. All numbers in Mt of CO_2.

Chapter 5

Data

The data for this study comes from the recently constructed World Input-Output Database (WIOD). This is the first database that provides a detailed annual time-series on trade and GHG emissions for the period from 1995 to 2009/2011 (Timmer, 2012). The WIOD consist of series of sub-databases covering 35 industries and 41 countries/regions, including 27 EU and 13 other major advanced and emerging economies, plus a region called "Rest of the World" (see Appendix A, for complete list of countries/regions and sectors). This study makes use of two sub-databases: the database on World Input-Output Tables (WIOTs) and the database on "Environmental Accounts".

5.1 World Input-Output Table

A World Input-Output Table (WIOT) can be seen as a set of national IO tables that are connected with each other by bilateral international trade flows. The construction of such table requires significant amounts of data that comes from publicly available national statistical offices around the world, plus various international statistical sources such as OECD and UN National Accounts, UN Comtrade and IMF trade statistics (Timmer et al., 2014).

A simplified structure of the WIOT with three countries/regions: A, B, and the RoW, is displayed in figure 5.1 (see Appendix B, for a more detailed explanation). This example assumes that each country/region has only one industry and produces only one unique product. The use of industry products for either intermediate (denoted with $\mathbf{Z}$) or final use (denoted with $\mathbf{f}$) is indicated in the rows of the table. First element ($Z_{A,A}$ colored in green) indicates the domestic use product, while second ($Z_{A,B}$) and third ($Z_{A,RoW}$) elements indicate the intermediate use of Country A's product by Country B and RoW, these two elements (colored in blue) can be seen as exports from A to B and RoW. Similar explanations can be applied to the elements in the final use section, so that $f_{A,A}$ is the domestic final consumption while $f_{A,B}$ and $f_{A,RoW}$ are exports from A, for final use in B and RoW. The final element (X_A) in this RoW indicates the total use of the product. The columns of the table contain the information on the supply of each product. The product can be produced domestically ($Z_{A,A}$) or imported, for instance elements $Z_{A,B}$ and $Z_{RoW,A}$ in the first colored column show the imports from B and the RoW to A.

Figure 5.1: World Input-Output Table Structure

	Intermediate Consumption			**Final Demand**			**Output**
	Country A	Country B	Country RoW	$\mathbf{f_A}$	$\mathbf{f_B}$	$\mathbf{f_{RoW}}$	
Country A	$Z_{A,A}$	$Z_{A,B}$	$Z_{A,RoW}$	$f_{A,A}$	$f_{A,B}$	$f_{A,RoW}$	X_A
Country B	$Z_{B,A}$	$Z_{B,B}$	$Z_{B,RoW}$	$f_{B,A}$	$f_{B,B}$	$f_{B,RoW}$	X_B
Country RoW	$Z_{RoW,A}$	$Z_{RoW,B}$	$Z_{RoW,RoW}$	$f_{RoW,A}$	$f_{RoW,B}$	$f_{RoW,RoW}$	X_{RoW}
VA	VA_A	VA_B	VA_{RoW}				
Output	X_A	X_B	X_{RoW}				

In WIOTs final consumption of an individual country is divided into several separate categories: Final consumption expenditure by Households (H), Final consumption expenditure by non-profit organisations serving households (NPISH), Final Consumption expenditure by Government (Gov), Gross fixed capital formation (Stock), Changes in inventories and valuables (INV). These final demands are summed so they represent an aggregate final demand of a given country, e.g. fa,b indicates total final demand (f = H+NPISH+Gov+Stock+INV) in country A for country B's product.

A complete WIOT has the dimension of 1443 rows and 1641 columns. As displayed in figure X intermediate use in WIOT consist of 1435 industry-country pairs (41 countries x 35 industries), with remaining rows representing VA, Output and other adjustment items. Similarly there are a 1435 industry-country pairs as users of intermediates in the columns and 205 additional columns for final consumption per country (41 x 5 Types of Final consumption, this become 41 x 1 when final consumption is aggregated). All transactions in WIOT are expressed in US dollars and market exchange rate was used for currency conversions of original data from individual countries.

Figure 5.2: World Input-Output Table Size

	Intermediate Consumption			**Final Demand**			**Output**
	Country A	Country ...	Country RoW	$\mathbf{f_A}$	$\mathbf{f_{...}}$	$\mathbf{f_{RoW}}$	
Country A							
Country ...	1435 x 1435			1435 x 205			1435 x 1
Country RoW							
VA	7 x 1435						
Output	1 x 1435						

5.2 Environmental Accounts

The data for CO_2 emissions comes from the WIOD Environmental Accounts (sometimes referred to as Environmental Satellites). Similarly, as for WIOTs data for CO_2 emissions includes 41 countries and 35 economic sectors. However, the time period covered by environmental accounts is two years shorter 1995-2009. This is the main reason why this study examines CO_2 emissions embodied in trade for this period.

The WIOD environmental accounts were compiled using various sources of information. For CO_2 emission data, the main source of information for EU countries is the full EU27 NAMEA-air dataset from Eurostat (2012). While data for non-EU countries came from the UNFCCC and the Emissions Database from Global Atmospheric Research (EDGAR).

Aggregate CO_2 emissions data is expressed in 1000 kilo tonnes and is available for each of 35 economic sectors plus households.

Chapter 6

Methodological Framework

6.1 Leontief

Input-output (IO) analysis is a name given to an analytical framework developed by Wasily Leontief in 1936, in recognition of which he was awarded the Nobel Memorial Prize in Economic Sciences in 1973. The basic idea behind IO analysis is that a national (or regional) economy can be divided into a number of sectors that are interlinked and whose relationship can be represented in a mathematical matrix. One particular application of input-output models is in the field of environmental economics, where they have proven useful for examining the embodiment of various production factors (e.g., CO_2 emissions) in commodities (Murray and Lenzen, 2010).

It is always important that the reader completely understands an intuition behind the methodological framework that is being used in the analysis. However, personal experience shows that it is not always the case, in particular when it comes to input-output studies, thus to give more transparency and to avoid confusion this section is accompanied with a simplified input-output numerical example in Appendix C.

6.2 Input Output Fundamentals

The fundamental information used in IO analysis concerns the flow from each industrial or service sector considered as a producer, to each of the sectors, itself and others, considered as consumers. This basic information is essential for the development of the IO model and is contained in an input-output transaction table (IOT) (see Appendix B for example of IOT). The input-output table describes the flow of goods and services (in value) between all the individual sectors of the economy over a stated period of time. It has one RoW and one column for each sector of the economy. The rows of such table shows the distribution of producer's output throughout the economy, while the columns describe the composition of inputs necessary for a certain industry to produce its output.

Let us assume that the national economy can be divided into n number of sectors (the following explanation is mostly based on Miller and Blair, 2009. The total output (production) of sector i can be written as x_i and the total final demand for sector i's product can be represented as f_i. Then the distribution of sectors i product to other sectors and to final demand can be written as:

$$x_i = z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i = \sum_{j=1}^{n} z_{ij} + f_i \tag{6.1}$$

Here the z_{ij} term shows interindustry transactions (these are also known as intermediate sales) by sector i to all sectors j and itself (when j=i). Equation 1 shows the distribution of sector i sales to other industries and final demand i.e. output. With the n number of sectors in the economy each of the sector will have an equation like eq 6.1 that identifies their output:

$$\begin{aligned} x_1 &= z_{11} + \cdots + z_{1j} + \cdots + z_{1n} + f_1 \\ &\vdots \\ x_i &= z_{i1} + \cdots + z_{ij} + \cdots + z_{in} + f_i \\ &\vdots \\ x_n &= z_{n1} + \cdots + z_{nj} + \cdots + z_{nn} + f_n \end{aligned} \tag{6.2}$$

this can be rewritten as:

$$\mathbf{x} = \begin{bmatrix} x_1 \\ \vdots \\ x_n \end{bmatrix}, \quad \mathbf{Z} = \begin{bmatrix} z_{11} & \cdots & z_{1n} \\ \vdots & \ddots & \vdots \\ z_{n1} & \cdots & z_{nn} \end{bmatrix}, \quad \mathbf{f} = \begin{bmatrix} f_1 \\ \vdots \\ f_n \end{bmatrix} \tag{6.3}$$

The *z's* in jth column represent the sales to j sector, or put it differently it shows the purchases of sector j of various products from other sectors (e.g. to make a car we need rubber, steel etc.). It is important to note that the producing sector also requires other inputs like for example labor and capital, these are termed as value added in sector j, similarly inputs for sector j that come from abroad are regarded as imports. Lower-case letters **f** and **x** corresponds to the vectors of final demand and total output respectively, and upper case letter **Z** represents matrix of interindustry sales.

6.2.1 Technical Coefficient

The input-output transaction table provides a very detailed picture of the structure of the economy. However, in such form it is not useful for analytical analysis and thus has to be transformed to what is called a technical coefficient table.

The technical coefficients in input -output analysis (IOA) reflect the direct effects of change in final demand for a certain sector. They show the total amount of product i (domestically produced and imported) used as input in the production of one monetary unit of industry j's output. The technical coefficient can be calculated by dividing input in certain sector with the sum of total inputs in that sector. For instance if the x_j represents the total output of sector j and z_{ij} represents the value of sales from sector i to sector j then technical coefficient (a_{ij}) can be derived as:

$$a_{ij} = \frac{z_{ij}}{x_j} \tag{6.4}$$

A complete set of such coefficients for all sectors of an economy in the format of rectangular table is called the technical coefficient matrix or the direct coefficient matrix. In this paper (as well as in most of the literature) the technical coefficient matrix is presented with the capital letter **A**.

6.2.2 Interdependence Coefficient

The technical coefficient matrix described in the previous section reflects the direct effect of change in final demand to change in production of certain sector. To measure the indirect effect we need to use the so-called interdependence coefficients matrix. The coefficients of this matrix measure the total (direct and indirect) effect, in other words it shows how much production will be induced in all sectors by a demand increase of one unit in a certain sector.

The paragraph below shows how the interdependence coefficients are derived in input-output framework. A mentioned in previous section interindustry relationships among sectors can be presented as $a_{ij} = z_{ij}/x_j$. This equation can be rearranged and rewritten as $a_{ij}x_j = z_{ij}$, which implies that the intermediate sales from sector i to sector j depends on the output in sector j (x_j) and technical coefficient (a_{ij}). Given this we can rewrite equation 6.1, as:

$$
\begin{aligned}
x_1 &= a_{11}x_1 + \cdots + a_{1i}x_i + \cdots + a_{1n}x_n + f_1 \\
&\vdots \\
x_i &= a_{i1}x_1 + \cdots + a_{ii}x_i + \cdots + a_{in}x_n + f_i \\
&\vdots \\
x_n &= a_{n1}x_1 + \cdots + a_{ni}x_i + \cdots + a_{nn}x_n + f_n
\end{aligned}
\tag{6.5}
$$

This equation show that the level of output in any particular sector depends on the level of output in other sectors, input requirements of each sector and its own final demand. We can find final demand in each of these sectors, by bringing x terms to the left hand side:

$$
\begin{aligned}
x_1 - a_{11}x_1 - \cdots - a_{1i}x_i - \cdots - a_{1n}x_n &= f_1 \\
&\vdots \\
x_i - a_{i1}x_1 - \cdots - a_{ii}x_i - \cdots - a_{in}x_n &= f_i \\
&\vdots \\
x_n - a_{n1}x_1 - \cdots - a_{ni}x_i - \cdots - a_{nn}x_n &= f_n
\end{aligned}
\tag{6.6}
$$

Grouping the x_1 in the first equation, x_2 in the second and so on, gives us

$$
\begin{aligned}
(1 - a_{11})x_1 - \cdots - a_{1i}x_i - \cdots - a_{1n}x_n &= f_1 \\
&\vdots \\
-a_{i1}x_1 - \cdots + (1 - a_{ii})x_i - \cdots - a_{in}x_n &= f_i \\
&\vdots \\
-a_{n1}x_1 - \cdots - a_{ni}x_i - \cdots + (1 - a_{nn})x_n &= f_n
\end{aligned}
\tag{6.7}
$$

The matrix expression for eq 6.7 is:

$$
(\mathbf{I} - \mathbf{A})\mathbf{x} = \mathbf{f} \tag{6.8}
$$

where, **I** is the n x n identity matrix with the ones on the main diagonal and zeros elsewhere:

$$\mathbf{I}=\begin{bmatrix}1 & \cdots & 0\\ \vdots & \ddots & \vdots\\ 0 & \cdots & 1\end{bmatrix}, \text{so then } (\mathbf{I}-\mathbf{A})=\begin{bmatrix}(1-a_{11}) & -a_{12} & \cdots & -a_{1n}\\ -a_{21} & (1-a_{22}) & \cdots & -a_{2n}\\ \vdots & \vdots & \ddots & \vdots\\ -a_{n1} & -a_{n2} & \cdots & (1-a_{nn})\end{bmatrix}$$

The unique solution for eq 6.8 can be found by using standard matrix algebra i.e. taking $(\mathbf{I}-\mathbf{A})$ to the other side of the equation:

$$\mathbf{x}=(\mathbf{I}-\mathbf{A})^{-\mathbf{1}}\mathbf{f} \tag{6.9}$$

where $(\mathbf{I}-\mathbf{A})^{-\mathbf{1}}=\mathbf{L}=[l_{ij}]$ is the *Leontief inverse* or the total requirements matrix[4]. The coefficients of this matrix shows the effect on production in sector i from a unit change in final demand in sector j $(\partial x_i/\partial f_j = l_{ij})$. The Leontief inverse gives us the solution to the input-output system with which we can identify the levels of output from all sectors of the economy required to achieve the specified level of final demand in all sectors. The Leontief inverse is the fundamental part of the input-output analysis and will be the empirical cornerstone of this thesis.

6.3 Trade in Input-Output

So far in explaining input-output analysis, we only discussed the production that is produced domestically to satisfy a certain final demand. Bellow we will discuss how imports and exports required to satisfy a final demand in a certain country are incorporated in input-output analysis. A variety of approaches and indicators have been developed to evaluate the environmental impacts of trade in certain countries (Wiedmann, 2009; Sato, 2013). In environmentally extended input-output studies, two methods are commonly used to calculate emissions embodied in international trade: The single region input–output (SRIO) model and the multi region input-output (MRIO) model (Wiedmann et al., 2007). Both methods are based on different underlying assumptions and have different data requirements. A detailed review of these methods and their application to environmental studies can be found in Peters (2008b) and Solli and Peters (2010).

[4]Readers not familiar with the matrix algebra should note that it is not possible to divide by matrix and thus we have to make use of an inverse. For instance, a simple equation $5x = 10$ can be solved by $x = 10/5$, however if the division is not possible then the equation can still be solved by multiplying it with the reciprocal of 5 which can be written as 5^{-1} and is equal to 0.2, so $x = 10{*}5^{-1} \Rightarrow x = 10{*}0.2 = 2$, exactly the same as $x = 10/5 = 2$.

6.4 Single Region Input-Output

The SRIO model estimates the emissions associated with its total consumption by assuming that all other countries in the world (i.e., RoW) have the same technological structure as the modeled country i.e. the imported goods and services are produced with the same technology as domestic technology in the same sector. In the case of the UK it means that producing a certain good (e.g., mobile phone) emits the same amount of GHG as making the same mobile phone in one of its trading partners (e.g., China). This is a rather strong assumption, because in reality, imports to one country come from a number of different countries with different production structures and thus different emissions and resource intensities (Wiedmann, 2009). Estimating emissions using SRIO would therefore produce estimates that do not reflect the likely environmental pressures.

6.5 Multi Regional Input-Output

Since we are not only interested in the pollution produced in one country but rather a pollution embodied in international trade of multiple countries, we need to look at the multi-region input output model (MRIO) (explanation and detailed version of MRIO table is given in Appendix B). This model, where different technology factors are used for different countries, is regarded as a sound response to the challenges associated with the previously mentioned SRIO. In other words MRIO overcomes the issues associated with the SRIO method by eliminating the domestic technology assumption. MRIO approach distinguishes between the imports that are directed towards the final consumption versus those that are directed towards intermediate consumption. Those imports that are directed towards intermediate consumption can be allocated to either the production of goods for domestic use or the production of exports.

It is worth noting that the term MRIO has its origins in regional economics interested in differences between regions within a certain nation. Already in early 1950s Isard (1951) extended the classical Leontief model to account for regional analyses by formulating an inter-regional input-output (IRIO) model. Not long after this the input-output community turned its attention to the world economy by developing international and multinational models (Leontief, 1974). Although the idea was developed much earlier, the term MRIO has only begun to be used more widely in the last decade. One of the main reasons for this late start is the data-hungry and computationally intensive process of the construction of MRIO table (Kanemoto and Murray, 2013). A Practical application of MRIO analysis is far from simple and has been described by Weber (2008) as a, “minefield for practitioners desiring fairly accurate numbers”. Nevertheless, despite all of the difficulties environmentally extended MRIO analysis is *en vogue* Wiedmann et al. (2011) and regarded by many (Peters and Hertwich, 2009; Wiedmann et al., 2010) as the most appropriate approach for the estimation of emissions embodied in trade.

6.6 Environmental Extensions

The Input-output framework that we discussed so far is used for determining the total production needed throughout the supply chain (domestically and abroad) in order to satisfy the final demand in a given country. To estimate the embodied carbon emissions in international trade (i.e., consumption-based emissions) the traditional Leontief input-output model has to be extended and linked to the environmental accounts. In a simple one country model emissions are represented as follows:

$$\mathbf{E} = \mathbf{d}(\mathbf{I} - \mathbf{A})^{-\mathbf{1}}\mathbf{f} \tag{6.10}$$

where $\mathbf{d}$ is a row vector of region specific CO_2 emissions per unit of industry output, and $\mathbf{E}$ is consumption based emissions.

The first environmental extensions for the input-output model were developed in late 1960s (Miller and Blair, 2009). Leontief (1970) himself had an interest in ecological economics and proposed one of the key methodological extensions to account for the environmental pollution that has later been applied and developed further by many researchers. It is important to note that environmental extensions (pollution coefficients matrix) to the input-output that we are going to use in this thesis can be easily replaced with virtually any factor associated with inter-industry activity, e.g., energy consumption, employment or any other pollutant.

6.7 Assumptions

All empirical methods have their limitations and input-output analyses whether SRIO or MRIO are no exceptions. It is crucial to acknowledge these limitations and bear them in mind when analyzing and interpreting the results. According to Lee and Mokhtarian (2004) there are four basic assumptions of the input-output model, which simplify a more complex reality of a real economy.

One of the key assumptions in the IO framework is constant return to scale. It implies that the relationship between a sector's input and outputs is fixed. In other words if the output produced by a certain sector in a given country were to increase by x percent, the input required by that sector would also increase by the same percentage.

The next assumption is related to the homogeneity of industrial output, meaning that all firms within a certain industry in a given a country are characterized by a common production process. This implies that every good produced by a certain industry has no quality distinction from other products in the same industry and thus is regarded as equal or homogenous. In an input-output framework, this assumption is considered to be more controversial than the first, as it does not reflect a real economy very well.

A third assumption underlying input-output analysis is related to the fixed-production process. This assumption implies that all companies within a certain industry, in a given country produce goods or services in the same way, i.e. they require the same proportion of each input or in other words they have fixed technical coefficients (a_{ij}).

A fourth assumption postulates that the technological nature of the input-output relationships is uniform. This means that no technological improvement is generated during the analysis period, i.e., technical coefficients do not change.

6.8 Uncertainties

Although the data intensive nature of environmentally extended MRIO analysis is frequently noted, the reliability of underlying issues is often overlooked. The uncertainties of MRIO analysis include grouping of regions to reduce data collection, estimation of inter-industry trade flows from bilateral trade data, inflation/deflation of data from different years, different sector schemes, different valuation of IOTs, aggregation of IOTs, and exchange rates (Lenzen et al., 2004; Weber, 2008; Peters and Hertwich, 2009).

6.8.1 Rest of the World and Grouping

As mentioned before MRIO analysis requires large amounts of data. Sometimes this data may not be available in the required detail or may not be available at all, because not every country produces an IO table. One way to alleviate this problem is to assume that certain groups of countries have similar technology. In an input-output framework, these grouped countries are often referred to as a "Rest of the World" (RoW) but other groups can also exist. For instance, if it is assumed that all Asian countries (except from Japan) have a similar technology as China, then Asia can be treated as one region with the technology of China (Peters and Hertwich, 2004). Similar approaches apply for other regions; North America, Europe, Latin America, Africa and so on. The WIOD (section §5.1) database covers 40 major advanced and emerging economies, plus the region "Rest of the World".

6.8.2 Industry Classification and Aggregation

The data in different countries is commonly collected at the different levels of aggregation and classifications. In order to perform a MRIO analysis the data has to be matched to a consistent number of sectors and industry classifications. Summing two or more sectors to a single one is usually not so difficult, but difficulties arise when an IO table from a certain country has to be split between two or more sectors in a new consistent sector system (Owen, 2013).

The WIOD database used in this study provides harmonized MRIO tables with 35 industries (Dietzenbacher et al., 2013). The original data for this database have been either aggregated or disaggregated from national tables to match the common classification. The national tables might at some times differ substantially, for instance the US and Japan usually provide tables with around 500 sectors while the UK only 59 sectors. At this point it is constructive to ask how large is the aggregation error and how important it is for the environmental studies. Tukker (2009) suggest that 100-150 sectors are necessary for macro level study in order to avoid lumping together important sectors with different emission intensities. On the other hand, Su and Ang (2010) shows that 40 sectors are sufficient to calculate emission embodied in international trade.

6.8.3 Monetary data

Since MRIO involves comparison of foreign regions with the domestic technology, then exchange rates between these regions have to be considered. Studies have repeatedly shown that conversion of currencies is problematic in MRIO analyses and might lead to conflicting results (Ahmad and Wyckoff, 2003; Weber and Matthews, 2008).

Two primary ways to convert currency between countries are Market Exchange Rate (MER) the market price of currency in terms of another and Purchasing Power Parity (PPP), a measure that compares the prices of a basket of common household goods between countries. In general the issue arises when comparison involves developed and developing countries. This is because price levels tend to differ substantially between developed and developing countries leading to large difference between MEP and PPP.

Kanemoto and Tonooka (2009) for example, show that when PPP is used, Japan's emissions embodied in imports are reduced by a third when compared to the same scenario using MER, mainly because of different estimates of emissions from China. Weber and Matthews (2008) confirms that the differences between MER and PPP is large for developing countries and is relatively small for most of the developed countries, reflecting similar price levels. Authors further add that the true value of emissions embodied in imports lies somewhere between the values calculated using MER and PPP, however in the absence of a physical unit of data for all traded commodities, this uncertainty is difficult to reduce.

Chapter 7

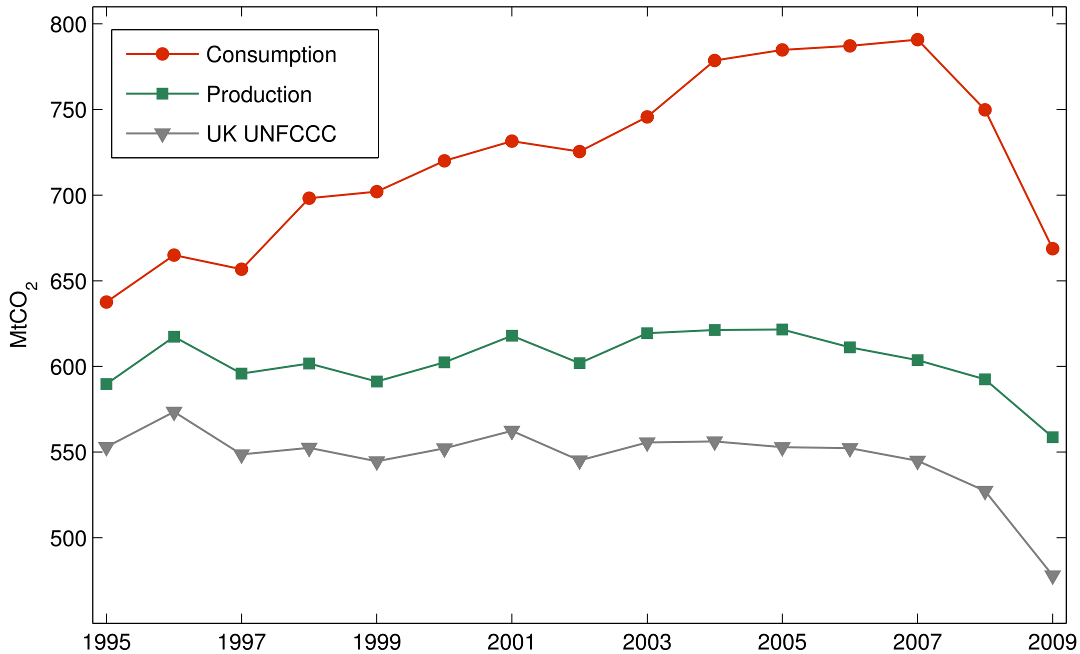
Results

The analysis of this empirical study entails over 30 million data points, thus making it highly challenging to display the results in an accurate and efficient way. The most important results are presented in table 7.1 on page 56. The analysis of the results in this chapter have been organized by following the questions raised in the introduction of this thesis, which are directly related to three hypotheses.

7.1 Consumption vs Production

Figure 7.1 displays the overall results of this study. In addition to production and consumption based emissions calculated in this study the UK emissions reported to UNFCCC are presented as well. As can be seen, the production and the UK UNFCCC (these are regarded as territorial) follow almost exactly the same trend. The only difference between these is that the UK UNFCCC does not include emissions that come from international shipping and aviation.

Figure 7.1: UK Consumption and Production Emissions, 1995-2009



Over the period 1995 to 2009, the consumption-based emissions were significantly higher than the production-based emission or the UK UNFCCC. From a Production point of view, emissions in 2009 amounted to 558 MtCO_2; this was about 6% lower than emissions in 1995 of 589 MtCO_2. In contrast, consumer emissions have risen by about 5% from 638 MtCO_2 in 1995 to 669 MtCO_2 in 2009. In 2007 consumption based emissions were at a peak, amounting to 791 MtCO_2, or about 20% higher than in 1995. A significant drop in consumption-based and to some degree production based-emissions, since 2007, was mainly due to the effects of the global financial crisis on the UK.

Figure 7.2: CO_2 Emissions Embodied in UK Exports (EEE), Imports (EEI) and the Difference (BEET), 1995-2009

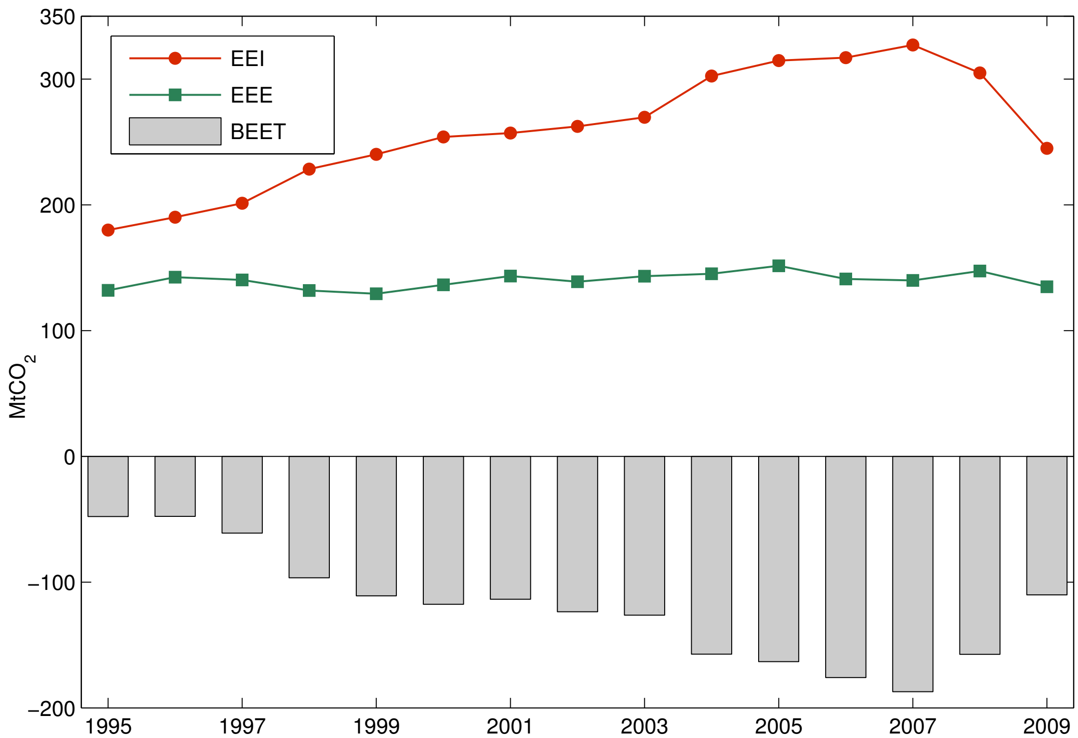
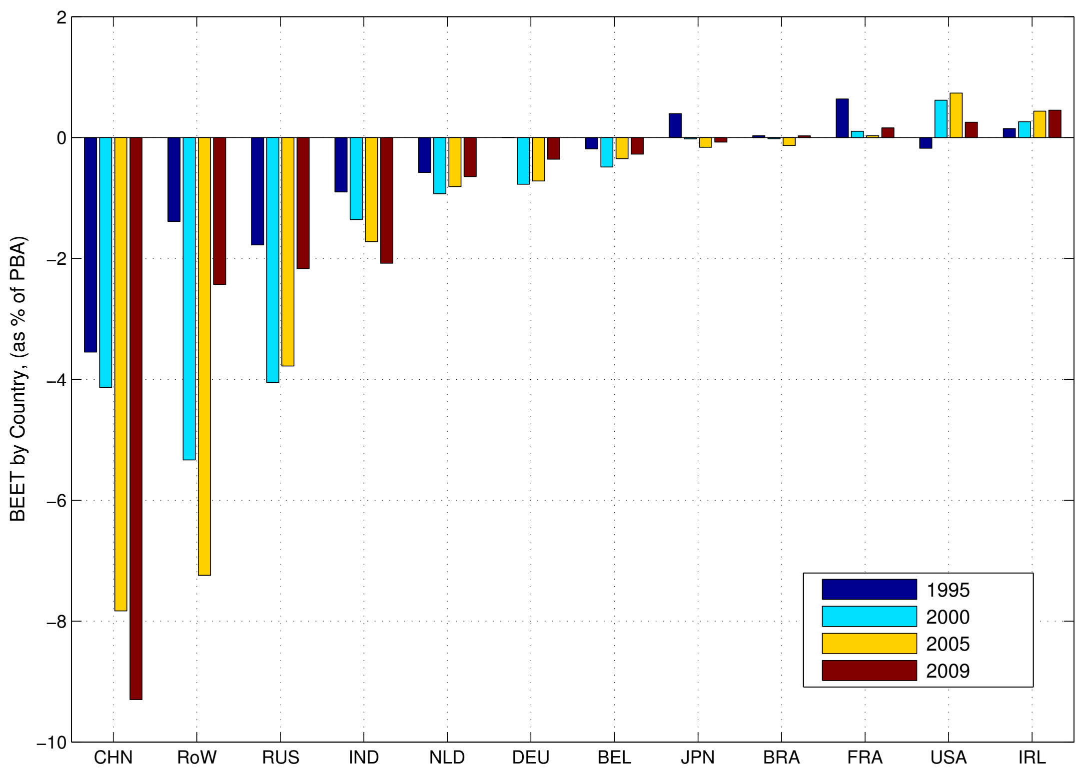


Figure 7.2 displays emissions embodied in imports and exports, plus the balance of emissions embodied in trade (BEET), which is equivalent to emissions embodied in exports (EEE) minus emissions embodied in imports (EEI). Emissions embodied in exports remained stable over the whole study period, while emissions embodied in imports grew by 26% from 180 $MtCO_2$ in 1995 to 245 $MtCO_2$ in 2009. In 1995 EEE accounted for about 22% of PB emissions and in 2009 for about 24%, whereas EEI were not only higher in 1995 at 31%, but also grew significantly to 44% of production-based emissions in 2009. The faster growth of emissions embodied in imports is reflected in a negative BEET trend over the period, meaning that more emissions have been imported than exported. It is important to note that the BEET not only shows the difference between the EEE and EEI, but also the difference between production-based accounts (PBA) and consumption-based accounts (CBA). The BEET reached its peak of -187 $MtCO_2$ in 2007 followed by a decline in later years due to the falling consumption of UK residents, which was brought about by the financial crisis.

7.2 Balance of Emissions Embodied in Trade by Country

Figure 7.3 shows the origin and destination of emissions embodied in UK trade with its main trading partners (accounting to about 80% of all emissions embodied in trade) for the selective years: 1995, 2000, 2005, and 2009 (Displaying results for all years would have required numerous graphs and figures thus it was decided to display results only for this specific years). The largest sources of net imports are shown on the left-hand side and the largest sources of net exports on the right-hand side. Net imports implies that more emissions are imported from that country to the UK than exported and net exports indicate that the UK exports more emissions to a certain country than it imports. The results presented in UK Balance of Emissions Embodied in Trade (BEET) by Country, 1995-2009 were normalized on PBA.

Figure 7.3: UK Balance of Emissions Embodied in Trade (BEET) by Country, 1995-2009



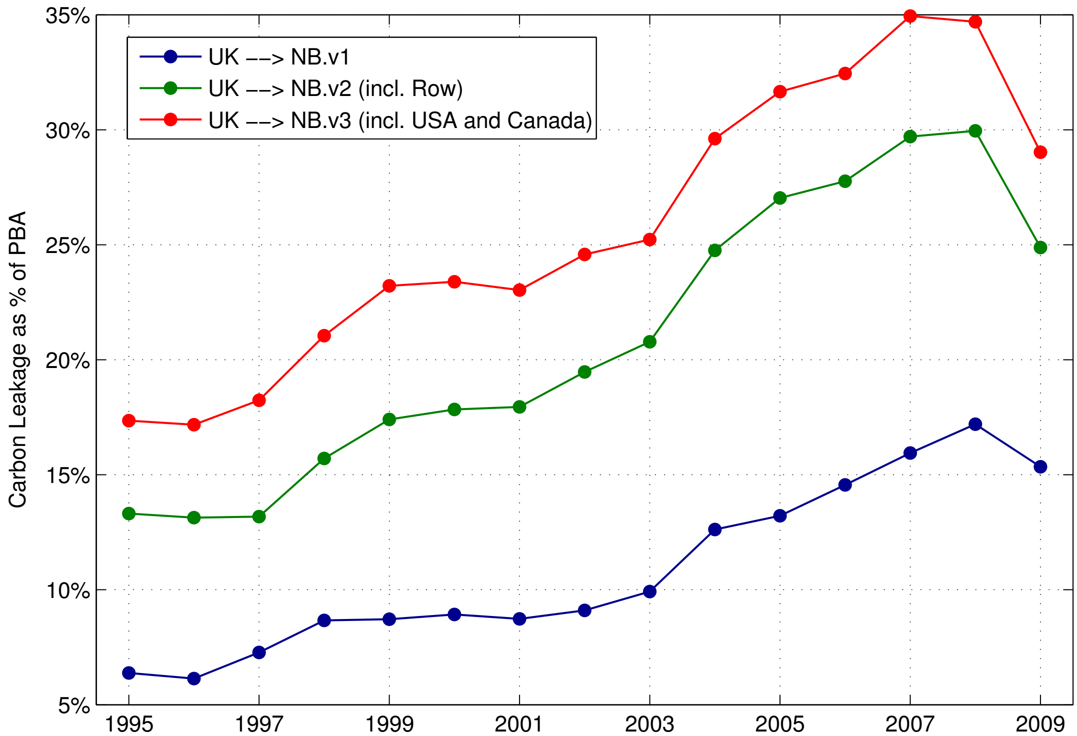
Most of the UK imports come from the developing (in 2009 Russia was regarded as developing and most countries in RoW are developing) or emerging economies: China, RoW, Russian Federation and India. Slightly lower, but still quite a significant share of emissions come from the Netherlands, Germany and Belgium. Interestingly imports from China and India demonstrate an increasing trend for the whole study period. On the other hand, imports from the RoW have declined since 2005 and from Russia, the Netherlands and Belgium since 2000. In 1995 net imports from China accounted for about 3.5% (21 $MtCO_2$) of PB emissions, by 2009 net imports grew to more than 9% (52 $MtCO_2$) of PB, making China the single largest source of UK imports, even larger than the RoW region.

Imports of emissions from both Brazil and Japan (except year 1995) were very similar to exports from the UK, resulting in a balanced trade of emissions between these countries. The trade between the remaining three countries indicates a net export of emissions from the UK (except the US in 1995). Since 1995 net exports to France have fallen from 0.64% (3.8 $MtCO_2$) to 0.16% (1 MtCO2) of PBA in 2009. Exports to the US grew significantly over the period, reaching the peak 0.74% (4.5 $MtCO_2$) in 2005 after which they have declined to 0.25% (1.4 $MtCO_2$). It is also evident that UK exports to Ireland have risen steadily over the period, and in 2009 accounted for 0.45% (2.5 $MtCO_2$) of production-based emissions.

7.2.1 Carbon Leakage

Table 7.1 shows the carbon leakage from the UK to non-Annex B countries for the entire study period. Several different versions and measures of carbon leakage are used in this study. The first version (NB.v1) shows carbon leakage from the UK to those non-Annex B countries, which are directly given in the dataset (e.g., China, India, Brazil etc.). The second version (NB.v2), which is also regarded as the "true" version of carbon leakage in this study, assumes the RoW as a non-annex B region. It is important to note that although most of the countries in the RoW are non-Annex B, there are also some exceptions e.g. Norway and Switzerland are Annex B countries included in the RoW. The third version (NB.v3) adds the US and Canada to the list of non-Annex B countries. This is done because these two countries are the only developed countries which did not ratify (US) or withdrew (Canada) from the Kyoto Protocol and thus technically cannot be considered as Annex B countries. Furthermore, the carbon leakage is presented in two different ways. The first gives the carbon leakage compared to the total UK production emissions, which indicates the magnitude of the leakage. The second measure normalizes carbon leakage relative to EEI, which indicates the share of EEI coming from non-Annex B countries.

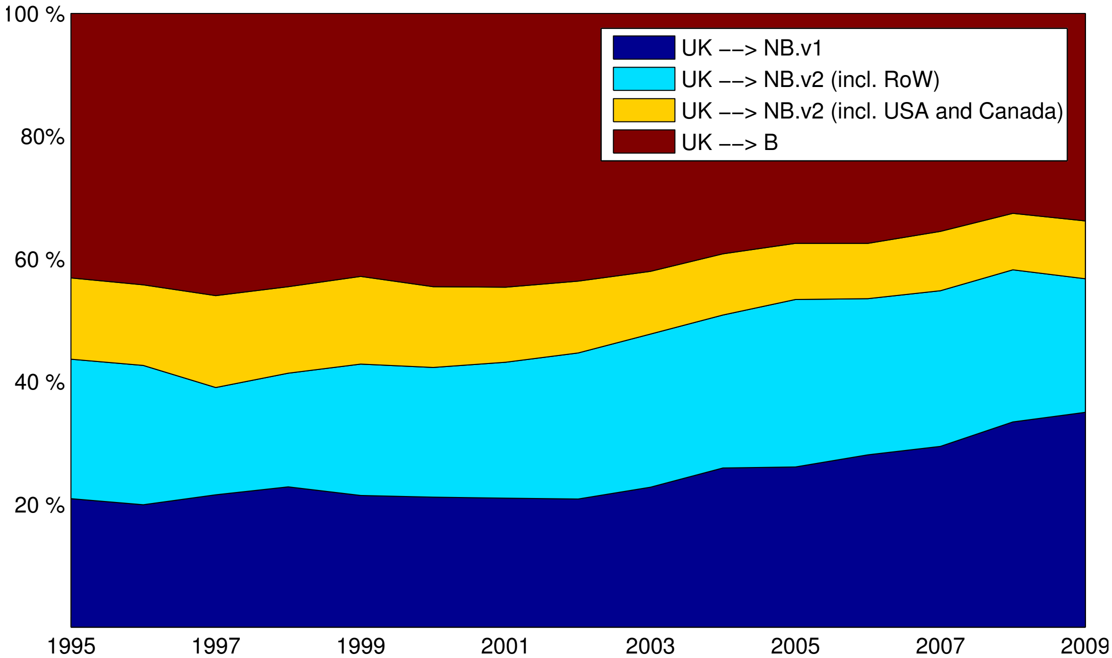
Figure 7.4: UK Carbon Leakage as Percentage of PBA, 1995-2009



As shown in UK Carbon Leakage as Percentage of PBA, 1995-2009 all three versions of carbon leakage display almost exactly the same trend of increasing carbon leakage from the UK to non-Annex B countries. According to the first version carbon leakage as percentage of PBA has increased from 6.4% (38 MtCO_2) in 1995 to 15.3% (86 MtCO_2) in 2009. The second version of carbon leakage has grown from 13.3% (79 MtCO_2) in 1995 to 24.9% (139 MtCO_2) in 2009, and before the decline it was as high as 30% (177 MtCO_2) in 2008. When the US and Canada are added to the list of non Annex B countries carbon leakage increases from 17.4% (102 MtCO_2) in 1995 to 29% (162 MtCO_2) in 2009. Although the magnitude of carbon leakage is different when different versions of countries are considered, the general trend suggest that carbon leakage in the UK has grown since 1995 to 2009 by about 10%.

Figure 7.5 below presents the share of carbon leakage relative to emissions embodied in imports. Although there were some fluctuations the shares for three (NB.v1, NB.v2, NB.v3) carbon leakage versions remained more or less unchanged until about 2001/2002, after which they have increased following a similar trend until 2008. At this point, NB.v2 and NB.v3 declined, while NB.v1 continued growth, even during the crisis. This divergence can be attributed to different countries covered by NB.v1 (contains only developing countries); NB.v2, and NB.v3 (includes some developed nations). Whilst the overall level of imports decline during the economic downturn, imports from developing countries decline relatively less compared to imports from developed countries, because of substitution for cheaper goods when real income declines.

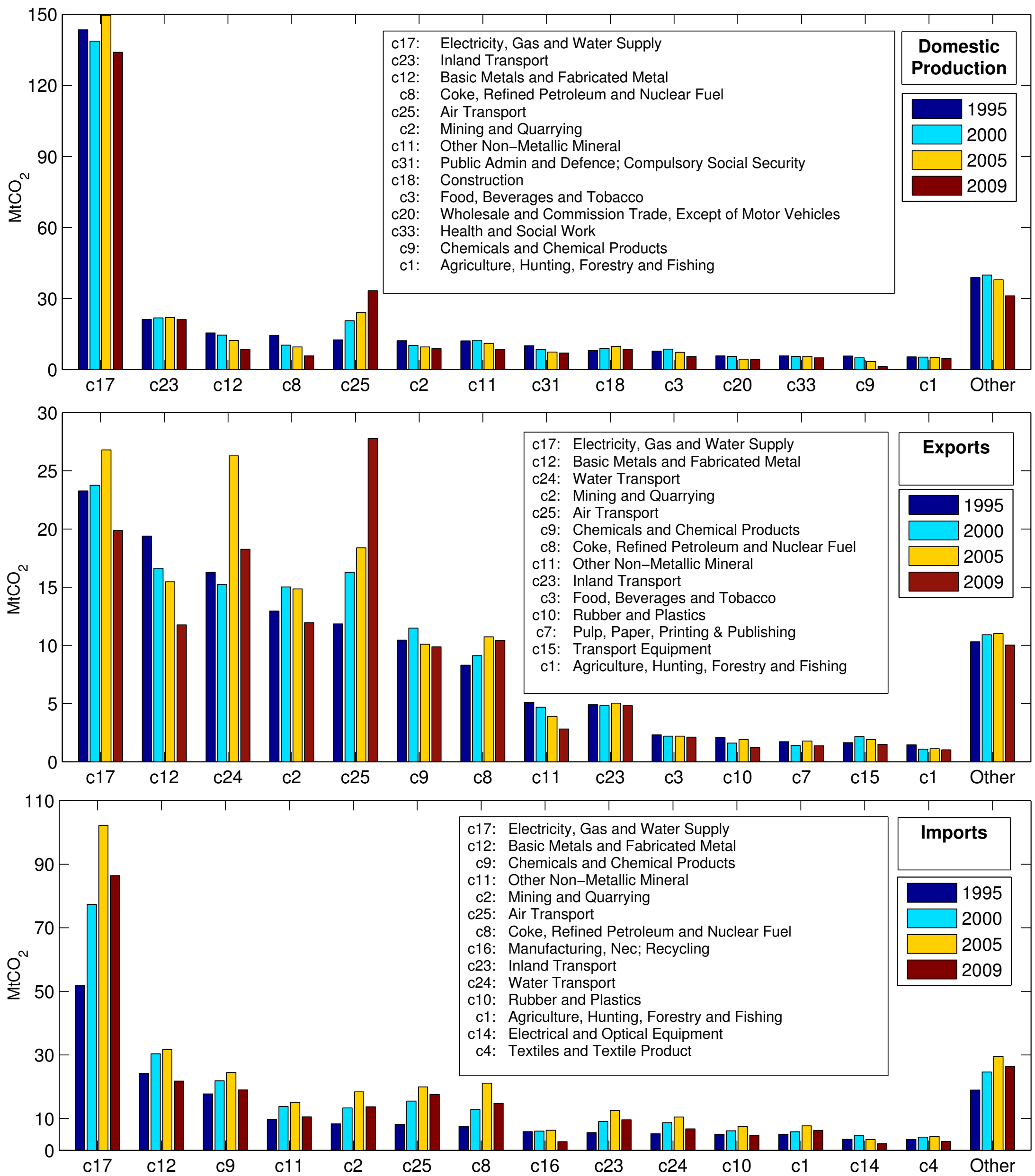
Figure 7.5: Carbon Leakage as Percentage of EEI, 1995-2009



7.3 Emissions Embodied in Imports and Exports by Sector

The UK produces, exports and imports embodied emissions across a wide range of economic sectors. The following three graphs present the development of these flows for the top 14 economic sectors with the highest CO_2 emissions. On average these sectors account for about 90% of total emissions. The remaining emissions from 20 sectors are aggregated and presented in “other”. It is important to note that the top 14 sectors for domestic production, exports and imports are different e.g. c20 and c33 are in the top 14 list of domestic production, but not in the top list of Exports or Imports.

Figure 7.6: CO_2 Emissions Embodied in Imports and Exports by Sector, 1995-2009



First of all, looking at domestic production[5] in figure 7.6, it is clear that Electricity, Gas and Water supply is the single biggest emitting sector. The total for the sector varies over the years, but on average it amounts to about 140 $MtCO_2$, which is about seven times the amount of the second highest sector. The Inland transport category

[5]In this case it represents the emissions that occur in the UK to satisfy the UK final demand, but it does not include direct emissions from households that come from heat and transport, these are presented as "Households (1a)" in table 7.1 on page 56, similarly domestic industry emissions considered in this graph are presented as "Industry (1b)".

(comprising railways, road freight, buses, coaches, taxis etc.) the second biggest source of emissions (21.5 $MtCO_2$ on average) remained stable during all years. Manufacture of Basic Metals (c12) and manufacture of Coke, Refined Petroleum and Nuclear Fuel (c8) show a clear decline in emissions since 1995. In contrast emissions from Air transport (c25) have increased significantly from 12 MtCO2 in 1995 to 33 $MtCO_2$ in 2009. In general most sectors display a declining trend of emissions and only a few show an increase. Furthermore, it is also evident that the sectors relating to the provision of finished/semi-finished goods or services (e.g. c31, c3, c20, c33, c1) to consumers, have on average much lower CO_2 emissions than intermediary products (e.g. c8).

The second graph shows emissions that occur in UK industry in order to satisfy consumption in other countries. Similarly, as before, Electricity, Gas and Water Supply (c17) has the greatest impact, totaling about 23 $MtCO_2$. The following four sectors (c12, c24, c2 and c25) show similarly high emissions, which decreased (c12), increased (c25) or fluctuated over the period (c2, c25). It is important to note that there was a significant increase in water (in year 2005) and air transport, which can be explained by the increasing reliance on these modes of transport for the international travel and shipment of primary and intermediary products. The UK also exports large amounts of emissions in primary manufacturing products, in particular chemicals and chemical products (c9) as well as Coke, Reined Petroleum and Nuclear Fuel (c8) and to a lesser extent, other Non-Metallic mineral (c11). Exports from the remaining sectors (c3, c10, c7 c15 and c1) most of which relate to provisions of final products have emissions of about 2 $MtCO_2$.

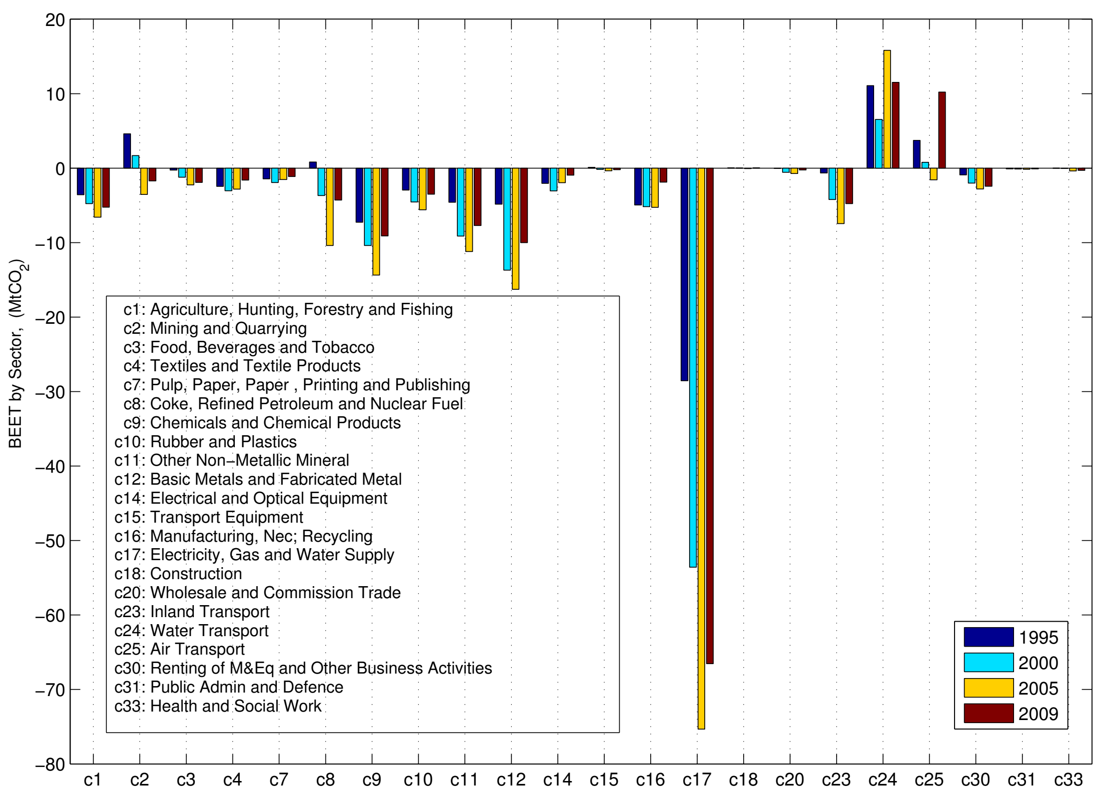
The final graph in figure 7.6 figure 7.6 gives an indication of embodied emissions flows into the UK from industries outside the UK. The highest carbon emissions associated with imports occur in the same sectors (c17, c12) as emissions associated with production for exports. However the magnitude is different. For instance, in 2005, emissions in imports of energy accounted for 102 $MtCO_2$, while exports from the same sector in the same year were 26 $MtCO_2$. Differently from exports, where emissions from different sectors tend to fluctuate, emissions embodied in imports for all sectors (except c4) indicate an increasing trend between 1995 and 2005, after which they all decline. Furthermore, it is also important to note that a significantly high share of emissions flow into the UK from Electricity, Gas and Water Supply (c17); manufacture of Basic Metals and Fabricated Metals (c12); manufacture of Chemicals and Chemical Products (c9); manufacture of Coke, Refined Petroleum and Nuclear Fuel (c8); manufacture of Other Non-Metallic Mineral (c11); manufacture of Rubber and Plastics (c10). These are regarded as energy intensive industries (manufacturing), which are subject to various regulations regarding CO_2 emissions, like for example EU ETS which places a “cap” or limit on the total amount that can be emitted by these industrial sectors. Mining and

Quarrying (c2) and Agriculture, Hunting, Forestry and Fishing (c1) are also regarded as energy intensive industries (non-manufacturing) but because of difficulties associated with defining, measuring and monitoring, their emissions are not yet subject to international regulations (UK Parliament, 2014). Overall imports from energy intensive sectors (c17, c12, c9 c8, c11, c10) amount to an average of 64% and when non-manufacturing intensive sectors (c1, c2) are added, it increases to 72% of total emissions embodied in imports.

7.3.1 Balance of Emissions Embodied in Trade by Sector

It is clear that emissions flow from abroad is high, particularly from energy intensive sectors. However, since the UK also exports emissions from these sectors, it is important to look at the balance of imports and exports. Figure figure 7.7 below presents the BEET for the top 22 economic sectors (the number of sectors is higher because imports and exports did not come from exactly the same top 14 sectors and thus additional sectors had to be included), which account for about 95% of emissions embodied in imports and exports.

Figure 7.7: Balance of Emissions Embodied in Trade by Sector, 1995-2009



As it can be seen from figure 7.7, nearly all of the sectors have negative BEET, meaning that the UK imports more from a certain sector abroad than it exports. The Electricity, Gas and Water Supply (c17) category has the highest negative balance, which more than doubled between 1995 and 2009. Interestingly, the balance for this category is also negative for years 1995 and 2000, during which the UK had a significantly positive trade balance of energy supplies (see figure 3.3 in section §3.1). This is because the balance e of energy supplies in section §3.1 is associated with physical flows, while results shown in figure 7.7 above presents embodied flows, which include both: emissions associated with physical flows and electricity emissions that are embodied in the goods imported into UK. For example, the emissions arising from the generation of electricity in China to manufacture a mobile phone that is later sold in the UK.

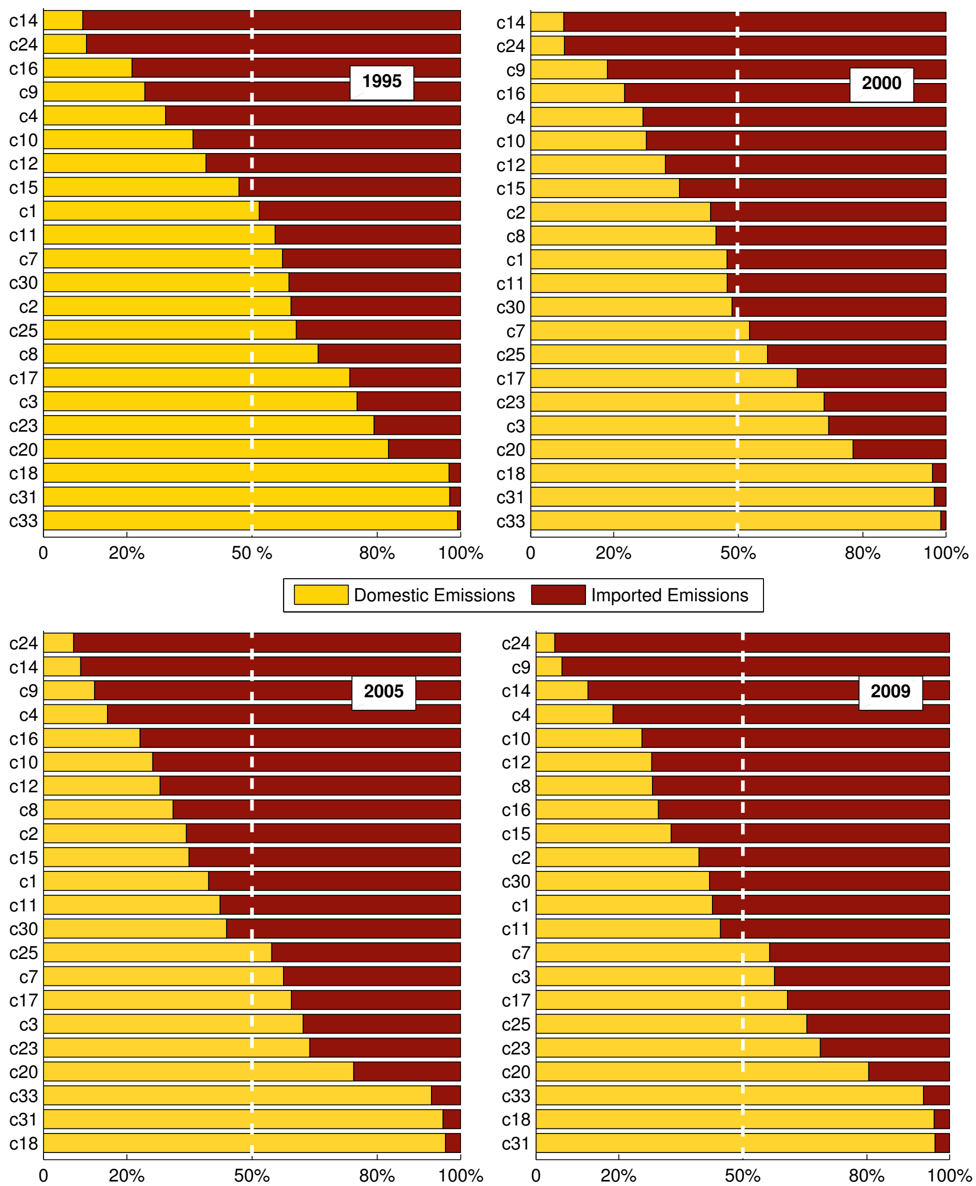
The remaining energy intensive categories also show a large negative balance of emissions particularly Basic Metals (c12), Chemicals (c9) and Other Non-Metallic Minerals (c12). For most energy intensive categories, the balance of emissions was negative in 1995 (except c2 in 1995, 2000; and c8 in 1995) and increased over time until a decline in 2009. Inland and Water transport are the only two sectors that display a positive balance of emissions flows. This implies that a significant share of the UK registered shipping and aviation companies provide passenger and freight transport services for consumers and industries abroad. Most of the remaining sectors associated with provision of services (c20, c31, c33) show balanced flow of emissions. Renting of M&Eq and Other Business Activities (c30) is the only service sector that displays a noticeable negative balance of emissions flow.

7.3.2 Relative Importance of Imported Emissions

Figure 7.8 shows proportion of UK consumption emissions occurring inside and outside the UK for 22 sectors. As can be seen the relative importance of embodied emissions flows vary by sector and by year. For the Electrical and Optical Equipment (c14) about 90% of emissions occur outside the UK and only the remaining 10% are emitted in the UK. The same can be said about Water transport (c24) where more than 90% of emissions occur outside the UK to satisfy UK consumption. In contrast for services sectors (c31, c32) and for Construction (c18) majority of emissions (on average 95%) occur within the UK territory and only small share is imported.

It is important to note that over time number of sectors with the share of imported emissions higher than the share of UK domestic emissions has increased. In 1995 there were only 8 sectors with the share of imported emissions above 50%, whereas by 2000 it has increased to 13 sectors. Although it remained unchanged in 2005 and 2009 the share of imports for 13 sectors continued to growth.

Figure 7.8: UK Consumption Emissions occurring inside and outside the UK, 1995-2009



In addition, most of the sectors (c1, c2, c4, c8, c9, c10, c11, c12, c14) where the share of imported emissions exceeds 50% are associated with the energy intensive production. In contrast, most of the sectors with a higher share o UK domestic emissions are related Service industry (c25, c23, c20, c33, c31). In fact there are only two energy intensive industries for which UK domestic emissions exceed emissions occurring overseas namely: Pulp, Paper and Printing (c7) and Electricity Gas and Supply (c17).

Table 7.1: CO_2 Emissions Embodied in International Trade to and from the UK, 1995 and 2009

	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Consumption vs Production															
PBA (1a+1b+2)	590	617	596	602	591	602	618	602	619	621	622	611	604	592	559
CBA (1a+1b+3)	638	665	657	698	702	720	732	725	746	779	785	787	791	750	669
UK GHG Inventory	553	574	549	552	545	552	562	545	556	556	553	552	545	527	478
Domestic															
Households (1a)	139	153	147	149	149	150	153	152	155	155	151	147	143	144	136
Industry (1b)	319	322	308	321	313	316	321	311	321	321	319	323	321	301	287
EEE (2)	132	142	140	132	129	136	143	139	143	145	152	141	140	147	135
EEE as % of PBA	22%	23%	24%	22%	22%	23%	23%	23%	23%	23%	24%	23%	23%	25%	24%
EEI (3)	180	190	201	228	240	254	257	262	270	302	315	317	327	305	245
EEI as % of PBA	31%	31%	34%	38%	41%	42%	42%	44%	44%	49%	51%	52%	54%	51%	44%
BEET	-48	-48	-61	-97	-111	-118	-114	-124	-126	-157	-163	-176	-187	-157	-110
BEET as % of PBA	-8%	-8%	-10%	-16%	-19%	-20%	-18%	-21%	-20%	-25%	-26%	-29%	-31%	-27%	-20%
Carbon Leakage															
NB.v1	38	38	43	52	52	54	54	55	61	78	82	89	96	102	86
as % of PBA	6%	6%	7%	9%	9%	9%	9%	9%	10%	13%	13%	15%	16%	17%	15%
as % of EEI	21%	20%	22%	23%	21%	21%	21%	21%	23%	26%	26%	28%	29%	33%	35%
NB.v2	79	81	79	95	103	107	111	117	129	154	168	170	179	177	139
as % of PBA	13%	13%	13%	16%	17%	18%	18%	19%	21%	25%	27%	28%	30%	30%	25%
as % of EEI	44%	43%	39%	41%	43%	42%	43%	45%	48%	51%	53%	54%	55%	58%	57%
NB.v3	102	106	109	127	137	141	142	148	156	184	197	198	211	206	162
as % of PBA	17%	17%	18%	21%	23%	23%	23%	25%	25%	30%	32%	32%	35%	35%	29%
as % of EEI	57%	56%	54%	55%	57%	55%	55%	56%	58%	61%	63%	63%	64%	67%	66%

Note: **PBA**-Production-based Account; CBA - Consumption-based Account; **EEE** - Emissions Embodied in Exports; **EEI** - Emissions Embodied in Imports; **BEET** - Balance of Emissions Embodied In Trade; BEET = EEE - EEI; UK GHG Inventory is given for comparison purposes it does not include emissions from aviation and shipping. **NB.v1** - Emissions Embodied in Imports from Non-Annex B countries; **NB.v2** - Emissions Embodied in Imports from Non-Annex B countries, assuming RoW as Non-Annex B country; **NB.v3** - Emissions Embodied in Imports from Non-Annex B countries, including USA and Canada and assuming RoW as Non-Annex B country. All numbers in Mt of CO_2

Chapter 8

Discussion and Implications

8.1 Hypothesis I

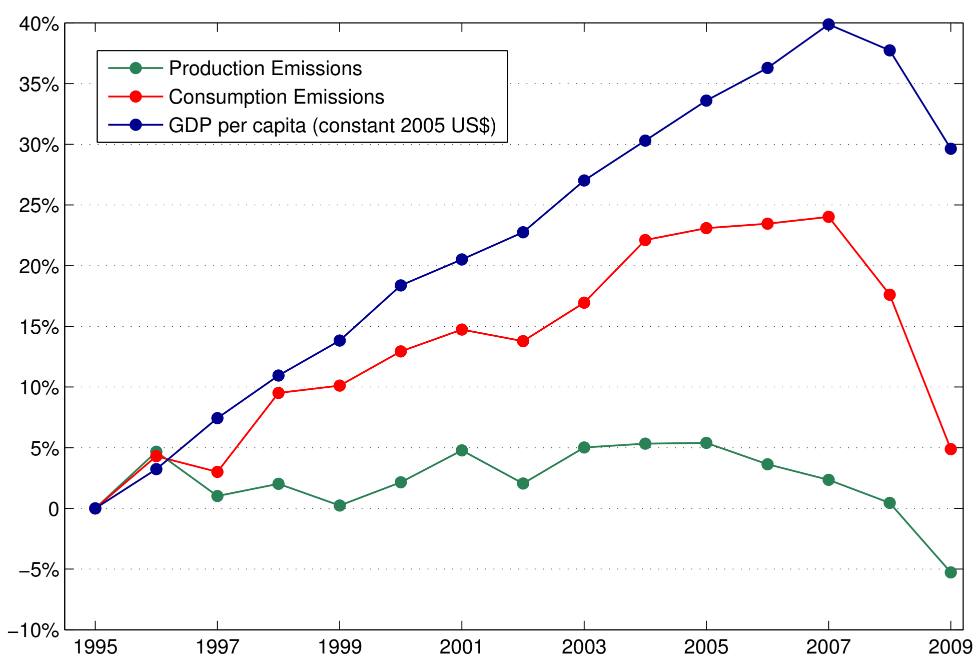
In the beginning of this study it was hypothesized that the UK imports more CO_2 emissions from abroad than it exports, in other words the Balance of Emissions Embodied in Trade (BEET) is negative. It should be noted that BEET is calculated by taking EEE and subtracting EEI, it is also equivalent to the difference between PBA and CBA, i.e. EEE-EEI = PBA-CBA.

The results presented in this study demonstrate that there is considerable amount of CO_2 emissions embodied in UK's international trade. Consumption-based and Production-based accounts showed that CO2 emissions associated with UK imports from abroad are greater than CO2 emissions associated with UK exports. The difference between the two resulted in a negative BEET, which has grown significantly from -48 $MtCO_2$ in 1995 to -110 $MtCO_2$ in 2009 (in 2007 it was -187 $MtCO_2$). These results highly support hypothesis 1 and reflect the UKs net position as a "CO2-consumer" rather than a "CO2-producer".

The results from this study are also in line with findings from other researchers. All UK specific studies presented in table 4.1 report negative BEET, suggesting that more embodied CO_2 emissions are imported into the UK than exported. However, the results vary between studies and in some cases the difference is quite significant. The difference in reported results can be attributed to the use of different baseline estimates for production emissions, the use of different databases and the use of different input-output techniques. In general the results from this study fall somewhere in the middle and are highly similar to the results by Boitier (2012). This is not surprising, since the database and the methodology used in this study is the same. However, the focus and purpose of two studies is different. Boitier (2012) reports emissions for all countries in the WIOD database, while this study takes the UK as a specific case, and investigates its emissions in more depth, analyzing sectors and trading partners in more detail.

As noted in section §2.5, the downward slope of the Environmental Kuznets Curve has been explained in terms of structural changes in the composition of economic output, and increased environmental awareness at higher income levels. However, international trade is often omitted from the explanation of the EKC pattern and only a few studies have attempted to quantify its effect empirically (Suri and Chapman, 1998). Although it is not the aim of this thesis to do the latter, the results can still be used to draw some conclusions. Figure figure 8.1 shows the growth rate of production and consumption emissions, and GDP per capita. From a production perspective we can see that emissions in the UK are declining over time, while GDP per capita continues to grow. This indicates decoupling of economic growth, meaning the possibility to achieve a higher output without increasing stress on the environment. This would explain the downward slope of the EKC. However, from a consumption perspective, emissions are growing over time parallel to income and contrary to production-based emissions, there is no evidence of decoupling. This clearly shows that international trade might be an explanation (or one of explanations) for the downward slope of the Environmental Kuznets Curve. However, further tests are needed to support this claim empirically, but this task is beyond the scope of this thesis.

Figure 8.1: Growth of CBA and PBA compared with GDP, 1995-2009



Source: World Bank (2014). Author's Construction.

8.2 Hypothesis II

The second hypothesis of this study postulates that the UK imports more CO_2 emissions from non-Annex B countries than from Annex B. In order to test this hypothesis, we looked at carbon leakage between Annex B and non-Annex B countries. Three separate versions (NB.v1, NB.v2, and NB.v3) of non-Annex B countries were formulated to provide robust conclusions related to carbon leakage.

The results have shown that the magnitude of carbon leakage is highly dependent on assumptions about non-Annex B countries. According to the first NB.v1 definition, imports from non-Annex B countries relative to imports from Annex B, have increased from 20.9 % in 1995 to 35% in 2009. For NB.v2, the share of imports has risen from 43.7% in 1995 to 56.8% in 2009, and for NB.v3 from 56.9% in 1995 to 66.2% in 2009. It is clear that imports from non-Annex B countries have grown over time, while imports from Annex B have declined. However, the shares are different for different versions of non Annex B. Looking at NB.v1, it is clear that the UK does not import more CO_2 emissions from non-Annex B countries than from Annex B. Evidence for NB.v2 is not so clear, the share of imports from non-Annex B countries was below 50% between 1995 and 2004, after which, it increased. Looking at NB.v3, it is clear that the UK imports more CO_2 emissions from non-Annex B than from Annex B.

Nevertheless it is important to note that NB.v3 is provided only for illustrative purposes and is not the focus of this thesis. The reason for this is that it includes two developed nations, the USA and Canada. They are not in line with the common definition of a non-Annex B country and are regarded as developing nations with lax environmental regulations and the presence of more pollution intensive industries.

Although many studies discuss carbon leakage, not many report it in terms of imports from non-Annex B and Annex B countries.Peters and Hertwich (2008b) estimate CO_2 embodied in trade and carbon leakage for 87 countries including the UK for the year 2001. The authors show that carbon leakage from the UK, as a percentage of PBA is 12.8%, while share of imports from non-Annex B countries amounts to 38.2%. This is best comparable with estimates of NB.v2, which appears to be slightly higher. Most of the difference is due to the assumption that RoW is a non-Annex B, which has a potential to overestimate the results, since it also includes Annex B countries. In contrast Peters and Hertwich (2008b) used a database covering 87 countries which allowed the grouping of annex-B and non-Annex B countries more accurately.

These results clearly show how production based emissions are falling in the UK in line with its Kyoto targets. However, this is a rather stark and frightening fact, because it means that despite enormous time and effort devoted to international and national climate policies, there are no reductions in global emissions associated with UK consumption, instead there is an increase.

One way to reduce carbon leakage is to allocate emissions based on consumption accounting rather than production. The consumption accounting principle might be perceived as a fairer system because it incorporates imports and measures the carbon footprint, and not the carbon production within a territory of a particular country. However, since emissions embodied in exports are excluded, it creates the possibility of a carbon leakage shift from imports to exports. In other words, if the UK is held responsible for imports from non-Annex B countries, then who is responsible for the UKs exports to non-Annex B countries? Several adjustments were proposed to extend these accounting principles (mentioned in section §2.2), so both producer and consumer are held responsible.

In addition to improvements of accounting principles, a tax on carbon consumption was suggested as one of the most effective ways to lower CO_2 emissions and fight climate change (Helm, 2008). A carbon tax with border adjustments ensures that imports of carbon intensive goods from countries without binding commitments are treated on the same basis as domestic production. Although carbon border adjustments entail several benefits, it is also severely criticized. This is mainly because countries might misuse carbon measure for protectionist reasons, just like other trade-affecting policy instruments (Horn and Sapir, 2013).

8.3 Hypothesis III

The third hypothesis sought to test that the UK creates pollution havens abroad by importing goods that are more pollution intensive than its exports. This hypothesis is tested by looking at the emissions embodied in the imports and exports of energy intensive industries.

The results show that on average 64% of emissions embodied in the UK's imports originate in energy intensive industries associated with manufacturing. Emissions from non-manufacturing energy intensive industries account for another 8%, making the total emissions embodied in imports from energy intensive industries amount to 72%. Exports from the same sectors are significantly lower, making the UK a net importer of emissions from energy intensive industries. The results also show that imported emissions from energy intensive industries make up a significant share when compared to domestic emissions and there were only two energy intensive industries in which UK domestic emissions exceed emissions occurring overseas.

It is relatively difficult to compare the results of this study directly (sector by sector) with results from other studies because of the use of different databases and different sector aggregation. The study by the Carbon-Trust (2011), using similar sector aggregation, showed that in all sectors except construction and oil, the emissions embodied in imports exceed those embodied in exports. In general, this is line with the findings of this study, which showed that BEET by sector is negative for most industries, except the Water and Air Transport sector, whilst Construction had relatively balanced trade. Similarly to this study, theCarbon-Trust (2011) also shows that the UK is a large net importer of emissions embodied in electricity. These results are also consistent with Barrett et al. (2011) who reported the emissions related to electricity to be the highest amongst the top 15 product groups. In addition, Barrett et al. (2011) and Minx et al. (2009) demonstrated the growing dependence on services and continual rise in emissions in this sector. This effect is difficult to see in this study since the service sector is disaggregated into a number of separate sectors, all of which indicate an increasing trend until 2009 (c23, c24, c25 figure 7.6, graph 3). However, it is also important to note that emissions embodied in exports from some service sectors are even higher than imports, making the UK a net exporter of emissions rather than importer.

In the beginning of this chapter it was shown that CO_2 emissions embodied in UK imports from abroad are higher than CO_2 emissions embodied in UK exports. An important conclusion from this section is that most CO_2 emissions associated with UK imports originate in industries that are more energy intensive and typically are more polluting. The relocation of these industries can be seen as the direct result of the development of the UK as a service based economy. However, the transition towards a less polluting, service economy has not significantly affected consumer demand for goods produced in pollution intensive industries. Most of these goods are now simply imported from overseas.

Chapter 9

Conclusion

9.1 Summary

The expansion of globalization over the last few decades has generated a significant growth in economic activities around the globe. Increasing global trade and, as a result, increasingly internationalized production chains have changed our production and consumption patterns completely and lead to a separation of the locations of production and consumption of goods and services. Many businesses in developed countries are purchasing goods and services from developing countries, which may lead to the relocation of energy use and pollution to developing countries.

The shifting of carbon between regions was not formally addressed in the initial Kyoto Protocol discussions, as it was anticipated to be a minor issue, or one to be addressed later. To date, a respectable number of studies have been undertaken worldwide in order to quantitatively examine emissions embodied in the international trade of different countries and world regions. Although the results from different studies have some variation in their final estimates, they all show similar trends: emissions from a production perspective have declined over time, while consumption based emissions have increased.

The results of this study are generally in line with the findings of other researchers. Consumption-based and Production- based accounts show that CO_2 emissions associated with UK imports from abroad are greater than CO_2 emissions associated with UK exports. From a Production point of view, emissions in 2009 amounted to 558 $MtCO_2$, this was about 6% lower than emissions in 1995 of 589 $MtCO_2$. In contrast, consumer emissions have risen by about 5% from 638 $MtCO_2$ in 1995 to 669 $MtCO_2$ in 2009. These results clearly indicate that international trade might be an explanation for the downward slope of the Environmental Kuznets Curve.

Further analysis revealed that a significant share of emissions is embodied in imports from non-Annex B countries, which are typically considered as developing nations. Although the shares for different versions of non-Annex B countries are different, the general trend suggests that carbon leakage in the UK has grown between 1995 and 2009 by about 10%. These results clearly show how production based emissions are falling in the UK, in line with its Kyoto targets. This is a worrying fact, because it means that despite enormous time and effort devoted to international and national climate policies, global emissions associated with UK consumption are increasing.

It is also evident that most CO_2 emissions associated with UK imports originate in industries that are more energy intensive and typically are more polluting. The results show that on average 64% of emissions embodied in UK's imports originate in energy intensive industries associated with manufacturing. Emissions from non-manufacturing energy intensive industries account for another 8%, making the total emissions embodied in imports from energy intensive industries amount to 72%. The relocation of these industries can be seen as the direct result of the development of the UK as a service based economy. However, the transition towards a less polluting, service economy has not significantly affected consumer demand for goods produced in pollution intensive industries. Most of these goods are now simply imported from overseas.

9.2 Limitation of the Study and Future Research

Although this research has been carefully prepared and reached its aims, there are however several shortcomings that need to be mentioned. From the uncertainties and limitations associated with multi region input-output analysis presented in section X, the Rest of the world assumption is of particular importance to this study.

In order to estimate carbon leakage one version of non-Annex B assumed that RoW is a non-annex B region. Although most countries in RoW are considered as non-Annex B, it also includes countries that are considered as Annex B, namely Switzerland, Norway and Iceland. Therefore, it is important to acknowledge that NB.v2 has a potential to overestimate the results of carbon leakage from the UK to non-Annex B countries. However, this overestimation should not be too large, since all countries have relatively clean energy structures: Norway is almost entirely powered by hydropower, Switzerland by hydropower and nuclear energy and in Iceland most of primary energy comes from hydropower and geothermal sources. This limitation could also be overcome by using a database that provides statistics for all annex B countries.

Furthermore, this study only considered the UKs carbon dioxide emissions, and while it is the most important of the greenhouse gases accounting for more than 80% of total, it is not the only one. So, emissions associated with other gases should also be considered. Although the data is available for different greenhouse gases, a conversion has to be made in order to present them in carbon dioxide equivalent emissions. It was not done in this particular study, as converting other gases into CO_2 equivalent emissions would have required a significant amount of time. This is mainly due to the fact that conversion factors (converting CH_4, N_2O, HFCs, PFCS. SF to CO_2e) are not static and change from year to year and vary by country.

The results of this thesis provided a clear indication of the magnitude, sources (i.e countries and sectors) and trends associated with the UKs consumption and production based CO_2 emissions. Once the emission flows are identified and calculated, the next logical step is to undertake a deeper structural analysis. The shift to a service economy and to lighter industries may look different if the interrelations between sectors are studied. Future lines of research need to expand in analyzing the key causes and factors behind the changing patterns of emission flows. A commonly used technique for identifying drivers of change is Structural Decomposition Analysis (SDA). The SDA technique has been used to unravel the roles of technological change, production structures, demand structures, affluence (per-capita consumption) and the mix and level of exports in driving up CO_2 emissions.

The decomposition analysis provides an overview of the causes of change. However, it does not identify the specific processes which have changed. As a recent addition to the environmental input-output methodology, structural path decomposition (SPD) can be applied to answer these questions. In SPD, the production structure of an economy is studied through series expansions of the direct requirement matrix, in order to identify the main environmentally relevant pathways. Changes in these pathways are then analyzed with structural decomposition. This method allows the study of change at a process level, instead of country level aggregates. The use of such a method can help identify the top sectors or sector chains that were the largest contributors towards CO_2 emissions in the UK.

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Appendices

Appendix A

Table A.1: World Input-Output Database Geographical Coverage

Code	Country		Code	Country
AUS	Australia		ITA	Italy
AUT	Austria		JPN	Japan
BEL	Belgium		KOR	South Korea
BGR	Bulgaria		LTU	Lithuania
BRA	Brazil		LUX	Luxembourg
CAN	Canada		LVA	Latvia
CHN	China		MEX	Mexico
CYP	Cyprus		MLT	Malta
CZE	Czech Republic		NLD	Netherlands
DEU	Germany		POL	Poland
DNK	Denmark		PRT	Portugal
ESP	Spain		ROM	Romania
EST	Estonia		RUS	Russian Federation
FIN	Finland		SVK	Slovakia
FRA	France		SVN	Slovenia
GBR	United Kingdom		SWE	Sweden
GRC	Greece		TUR	Turkey
HUN	Hungary		TWN	Taiwan
IDN	Indonesia		USA	United States of America
IND	India		RoW	Rest of the World
IRL	Ireland			

Table A.2: World Input-Output Database Sectoral Coverage

No	Name	Code		No	Name	Code
c1	Agriculture, Hunting, Forestry and Fishing	AtB		c19	Sale, Maintenance and Repair of Motor Vehicles and Motorcycles; Retail Sale of Fuel	50
c2	Mining and Quarrying	C		c20	Wholesale Trade and Commission Trade, Except of Motor Vehicles and Motorcycles	51
c3	Food, Beverages and Tobacco	15t16		c21	Retail Trade, Except of Motor Vehicles and Motorcycles; Repair of Household Goods	52
c4	Textiles and Textile Products	17t18		c22	Hotels and Restaurants	H
c5	Leather, Leather and Footwear	19		c23	Inland Transport	60
c6	Wood and Products of Wood and Cork	20		c24	Water Transport	61
c7	Pulp, Paper, Paper , Printing and Publishing	21t22		c25	Air Transport	62
c8	Coke, Refined Petroleum and Nuclear Fuel	23		c26	Other Supporting and Auxiliary Transport Activities; Activities of Travel Agencies	63
c9	Chemicals and Chemical Products	24		c27	Post and Telecommunications	64
c10	Rubber and Plastics	25		c28	Financial Intermediation	J
c11	Other Non-Metallic Mineral	26		c29	Real Estate Activities	70
c12	Basic Metals and Fabricated Metal	27t28		c30	Renting of M&Eq and Other Business Activities	71t74
c13	Machinery, Nec	29		c31	Public Admin and Defence; Compulsory Social Security	L
c14	Electrical and Optical Equipment	30t33		c32	Education	M
c15	Transport Equipment	34t35		c33	Health and Social Work	N
c16	Manufacturing, Nec; Recycling	36t37		c34	Other Community, Social and Personal Services	O
c17	Electricity, Gas and Water Supply	E		c35	Private Households with Employed Persons	P
c18	Construction	F				

Appendix B

World Input Output Table

Figure B.1: World Input-Output Table Explanation

	Intermediate Consumption			**Final Demand**			**Output**
	Country A	Country B	Country RoW	$\mathbf{f_A}$	$\mathbf{f_B}$	$\mathbf{f_{RoW}}$	
Country A	Intermediate use by A of Domestic output	Intermediate use by B of exports A	Intermediate use by RoW of exports A	Final use by A of domestic output	Final use by B of exports from A	Final use by RoW of exports from A	Output in A
Country B	Intermediate use by A of Exports from B	Intermediate use by B of Domestic output	Intermediate use by RoW of exports B	Final use by A of exports from B	Final use by A of domestic output	Final use by RoW of exports from B	Output in B
Country RoW	Intermediate use by A of exports from RoW	Intermediate use by B of exports from RoW	Intermediate use by RoW of Domestic ouptut	Final use by A of exports from RoW	Final use by B of exports from RoW	Final use by RoW of domestic output	Output in RoW
VA	Value added by labour and capital in A	Value added by labour and capital in B	Value added by labour and capital in RoW				
Output	Output A	Output B	Output RoW				

Figure B.2: Detailed Structure of World Input-Output Table

	Intermediate Consumption											Final Demand					Output
	$\mathbf{IND}_{\mathrm{AUS,01}}$	$\mathbf{IND}_{\mathrm{AUS,02}}$	.	.	.	$\mathbf{IND}_{\mathrm{CY,SY}}$	.	.	.	$\mathbf{IND}_{\mathrm{RoW,34}}$	$\mathbf{IND}_{\mathrm{RoW,35}}$	$\mathbf{f}_{\mathbf{AUS}}$	.	.	.	$\mathbf{f}_{\mathbf{RoW}}$	
$\mathbf{IND}_{\mathrm{AUS,01}}$	$\mathrm{Z}_{\mathrm{AUS,01;AUS,01}}$	.	.	.	.	.	.	.	.	.	$\mathrm{Z}_{\mathrm{AUS,01;RoW,35}}$	$\mathrm{f}_{\mathrm{AUS,01;AUS}}$	.	.	.	$\mathrm{f}_{\mathrm{AUS,01;RoW}}$	$\mathrm{X}_{\mathrm{AUS,01}}$
$\mathbf{IND}_{\mathrm{AUS,02}}$	$\mathrm{Z}_{\mathrm{AUS,02;AUS,01}}$	.	.	.	.	.	.	.	.	.	$\mathrm{Z}_{\mathrm{AUS,02;RoW,35}}$		.	.	.		$\mathrm{X}_{\mathrm{AUS,02}}$
.	.		.			.			.		.				.		
.	.			.				.			.			.			
.	.				.		.				.		.				
$\mathbf{IND}_{\mathrm{CX,SX}}$	$\mathrm{Z}_{\mathrm{CX,SX;AUS,01}}$	.	.	.	.	$\mathrm{Z}_{\mathrm{CX,SX;CY,SY}}$	.	.	.	.	$\mathrm{Z}_{\mathrm{CX,SX;RoW,35}}$	$\mathrm{f}_{\mathrm{CX,SX;AUS}}$	.	.	.		$\mathrm{X}_{\mathrm{CX,SX}}$
.	.		.			.			.		.				.		
.	.			.				.			.			.			
.	.				.		.				.		.				
$\mathbf{IND}_{\mathrm{RoW,34}}$	$\mathrm{Z}_{\mathrm{RoW,34;AUS,01}}$	.	.	.	.	.	.	.	.	.	$\mathrm{Z}_{\mathrm{RoW,34;RoW,35}}$	$\mathrm{f}_{\mathrm{RoW,34;AUS}}$	.	.	.	$\mathrm{f}_{\mathrm{RoW,34,RoW}}$	$\mathrm{X}_{\mathrm{RoW,34}}$
$\mathbf{IND}_{\mathrm{RoW,35}}$	$\mathrm{Z}_{\mathrm{RoW,35;AUS,01}}$	.	.	.	.		.	.	.	.	$\mathrm{Z}_{\mathrm{RoW,35;RoW,35}}$	$\mathrm{f}_{\mathrm{RoW,35;AUS}}$	.	.	.	$\mathrm{f}_{\mathrm{RoW,35,RoW}}$	$\mathrm{X}_{\mathrm{RoW,35}}$
VA	$\mathrm{VA}_{\mathrm{AUS,01}}$	$\mathrm{VA}_{\mathrm{AUS,02}}$	.	.	.	$\mathrm{VA}_{\mathrm{CY,SY}}$	.	.	.	$\mathrm{VA}_{\mathrm{RoW,34}}$	$\mathrm{VA}_{\mathrm{RoW,35}}$						
Output	$\mathrm{X}_{\mathrm{AUS,01}}$	$\mathrm{X}_{\mathrm{AUS,02}}$				$\mathrm{X}_{\mathrm{CY,SY}}$				$\mathrm{X}_{\mathrm{RoW,34}}$	$\mathrm{X}_{\mathrm{RoW,35}}$						

Note: $IND_{CX,SX}$ - the industry SX in the Country CX. CX indicates the country where the good is produced and SP indicates the sector in which the good is produced. CY indicates the country where the good is consumed and SY indicates the sector. Based on Boitier (2012).

Appendix C

An example of CO_2 calculations with MRIO model

Table C.1 bellow represents a simplified version of WIOD table. In this example we assume that there are 3 countries/regions and 2 sectors/industries.

Table C.1: An Example of 3 Country 2 Sector Table

		A		B		RoW		A	B	RoW	Output
		Agr	Ind	Agr	Ind	Agr	Ind				
A	Agr	20	5	1	0	7	5	22	3	4	67
	Ind	7	17	4	6	6	2	20	5	8	75
B	Agr	3	6	30	9	3	3	14	30	10	108
	Ind	2	1	12	25	1	5	7	35	3	91
RoW	Agr	4	2	6	5	33	11	5	9	45	120
	Ind	0	4	3	5	7	43	9	10	33	114
VA		31	40	52	41	63	45				
Output		67	75	108	91	120	114				
CO_2		20	40	25	70	60	40				

The aim of this example is to solve the following equation $\mathbf{E} = \mathbf{D} \times \mathbf{L} \times \mathbf{F}$ definition for variables is given bellow. First step in input-output analysis is to obtain the coefficient matrix. As explained in section 6.2.1 the coefficient matrix is obtained by dividing input in sector j with the sum of total inputs in sector j i.e., $a_{ij} = z_{ij}/x_{ij}$ these numbers indicate quantity of the RoW product that is needed to produce one unit of the column product.

$$\mathbf{A} = \begin{bmatrix} 20/67 & 5/75 & 1/108 & 0/91 & 7/120 & 5/114 \\ 7/67 & 17/75 & 4/108 & 6/91 & 6/120 & 2/114 \\ 3/67 & 6/75 & 30/108 & 9/91 & 3/120 & 3/114 \\ 2/67 & 1/75 & 12/108 & 25/91 & 1/120 & 5/114 \\ 4/67 & 2/75 & 6/108 & 5/91 & 33/120 & 11/114 \\ 0/67 & 4/75 & 3/108 & 5/91 & 7/120 & 43/114 \end{bmatrix} \Rightarrow$$

after dividing each element in transaction table (green area) with the total output in corresponding sector (grey area) we obtain the following 6 x 6 matrix:

$$\mathbf{A} = \begin{bmatrix} 0.30 & 0.07 & 0.01 & 0.00 & 0.06 & 0.04 \\ 0.10 & 0.23 & 0.04 & 0.07 & 0.05 & 0.02 \\ 0.04 & 0.08 & 0.28 & 0.10 & 0.03 & 0.03 \\ 0.03 & 0.01 & 0.11 & 0.27 & 0.01 & 0.04 \\ 0.06 & 0.03 & 0.06 & 0.05 & 0.28 & 0.10 \\ 0.00 & 0.05 & 0.03 & 0.05 & 0.06 & 0.38 \end{bmatrix}$$

Next step is to generate 6 x 6 identity matrix (**I**) with the ones on the main diagonal and zeros elsewhere:

$$\mathbf{I} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Leontief inverse (in this case we call it **L**) is obtained by subtracting coefficient matrix **A** from Identity matrix **I** and taking the inverse:

$$\mathbf{L} = (\mathbf{I} - \mathbf{A})^{-\mathbf{1}} = \begin{bmatrix} 1.46 & 0.15 & 0.05 & 0.04 & 0.14 & 0.13 \\ 0.22 & 1.34 & 0.11 & 0.15 & 0.12 & 0.09 \\ 0.13 & 0.17 & 1.44 & 0.23 & 0.08 & 0.10 \\ 0.09 & 0.07 & 0.23 & 1.43 & 0.05 & 0.13 \\ 0.15 & 0.10 & 0.15 & 0.16 & 1.43 & 0.25 \\ 0.05 & 0.14 & 0.11 & 0.16 & 0.15 & 1.65 \end{bmatrix}$$

Final demand in this case is presented with 6 x 3 matrix. Each column of this matrix shows final demand for a separate country. As mentioned in section 5.1 final demand in this study was compiled from 5 different categories, but it is also possible to assign embodied emissions without aggregating final demand. In such case we would have 6 x 15 matrix, which could provide us with further insights into flows of embodied emissions, but this task was beyond the scope of this study.

$$\mathbf{F} = \begin{bmatrix} 22 & 3 & 4 \\ 20 & 5 & 8 \\ 14 & 30 & 10 \\ 7 & 35 & 3 \\ 5 & 9 & 45 \\ 9 & 10 & 33 \end{bmatrix}$$

Emissions per unit of industry output are calculated by dividing total output in sector j with total emissions in sector j:

$$\mathbf{D} = \begin{bmatrix} 20/67 & 40/75 & 25/108 & 70/91 & 60/120 & 40/114 \end{bmatrix} \Rightarrow$$

$$\mathbf{D} = \begin{bmatrix} 0.3 & 0.5 & 0.2 & 0.8 & 0.5 & 0.4 \end{bmatrix}$$

In this study a RoW vector of region specific CO_2 emissions per unit of industry output is diagonalized in order to obtain emissions by sector and by country.

$$\widehat{\mathbf{D}} = \begin{bmatrix} 0.3 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0.2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0.8 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0.4 \end{bmatrix}$$

Multiplying matrices $\widehat{\mathbf{E}} \times \mathbf{L} \times \mathbf{F}$ we obtain the following output:

$$\mathbf{E} = \widehat{\mathbf{D}} \times \mathbf{L} \times \mathbf{F} = \begin{bmatrix} 11.34 & 3.17 & 5.49 \\ 18.99 & 9.54 & 11.48 \\ 6.84 & 12.55 & 5.61 \\ 13.80 & 45.62 & 10.58 \\ 8.59 & 13.14 & 37.91 \\ 7.75 & 9.72 & 22.53 \end{bmatrix}$$

Finally, in order to calculate EEI and EEE and then PBA and CBA we have to add certain elements in **E** matrix**,** which are presented in green area in table C.2. Domestic emissions are presented in diagonal of this matrix (colored in dark green). In order to obtain EEE we have to sum all elements of **E** matrix except the domestic emissions (i.e., we sum only light grey areas). The result of this summation is shown in column EEE. Production based emissions (PBA) are then calculated by adding $PBA = Domestic + EEE$. To calculate EEI we sum across rows, again not taking into account domestic emissions. Consumption based emissions (CBA) are calculated by adding $CBA = Domestic + EEI$.

It is important to note that total sum of $EEE = EEI \Rightarrow 106.5 = 106.5$ and total of $PBA = CBA \Rightarrow 255 = 255$, but $A_{EEE} \neq A_{EEI} \Rightarrow 8.66 + 21.01 \neq 37.34$ and similarly $A_{PBA} \neq A_{CBA} \Rightarrow 20 + 40 \neq 67.67$. This shows that emissions on a global level are the same but they distribution is different according to different accounting principles.

To see which countries are now "worse off" we can look at BEET, for country A:

(8.66+21.01) - 37.34 = -7.67; for country B: (12.45+24.38) - 35.36 = 1.27; for county RoW: (22.09 + 17.47) - 33.15 = 6.4. From these results we can conclude that country A is a net importer of emissions (-7.67), country B has more or less balanced account of emissions embodied in trade (1.27), and RoW is a net exporter of emissions embodied in trade (6.4).

Table C.2: An Example of PBA and CBA Calculation

	A	B	RoW	Domestic	EEE	PBA
A_{IND}	11.34	3.17	5.49	11.34	8.66	20
A_{AGR}	18.99	9.54	11.48	18.99	21.01	40
B_{AGR}	6.84	12.55	5.61	12.55	12.45	25
B_{IND}	13.80	45.62	10.58	45.62	24.38	70
RoW_{AGR}	8.95	13.14	37.91	37.91	22.09	60
RoW_{IND}	7.75	9.72	22.53	22.53	17.47	40
Domestic	30.33	58.17	60.44	148.95		
EEI	37.34	35.56	33.15		106.05	
CBA	67.67	93.73	93.60			255

Appendix D

Glossary and abbreviations

Annex B Developed countries with GHG emissions limitations or a reduction commitment. EU-15, Bulgaria, Czech Republic, Estonia, Latvia, Liechtenstein, Lithuania, Monaco, Romania, Slovakia, Slovenia, Switzerland, US (indicated its intention not to ratify the Kyoto Protocol), Canada (in 2011, withdrew from the Kyoto Protocol), Hungary, Japan, Poland, Croatia, New Zealand, Russian Federation, Ukraine, Norway, Australia, Iceland.

Annex I Developed countries with GHG emissions limitations or a reduction commitment mentioned in Annex B plus Belarus and Turkey .

BEET Balance of Emissions Embodied In Trade

CBA Consumption-based Accounting

CO_2 Carbon dioxide the most common greenhouse gas, emitted from the burning of fossil fuels (e.g. coal, oil, natural gas)

DTA Domestic Technology Assumption

EEE Emissions Embodied In Exports

EEE Emissions Embodied In Imports

EKC Environmental Kuznets Curve. T hypothesis saying that that environmental degradation as a function of economic level, will take an inverted U-shaped form.

ETS European Union Emissions Trading Scheme

EU European Union

GDP Gross Domestic Product

GHG Greenhouse Gases

MRIO Multi-region input-output model

NEI National Emission Inventories

Non - Annex B Mainly developing countries not included in Annex B to the UNFCCC

Non - Annex I Mainly developing countries not included in Annex I to the UNFCCC

OECD Organization for Economic Cooperation and Development

PBA Production-based Accounting

RoW Rest of the World

SRIO Single-region input-output model

UNFCCC United National Framework Convention of Climate Change

WIOD World Input Output Database

WIOT World Input Output Table