Measuring Denmark's CO_2 Emissions

1996–2009

Gagan P. Ghosh, Clinton J. Levitt,
Morten S. Pedersen and Anders Sørensen

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Address
The Rockwool Foundation
Kronprinsessegade 54, 2.
DK-1306 Copenhagen K
Denmark
Telephone +45 46 56 03 00
E-mail rockwool.fonden@rockwool.org
Home page rockwoolfoundation.org

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Foreword

It is generally understood that greenhouse gasses produced by human activities are having a warming effect on the climate. Carbon-dioxide (CO_2), which is emitted by burning various fossil fuels, is the primary greenhouse gas. The international push to reduce the consumption of fossil fuels and increase energy efficiency is aimed at curbing the emission of greenhouse gases into the atmosphere. Denmark has taken a particularly strong approach to reducing its greenhouse gas emissions.

International climate agreements define national obligations for reducing greenhouse gas emissions in terms of territorial borders. As a consequence, Denmark is only held responsible for CO_2 emissions occurring within its sovereign territory. However, CO_2 emissions embodied in internationally traded goods and services are likely to play an important role in total CO_2 emissions related to economic activities in small open economies like Denmark. For Denmark, the recent growth in imports from emerging markets with less restrictive environmental regulations and higher production emission intensities, may contribute further to the importance of international trade for the CO_2 emission attributable to Danish economic activity.

In this report, we present an emission inventory of the Danish economy, tracked over time, using the latest available data, which allows us to account for the international trade of CO_2 emissions through imports and exports of goods and services. The project is carried out by researchers affiliated with the Centre for Economic and Business Research (CEBR) at Copenhagen Business School. The study group consists of Lecturer Clinton J. Levitt, Tasmanian School of Business and Economics, Post doc Morten Saaby Pedersen, Assistant Professor Gagan P. Ghosh, and Professor Anders Sørensen, Copenhagen Business School. We are grateful for the financial support from the Rockwool Foundation.

A special thank goes to the reference group of the project consisting of Professor Torben M. Andersen (chairman), Department of Economics, University of Aarhus, retired Executive Vice President Palle Geleff, Energy E2, and Associate Professor Emeritus Jørgen Birk Mortensen, University of Copenhagen. The reference group tirelessly gave comments and asked questions. We would also like to thank Mathias Tolstrup Wester and Casper Winther Jørgensen for efficient research assistance. The contents of this work are the sole responsibility of the authors and do not necessarily represent the views of The Rockwool Foundation. The authors have no conflict of interest in this work.

Clinton J. Levitt, Morten Saaby Pedersen, Gagan P. Ghosh, Anders Sørensen, Copenhagen, October 2014

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Chapter 1

Summary of Main Results

1.1 Introduction

It is generally understood that greenhouse gasses produced by human activities are having a warming effect on the climate (IPCC, 2014). Carbon-dioxide (CO_2), which is emitted by burning various fossil fuels (coal, natural gas, and oil, for example) is the primary greenhouse gas. Over the past century, global CO_2 emissions have increased dramatically: Between 1900 and 2008, CO_2 emissions increased almost 16 fold and by a factor of about 1.5 between 1990 and 2008 (see figure 1.1). Reducing CO_2 emissions remains a priority on most political agendas around the world.

Denmark has taken a particularly strong approach to reducing its greenhouse gas emissions. As part of the 1997 Kyoto protocol, Denmark has adopted one of the most ambitious emission reduction targets (21 percent between 2008-2012, relative to 1990 emission levels) compared to other Annex I countries of the UN Framework Convention on Climate Change (UNFCCC).[1] Likewise, Denmark's target of reducing emissions by a further 20 percent between 2013 to 2020, independent of the Emissions Trading Scheme (ETS), is among the highest in the EU Burden-Sharing Mechanism. As outlined in the Danish government's *Energy Strategy 2050* launched in 2011, the long-term goal of Danish energy policy is to phase-out the use of fossil fuels by 2050 (Ministry of Climate, Energy and Building, 2011). In the shorter-term, the goal is to reduce the use of fossil fuels in the energy sector by 33 percent relative to 2009 levels. In addition, the share of renewable energy in Danish total energy supply is to increase to 33 percent by 2020 and primary energy consumption is to decrease by 6 percent by 2020, all relative to 2006 levels. The motivation behind the push to reduce fossil fuel consumption and increase energy efficiency is to curb the emitting of greenhouse gases into the atmosphere. Achieving these ambitious goals is expected to result in significant reductions in Denmark's territorial CO_2 emissions.

International climate agreements define obligations for reducing greenhouse gas emissions in terms of

[1] Annex I countries committed themselves specifically to the aim of returning to their 1990 levels of greenhouse gas emissions under the UNFCCC. There are 43 Annex I parties including the European Union.

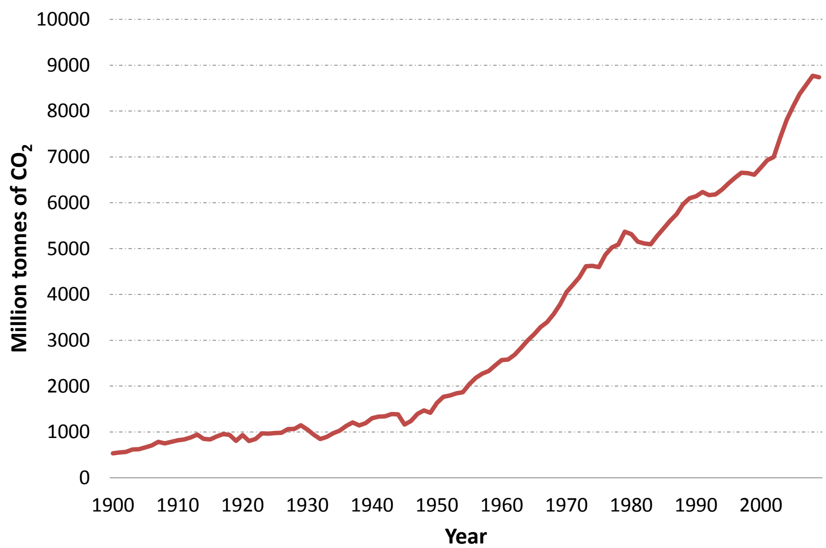

Figure 1.1: Total Global Emissions, 1900-2009

emissions produced within the sovereign boundaries of a country. Consequently, the vast majority of national emission inventories only account for those emissions produced from economic activity within national boundaries. Indeed, Denmark, as part of its international obligations, is held responsible for the CO_2 emitted from carbon-producing activities occurring only within its sovereign territory. Consequently, Danish national greenhouse emissions accounting only calculates emissions produced domestically. However, this is not the only way to assign responsibility for emissions. In recent decades, a growing number of studies have highlighted that emissions which occur along international value chains, to meet domestic consumer demand (through international trade of goods and services, for example), should also be considered when assessing a country's responsibility for abating climate change (Munksgaard and Pedersen, 2001).

International trade may impact a country's CO_2 accounting in at least three important ways:

1. Technology Effects: There could be large differences in emission-intensities in production across countries (e.g., Denmark has a relatively large renewable energy sector).

2. Supply- and Demand-Side Effects: Various policies could add a premium to certain fuels or other input commodities making input prices higher relative to less regulated economies.

3. Compositional Effects: Carbon leakage through relocation of dirty sectors from relatively high cost, regulated economies (Kyoto and EU:ETS) to low cost, less regulated economies.

As a small open economy, CO_2 emissions embodied in internationally traded goods and services are likely to have a significant impact on Denmark's "CO_2 responsibility". As shown in figure 1.2, international trade comprises a large proportion of Denmark's GDP. Similar to other OECD countries, Denmark has recently experienced an increase in imports from emerging markets, particularly China, that have comparatively less restrictive environmental regulations (or policies) and have higher production emission intensities. As shown in figures 1.3 and 1.4, the share of imports coming from China increased to 5 percent, representing nearly 270 percent increase from their share in 1996. The observed increase in imports from China was likely due to its accession to the WTO in December 2001. This increase in imports was paralleled by a decrease in imports from EU-15 countries by 7.6 percentage points (11 percent) during the same period.

In this report, we present an emission inventory of the Danish economy, tracked over time, using the latest available data that allows us to account for the international trade of CO_2 emissions through imports and exports of goods and services. The latest year for which comprehensive data are available is 2009; however, as a consequence of the financial crisis we mainly refer to 2008 for comparisons. The main conclusions of the report are:

1. Substantial CO_2 emissions are traded internationally and these are not included in Denmark's traditional production-based emission inventory. In 2008, total CO_2 emissions from the Danish economy was 70 million tonnes (Mt) according to the consumption-based approach and 62 Mt according to the production-based approach, indicating a net import of emissions of about 8 Mt CO_2 (11 percent of consumption).

2. From 1996 to 2002 the two accounting approaches have showed parallel trends in emissions. By contrast, the gap between the two accounting approaches has increased from 2003 to 2008 in part reflecting the increase in imports of goods and services from emission-intensive countries, particularly China.

It should be noted that our baseline results focus on CO_2 emissions alone. Aggregate greenhouse gas emissions that include methane, CH_4, and nitrous oxide, N_2O are presented separately in the appendix. Likewise, emissions associated with fuel bunkering (international transport carried out by Danish ships and planes) are also presented in the appendix as these are not covered by the Kyoto Agreement (see IPCC (1996) for a description of the reporting requirements under the Kyoto Agreement for Annex I countries.).

1.2 Production and Consumption Measures of CO_2

How should carbon emissions be measured? There are two broad-based approaches to calculating a country's CO_2 emissions: production-based and consumption-based. These two measures differ in how the responsibility of the carbon emitted into the atmosphere is assigned. Production-based measures imply that carbon emissions are the producer's responsibility, whereas measure based on consumption hold consumers responsible for the carbon emitted during the production of the goods and services they consume.

The production-based approach, proposed by the IPCCC (IPCC, 1996), and presumed in the Kyoto Agreement, is the most common method of measuring CO_2 emissions in national inventories (Peters and Hertwich, 2008). A production-based measure has been constructed, for example, by Gravgard et al. (2009)

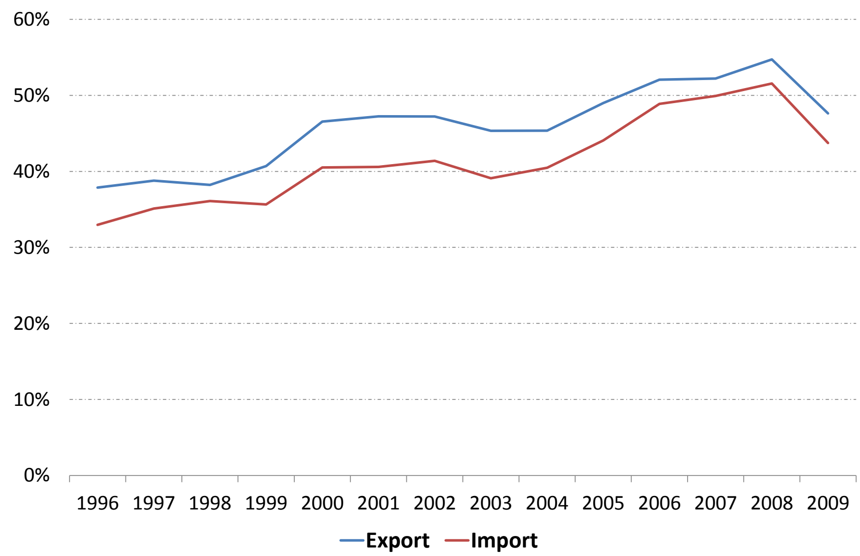

Figure 1.2: Danish imports and exports as a percentage of GDP, 1996-2009

for Denmark. In the production-based approach, a country is held responsible for CO_2 emissions produced within its sovereign territory. Therefore, calculating aggregate CO_2 emissions using the production-based approach involves aggregating emissions from the domestic production of goods and services irrespective of whether the goods and services are consumed domestically or are exported.

Several studies have advocated for adopting a consumption-based accounting approach (see Bastianoni et al. (2004), Munksgaard and Pedersen (2001), Proops et al. (1999), Ferng (2003) and Peters (2008)). This approach aggregates CO_2 emissions from goods and services produced domestically which serve domestic aggregate demand as well as emissions produced abroad from producing goods and services that are imported and then consumed domestically. As described in more detail in chapter 5, our analytical approach to calculating consumption-based CO_2 emissions is based on the flows of goods and services between sectors and countries in a multi-country input-output (I-O) analysis. This approach provides a well-established method of allocating responsibility of CO_2 emissions to consumers (Minx et al., 2009).

Consumption-based measures essentially allocates CO_2 emissions associated with the consumption of goods and services back to the consuming country and sector, even if the goods arrived at the consuming country via other countries, or were intermediate goods in a multi-country production supply chain. We calculated various consumption-based measures of carbon emissions for a number of years. The main difficulty with computing these measures is tracking the flow of intermediate goods and services between countries and sectors. However, our approach is feasible because we have access to a new set longitudinal world I-O tables as well as environmental data covering the whole post-Kyoto period between 1996 to 2009. In addition, we create links between these international data and Danish administrative register data.

Several previous studies have sought to compare emissions associated with production and consumption

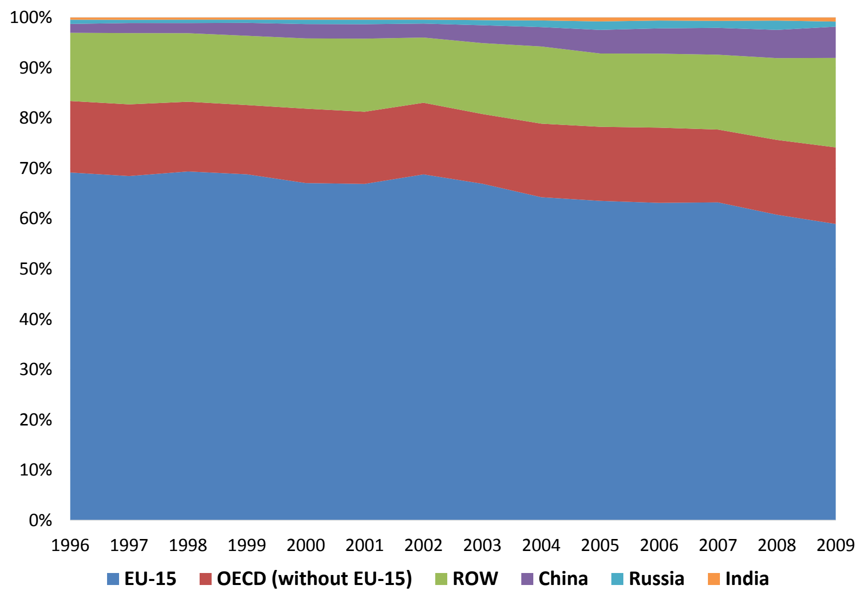

Figure 1.3: Danish imports (DKK) by country, 1996-2009

(for a review, see Wiedmann 2009). With particular relevance to the present study, Nakano et al. (2009) compare consumption- and production-based CO_2 inventories using a I-O analysis for 28 OECD countries and 12 non-OECD countries for two years (1995 and 2000). The authors find that in 2000, total consumption-based CO_2 emissions were 395 tonnes CO_2 per million US dollar GDP in Denmark, a reduction of nearly 17 percent from 1995. Moreover, net imported emissions were 17 percent of consumption. In a more recent study, Davis and Caldeira (2010) constructed consumption-based CO_2 inventories for a single year (2004), for 113 countries, using a similar approach. The authors find that in Western Europe, net imported emissions were 20-50 percent of consumption, originating primarily from China. For Denmark, CO_2 emissions amounted to 0.31 kg CO_2 per US dollar GDP ranking Denmark as the country with the seventh lowest CO_2 emissions per GDP, after countries such as Norway, Sweden, Switzerland, Ireland and France. Relative to these studies, an important advantage of our study is that we have access to longitudinal data covering a relatively large time period (14 years), which is important for evaluating trends in CO_2 emissions over time.

1.3 Overview of Results

In this section, we provide a brief overview of the results of our computations and analysis. Of course, the details of all the computations as well as a more complete analysis of the results are provided in the forthcoming chapters. We begin the brief overview by reporting the production-based measure of carbon emissions as well as the consumption-based measure.

In figure 1.5, we show the evolution of Denmark's CO_2 consumption and production emissions from 1996

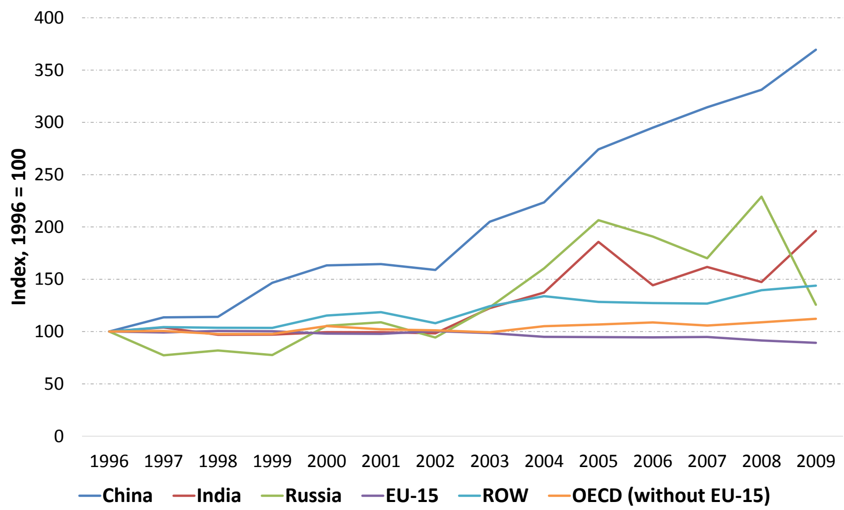

Figure 1.4: Change in Danish imports (DKK), 1996-2009

to 2009. Production emissions peaked in 1996 due in part to an increase in coal-fired electricity generation (Danish Energy Agency (2012)). Consumption emissions peaked one year later 1997. Apart from 1996, CO_2 consumption emissions were notably larger than production emission suggesting that imported goods and services were more emission-intensive than Danish produced exported goods. In 2008, consumption emissions in the Danish economy were 70 million tonnes (Mt), whereas production emissions were 62 Mt, indicating a net import of about 8 Mt of CO_2. This translates to about 11 percent of consumption, which is quite substantial given that Denmark, during the same year, recorded a trade surplus of about 6 percent.

Another interesting feature of the measures illustrated in figure 1.5 is that CO_2 emissions tended to fluctuate from year-to-year. These annual fluctuations are partially attributable to the amount of electricity generated domestically as well as internationally traded electricity, primarily with Denmark's Nordic neighbors (trade is sensitive to hydro resources in Sweden and Norway). Electricity generation is the largest source of carbon emissions in Denmark and variation in annual generation influences annual emission patterns.

Between 1996 and 2001, CO_2 emissions generally declined irrespective of how they were measured. A significant proportion of this reduction is related to the interfuel substitution away from coal to natural gas in thermal electricity generation as well as to the growth in renewable energy, primarily wind turbines(Danish Energy Agency (2012)). However, in 2002, consumption emissions started to increase peaking in 2007. An important contributor to the increase in consumption emissions was the increase in imports from China. In contrast, production emissions did not have much a trend over this period. We find that production-based CO_2 emissions declined by 24 percent from 1996 to 2008, whereas the consumption-based emissions declined by only 13 percent. Importantly, the gap between the two measures, over the most recent years, has increased. The gap is increasing because the imports of goods and services produced in countries having more emission-intensive production processes has increased. The effect is particularly evident after December

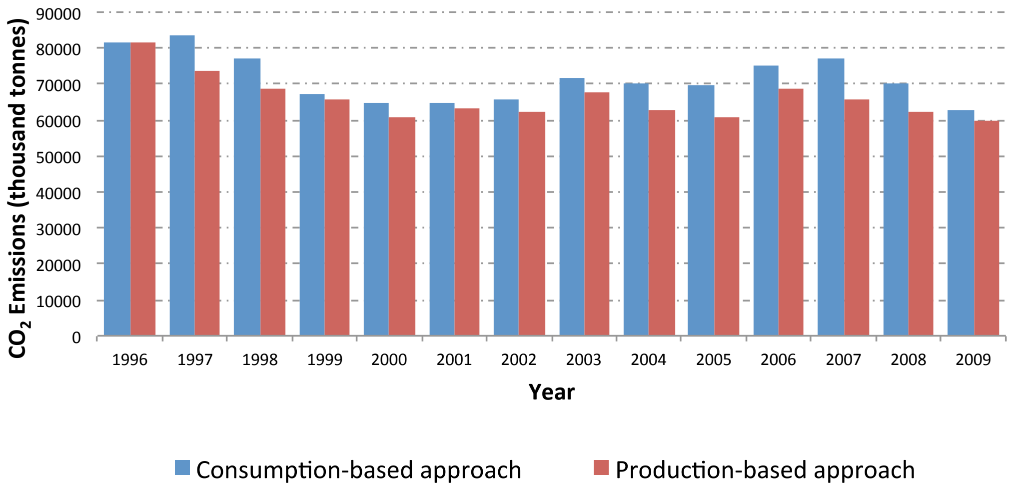

Figure 1.5: Total Danish CO_2 Emissions, 1996-2009

2001, when China became a member of the World Trade Organization.

1.3.1 CO_2 Emissions by Types of Final Demand

Next, we report consumption emissions categorized by final demand. Figure 1.6 provides a breakdown of emissions into those caused by household consumption, government consumption as well as investment. The vast majority of CO_2 emissions were caused by direct or indirect private consumption. In 1996, private consumption was responsible for about 61 Mt CO_2 (75 percent) and in 2008, for about 44 Mt CO_2 (65 percent). Of this, about 12 Mt CO_2 was related directly to households' use of fuel for heating and other primary energy consumption including petrol and diesel used in transportation. The rest was indirect emissions by sectors that produced goods and services to meet domestic demand. By contrast, government consumption and investments (fixed capital formation) in buildings, machinery and transport equipment contributed 35 percent of total CO_2 emissions in 2008, more or less equally divided between the two categories.

1.3.2 CO_2 Emissions Embodied in International Trade

The difference between the production-based and consumption-based measures is the net amount of CO_2 emissions embodied in international trade. Specifically, the difference equals emissions embodied in exports of goods and services less emissions embodied in imports of goods and services. A positive difference indicates a net export of emissions, whereas a negative difference indicates a net import of emissions.

There are two reasons why net imports of CO_2 emissions were increasing: First, the volume of goods and services imported was increasing; second, production of the imported goods and services became more emission intensive. From an earlier discussion, we know that both imports and exports have been increasing.

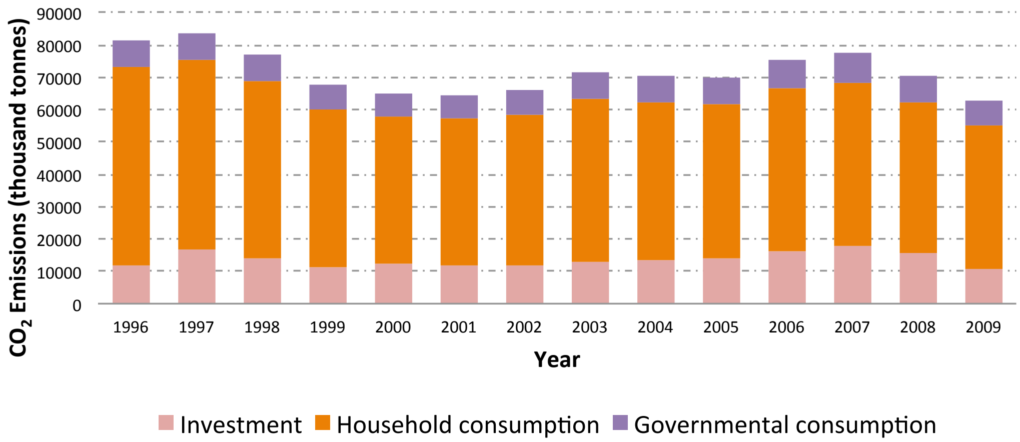

Figure 1.6: CO_2 Emissions by Types of Final Demand, 1996-2009

What we would like to know is what was happening to emission rates of imported and exported goods. In figure 1.7, we report emissions per 1000 DKK imports and exports.[2] The figure shows that CO_2 emissions per 1000 DKK imports declined initially. However, after reaching a minimum value of 0.03 tonnes in 2002, emissions steadily climbed reflecting in part the increase in imports from China and other emission-intensive countries. In contrast, CO_2 emissions embodied in Danish exports have been steadily decreasing from just over 0.04 tonnes per 1000 DKK exports in 1996 to 0.02 tonnes per 1000 DKK exports in 2009. In 2009, the per unit CO_2 emissions of imports were twice the size of the per unit CO_2 emissions of exports. Hence, the main reason for the rise in net imported CO_2 emissions is due to higher per unit CO_2 emissions of Danish imports. If this trend continues, we might expect to experience even larger gaps between the production- and the consumption-based CO_2 measures in the future.

1.3.3 Emissions by Country

From which countries did Denmark import emissions? In figure 1.8, we report the percentage of emissions imported from various countries in 2008. That is, the figure presents the percentage of CO_2 emissions caused by Danish demand for goods and serves produced in other countries. In 2008, the CO_2 emissions attributed to Danish consumption of goods and services was about 70 Mt. Of this, around 68 percent of the emissions occurred within Denmark through demand for domestically produced goods and services. The remaining 32 percent of emissions were embodied in imports. Interestingly, even though China only accounted for six percent of Danish imports of goods and services in 2008, it accounted for 17 percent of total imported

[2]It should be noted that the figure is constructed using a slightly different method for accounting for intermediate goods in the production process as described in chapter 2 (method 3). The reason is that it was not possible to extract emissions from imports and exports directly from I-O analysis. The main limitation is that this method does not take into account all intermediate goods and services in a multi-country production supply chain, see figure 5.6 for a comparison of the different methods.

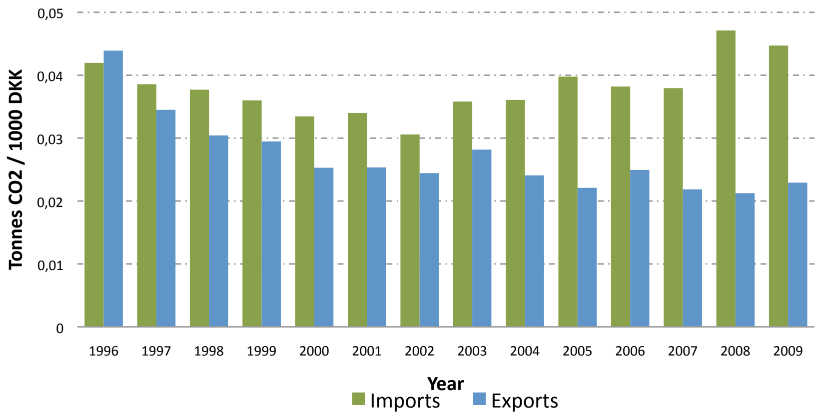

Figure 1.7: CO_2 Emissions/1000 DKK_{2005} of Danish Imports and Exports, 1996-2009

CO_2 emissions. China has a relatively more emission intensive production. Hence, the impact of even small increases in imports from China on emissions embodied in imports can be considerable.

1.3.4 Emissions by Industrial Sector

Different industrial sectors in an economy produce different levels of emissions. In figure 1.9 we present the percentage of CO_2 emissions caused by Danish final consumption in 2008 categorized by industrial sector. Note that unlike figure 1.8, this figure includes emissions from Danish production. In addition, the figure does not include household's direct use of energy (fuel for heating as well as petrol and diesel for cars, for example) since we focus on industrial sectors. The greatest contributor was the *Electricity, gas and water supply* sector (17 percent) due to the consumption of electricity and district heating. This is followed by the *Construction* (12 percent), *Machinery, Electrical and Optical Equipment* (8 percent) and the *Agriculture, Hunting, Forestry and Fishing, Food, Beverages and Tobacco* (7 percent) sector. Emissions from the *Transport* sector is generally small (2 percent). In the appendix we report this break down from 1996 to 2009.

1.3.5 Emissions and Economic growth

CO_2 emissions are influenced by both longrun and shortrun factors. One longrun factor that influences carbon emissions is economic growth. There is a relatively large body of research looking into the relationship between pollutants, or environmental degradation in general, and economic growth. For work relating to the relationship between carbon emissions and economic growth see Galeotti and Lanza (1999), Holtz-Eakin and Selden (1995) and Tucker (1995) as well as Grossman and Krueger (1995) which look at a range of pollutants. Most of this research involves characterizing the relationship between a country's economic growth and the quantity of pollutants produced. Most empirical studies focus on the environmental Kuznets curve. The

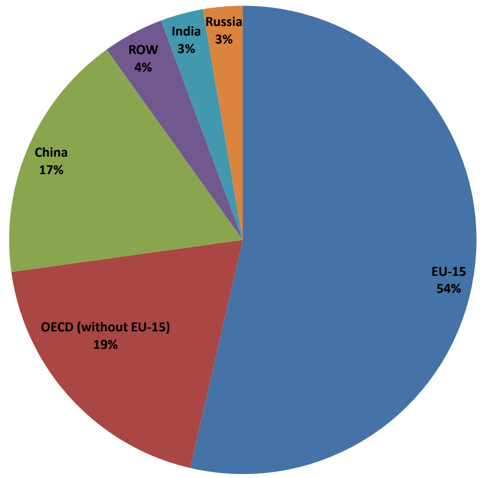

Figure 1.8: CO_2 Emissions by Countries, 2008

environmental Kuznets curve theorizes that there exists an inverted-U shaped relationship between economic growth and pollution. Here we focus only on CO_2 emissions (note, however, that the theory is more general). In terms of carbon emissions, the theory suggests that early in a countries development, there is a positive correlation between economic growth and the quantity of carbon emitted into the atmosphere, however, once the country reaches a certain income level, there is a decoupling between growth and emissions, and eventually, as the income increases, the quantity of emissions emitted into the atmosphere declines (see Galeotti et al. (2006) for an empirical study of carbon and the environmental Kuznets curve). In figure 1.10, we illustrate the relationship between Denmark's GDP and its carbon emissions.

The figure suggests that there is a positive correlation between GDP and carbon emissions. The increase in GDP experienced from 2001 to 2007 is accompanied with an increase in emissions. In 2008, when the global financial crises hit most of the world's economies, there was a decline in GDP which was again accompanied with a decrease in carbon emissions. However, the more interesting relationship is between economic growth and the growth in emissions. This relationship is presented in figure 1.11. It is seen that there is a positive correlation between GDP growth and emissions growth. The correlation coefficient equals 0.38 but is not significantly different from zero at the 10 percent level.

1.3.6 Comparison with other Countries

Using our consumption-based approach, we also calculated CO_2 emissions for the other remaining countries in the WIOD over the period 1996-2009. To facilitate comparisons across countries, we normalised total emissions by fixed-price GDP as well as by population.

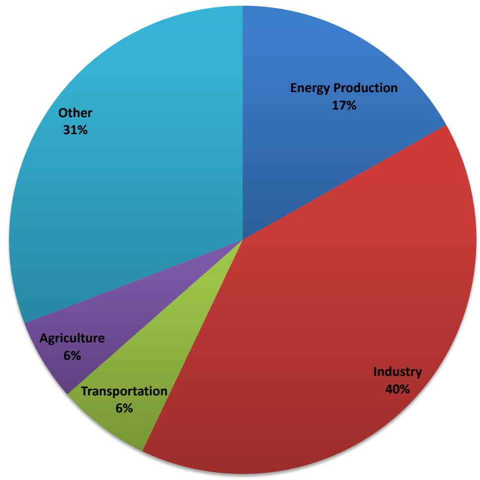

Figure 1.9: CO_2 Emissions by Economic Sectors, 2008

Emissions/GDP

First, we compare emissions across countries by calculating emissions per GPD (total CO_2 emission of each country was divided by GDP in constant 2005 prices). The results are presented in figure 1.12. Interestingly, Denmark had relatively low levels of CO_2 emissions per GDP relative to other countries. Between 1996-2009, CO_2 emissions declined from 431 tonnes per millions US dollars to 191 tonnes per million US dollar, ranking Denmark as the country with the fourth lowest emissions per GDP in 2008 after Luxembourg, Sweden and France (see figure 1.13). This result is in line with the findings reported in Nakano et al. (2009) and Davis and Caldeira (2010). The United States and countries in western Europe generally have lower CO_2 emissions per GDP because they have relatively high GDP. Countries like China and India have large populations which implies that they will have higher CO_2 emissions. Hence, they also have higher CO_2 emissions/GDP numbers.

Emissions per capita

In figure 1.14, we present CO_2 emissions per capita across countries between 1996-2009. This figure shows the importance of our approach of measuring emissions using consumption methods. Many wealthy countries, especially those in Western Europe, who have aggressive environmental policies actually have high emissions per capita, which have not necessarily declined since 1996. This implies, that many of these countries, like Denmark, are importing CO_2 emissions by way of international trade. In figure 1.15, it can be seen that Denmark has one of the highest levels of CO_2 emissions per capita in 2008, as do many other EU-15 countries.

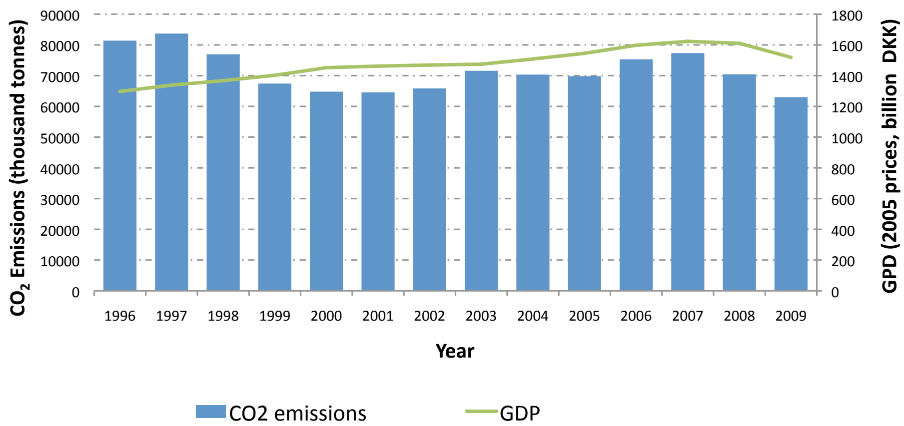

Figure 1.10: CO_2 Emissions and GDP

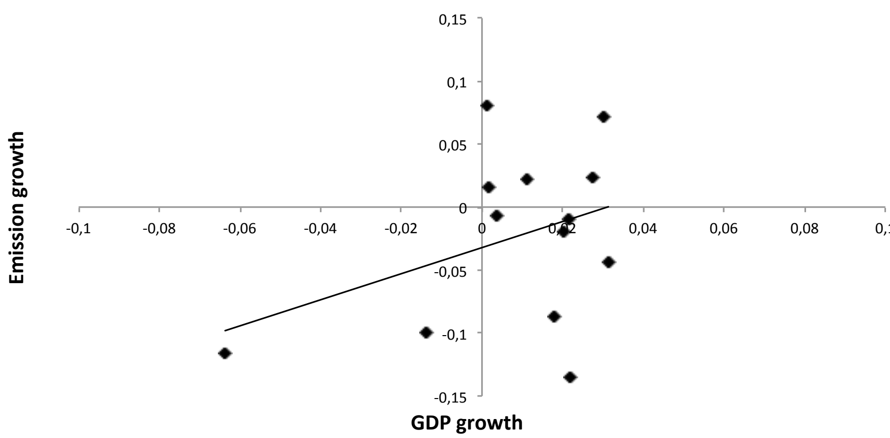

Figure 1.11: CO_2 Emissions and GDP Growth

1.3.7 Structure of the report

In the remaining chapters of this report, we detail all of our computations and provide more in-depth analysis of our results. In chapter 2, we provide an overview of the methods we used to measure emissions. We describe the data in chapter 3. In Chapter 4, we present the production-based CO_2 emissions, whereas in Chapter 5, we present our results of the various consumption-based measures of CO_2 emissions. Chapter 6 presents a set of analyses investigating the robustness of the results. Finally, we also include a number of additional computations in an appendix that extend the analysis in a number of different directions.

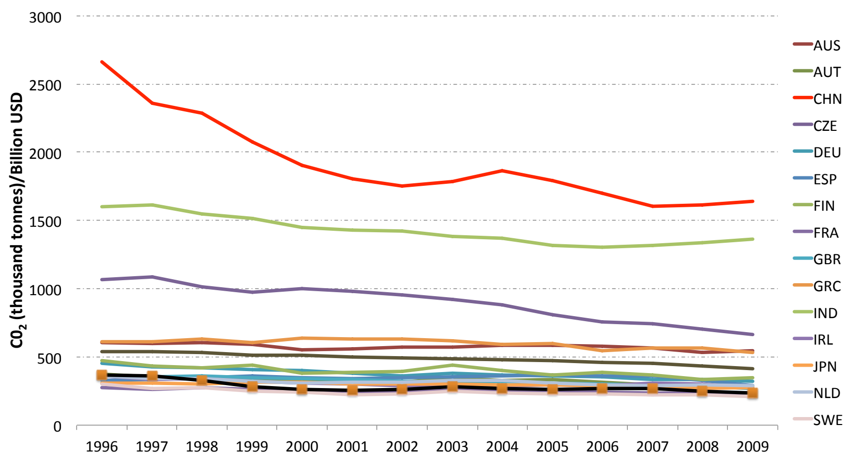

Figure 1.12: CO_2 Consumption-based Emissions per GDP, 1996-2009

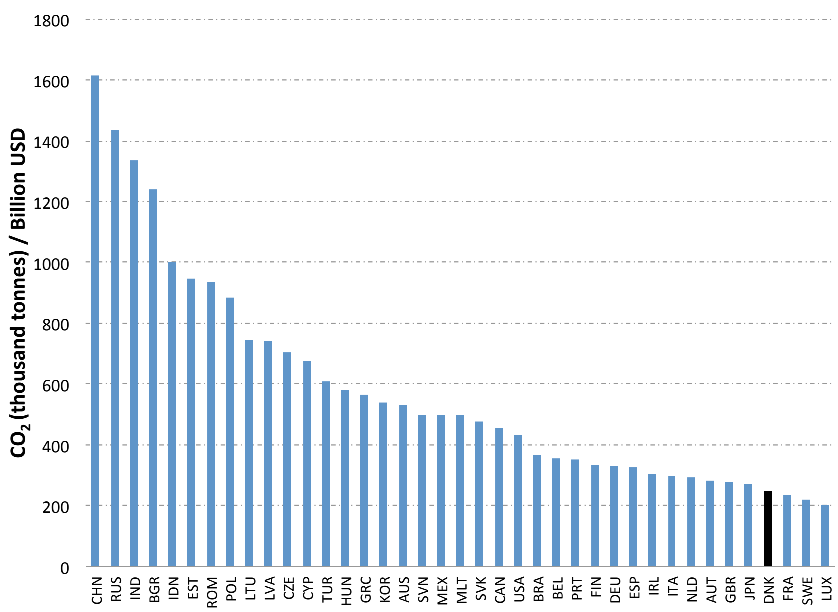

Figure 1.13: Ranking of Consumption-based CO_2 Emissions per GDP, 2008

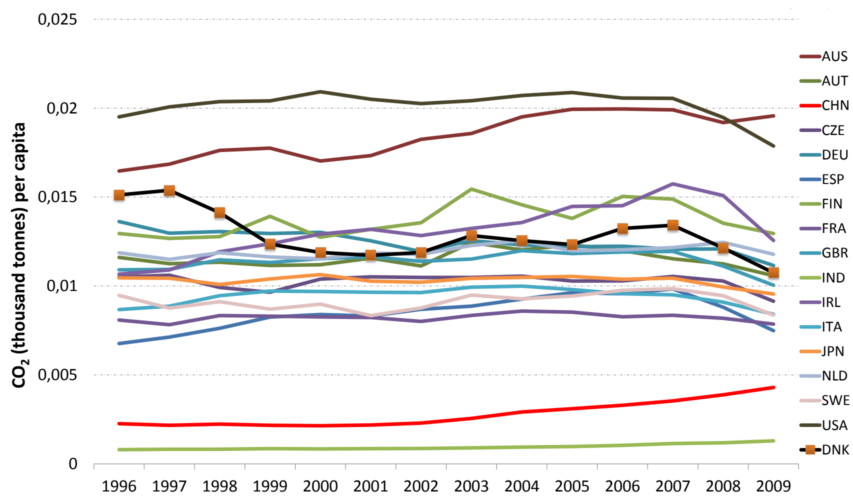

Figure 1.14: consumption-based CO_2 Emissions per capita, 1996-2009

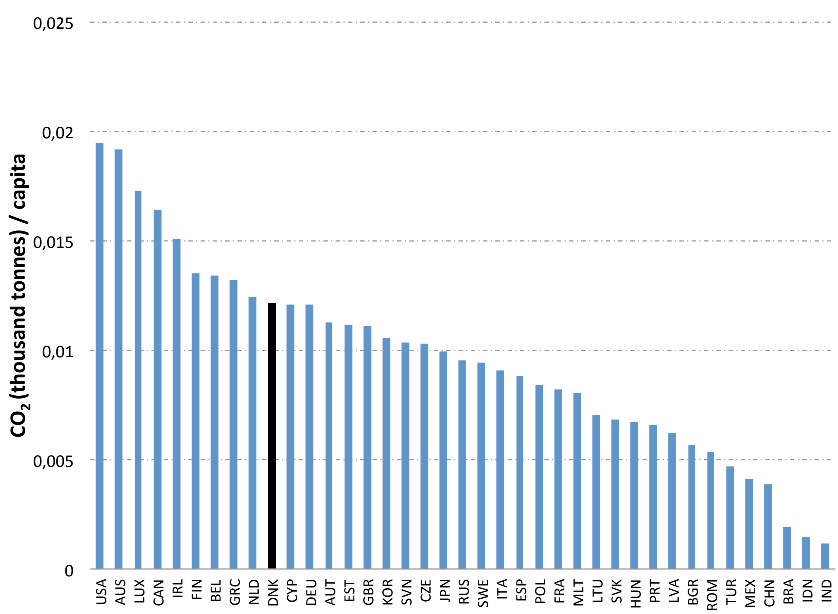

Figure 1.15: Ranking of Consumption-based CO_2 Emissions per capita, 2008

Chapter 2

Overview of Methods

2.1 Introduction

To achieve an overall understanding of how Danish economic activity, both production and consumption, affects the release of carbon into the atmosphere, we calculate Denmark's CO_2 emissions using a variety of different measures. The measures can be divided into two broad categories: production-based measures and consumption-based measures. The major computational difference between the production- and consumption-based measures is how the carbon embodied in the trade of goods and services is included in the two measures. There is also a significant conceptual difference: The two measures are distinguished by how they allocate responsibility for the emitted carbon. In the case of production emissions, responsibility for the carbon emitted into the atmosphere during the production of goods and services is assigned to producers, irrespective of where the final consumers of the goods and services are located. In contrast, the consumption measure assigns responsibility of carbon emission to final consumers, irrespective of were the goods and services were produced. In this chapter, we focus on providing an overview of the computations involved with calculating the two types of measures and in the process highlight what each measure actually measures. We do this by working through a simple 2 country, 2 sector, 2 good model of trade.

In the production-based method, Denmark's CO_2 emissions are calculated as the sum of all the carbon emissions produced by the various sectors of the economy **within** Denmark. Importantly, this method does not take into account the fact that some of the goods and services produced within Denmark are in fact consumed abroad. Neither does it include emissions produced in other countries as a result of Danish demand for foreign goods and Denmark's subsequent consumption of these goods. It is easy to see why this measure calculates the producer responsibility for the carbon emitted into the atmosphere.

The consumption measure of carbon emissions accounts for the fact that a significant amount of the production and subsequent consumption of goods and services occur in different countries (as well as in different sectors). International trade is an important characteristic of Denmark's macroeconomy. In the consumption measure of emissions, the accounting unit is the final Danish consumer and not the Danish producer. So, the emissions that are created by producing goods and services in Denmark which are then consumed abroad are not included in the consumption measure of emissions. Importantly, however, emissions created in other countries from producing goods and services which are consumed in Denmark are included in this measure. Again, it is clear that this calculation measure the consumers' responsibility for emissions.

Making this distinction is important for two reasons: First, Denmark's imports and exports differ in terms of both their value and composition; second, countries vary with regards to production processes, energy emission intensities, technologies, and environmental regulations. Moreover, in terms of thinking about policy, each of these measures have different implications. Policies aimed at reducing carbon emissions can be directed at changes at the industrial level or policies could be aimed at inducing changes in consumption patterns. In order to effectively assess the impacts of these different policies on emissions, it is necessary to calculate both producer and consumer emissions. Having both measures provides an overall picture of Denmark's carbon emissions.

2.2 $2 \times 2 \times 2$ Example

We begin our discussion of the two measures by constructing a simple $2 \times 2 \times 2$ model of trade. The trade model is a useful example illustrating how the two measures are calculated as well as highlighting the major differences between them. Begin by assuming that there are only two countries in the world (or that the two countries only trade with each other and not the rest of the world). These two countries are denoted by *Home, H* and *Foreign, F.* Each country's economy is divided into four sectors: Household, Firms, Government and the External sector. Recall from chapter 1 that the majority of a country's emissions result from industrial processes: Emissions caused by firms producing goods and services which are then consumed in other sectors of the economy. Therefore, we first concentrate on industrial emissions.

2.2.1 Industrial Emissions

Assume that each country has two industrial sectors. These sectors produce exactly one good each. The output from each sector can be used as inputs in the production of other goods or for final consumption by households, firms or government sector, in either of the two countries. We define additional variables:

- X_{ij}^{AB} = The amount of sector i's output, located in country A, that is used as an input in sector j located in country B;
- Y_i^{AB} = The amount of industry $i's$ output, located in country A, that is used for final consumption by households (C^B), firms (I^B) and the government (G^B) in country B;
- Z_i^A = The total output produced by sector i located in country A;
- e_i^A = The emissions per unit of output in the production process of sector i in country A;

- E^A_{Ip} = The total production-based industrial emissions of country A.

- E^A_{Ic} = The total consumption-based industrial emissions of country A.

Using these definitions, we define an input-output matrix for the industrial output of the world economy:

$$\begin{bmatrix} & HSector1 & HSector2 & FSector1 & FSector1 & C^H+I^H+G^H & C^F+I^F+G^F & Total \\ HSector1 & X^{HH}_{11} & X^{HH}_{12} & X^{HF}_{11} & X^{HF}_{12} & Y^{HH}_1 & Y^{HF}_1 & Z^H_1 \\ HSector2 & X^{HH}_{21} & X^{HH}_{22} & X^{HF}_{21} & X^{HF}_{22} & Y^{HH}_2 & Y^{HF}_2 & Z^H_2 \\ FSector1 & X^{FH}_{11} & X^{FH}_{12} & X^{FF}_{11} & X^{FF}_{12} & Y^{FH}_1 & Y^{FF}_1 & Z^F_1 \\ FSector2 & X^{FH}_{21} & X^{FH}_{12} & X^{FF}_{21} & X^{FF}_{22} & Y^{FH}_2 & Y^{FF}_2 & Z^F_2 \end{bmatrix} \quad (2.1)$$

The matrix 2.1 defines the flow of goods and services between the two countries and into the different sectors. For example, the second row of the matrix describes the flow of goods produced in sector 1 of the home country: X^{HH}_{11} is the amount of the good produced in sector 1 that is used again by the home country's sector 1, whereas X^{HF}_{12} is the amount of the good produced in sector 1 of the home country that is used in sector 2 of the foreign country.

Before illustrating how the data in the input-output matrix 2.1 are used to calculate measures of emissions, we first need to define two additional variables: emission factors and consumptions shares.

- e^A_i = The emission factor in sector i, located in country A;

- $a^{AB}_{ij} = \frac{X^{AB}_{ij}}{Z^A_j}$, a^{AB}_{ij} is the share of sector i's aggregate output, located in country A, that is consumed by sector j located in country B.

Next, we use these defined variables as well as the input-output table to construct production and consumption measures of emissions. We first discuss the production measure which is conceptually simpler than the consumption measure.

Production

Recall that the production measure of carbon emissions is the sum of all emissions which are produced by the various sectors of the economy within the sovereign boundaries of the country. When we focus on industrial emissions, this simply means summing up the amount of carbon that was emitted by all the industries producing goods and services. It accounts for all productive activities that take place within the borders of a country. The total production-based industrial emissions, denoted by E^H_{Ip}, for the home country in our model is

$$E_{Ip}^{H} = e_1^H Z_1^H + e_2^H Z_2^H. \tag{2.2}$$

Recall that there are only two industrial sectors in the economy, so aggregate industrial emissions is simply the sum of emissions over the two countries. In general, production-based industrial emissions is simply

$$E_{Ip}^{H} = \sum_{j=1}^{J} e_j^H Z_j^H. \tag{2.3}$$

Once we have the data Z_j^H, where j indexes all of the industries in the economy, the next step in the calculation is constructing the emission factors e_j^H's. If one has detailed data documenting all the emission producing steps of a production process for a sector, then we can calculate these emission factors. We describe our procedure for obtaining emission factors in chapter 4.

Consumption

There are two major issues with measuring emissions via production. First, the measure does not account for the fact that some of the goods and services produced in a country are consumed in foreign markets. Consequently, some of the carbon that is emitted domestically is due to foreign demand for the goods and services. For example, if we look at the input-output (I-O) table, part of the home country's total output by sector 1, Z_1^H, is in fact consumed by households, firms and the government in the foreign country, Y_1^{HF}. Of course, if we only wanted to track the emission levels of Danish producers, then there is no need to be concerned with trade. Moreover, there is good reason to be concerned with emissions levels of producers. However, using $e_1^H Z_1^H$ as a measure of sector $1's$ emissions does not measure emissions created via Danish aggregate demand. To get a complete picture of Danish carbon emissions, we need to understand the relationship between Danish consumption and emissions.

The second issue is a bit more subtle, but nevertheless important. The use of e_i^A to calculate total emissions from production ignores the role of intermediate goods in the production process. By way of an example, consider sector 1 in the home country. This sector is using inputs from the other sectors, including those produced in different countries, to produce. The problem is that these other sectors supplying the intermediate goods, which could be located in different countries, can have vastly different emission intensities, e_i^F, compared to the home country's, e_1^H. It could be the case that sector 1, in the home country, produces low levels of emissions, but uses inputs from other sectors, potentially located in other countries, which may have higher emission rates. Therefore, e_1^H may be underestimating the actual amount of emissions produced in the production of Z_1^H.

In order to see how these two drawbacks can be addressed, notice that we can use the data in the input-output table 2.1 to write the following equation:

$$\begin{bmatrix} Z_1^H \\ Z_2^H \\ Z_1^F \\ Z_2^F \end{bmatrix} = \begin{bmatrix} Y_1^{HH} + Y_1^{HF} \\ Y_2^{HH} + Y_2^{HF} \\ Y_1^{FH} + Y_1^{FF} \\ Y_2^{FH} + Y_2^{FF} \end{bmatrix} + \begin{bmatrix} a_{11}^{HH} & a_{12}^{HH} & a_{11}^{HF} & a_{12}^{HF} \\ a_{21}^{HH} & a_{22}^{HH} & a_{21}^{HF} & a_{22}^{HF} \\ a_{11}^{FF} & a_{12}^{FF} & a_{11}^{FH} & a_{12}^{FH} \\ a_{21}^{FF} & a_{22}^{FF} & a_{21}^{FH} & a_{22}^{FH} \end{bmatrix} \times \begin{bmatrix} Z_1^H \\ Z_2^H \\ Z_1^F \\ Z_2^F \end{bmatrix}. \tag{2.4}$$

Recall that $a_{ij}^{AB} = \frac{X_{ij}^{AB}}{Z_j^A}$. The matrices in equation (2.4) decompose the aggregate output of the two industrial sectors, in each country, into the part of the output that is consumed by households, firms and the government, and those that are used as intermediate goods, in each of the countries. We can simplify by rewriting equation 2.4 in matrix notation:

$$\begin{aligned} Z &= Y + A \times Z \\ \Longrightarrow Z &= (I - A)^{-1} \times \sum Y \end{aligned} \tag{2.5}$$

where I is the identity matrix. The inverse matrix $(I - A)^{-1}$ is called the Leontief inverse. Note that

$$(I - A)^{-1} = I + A + A^2 + A^3 + A^4 + \dots, \tag{2.6}$$

which implies that

$$Z = Y + Y \times A + Y \times A^2 + Y \times A^3 + Y \times A^4 + \dots. \tag{2.7}$$

The last equation decomposes total output into the total requirements for the production of the final demand Y.

Now, let us come to emissions. An important point to realize is that if we want to calculate total **world** emissions, then both the production and consumption measure are valid. Where these methods differ is in how they assign world emission to the different countries. Suppose that the vector e defines the emission rates for each industrial sector for each country:

$$e = \begin{bmatrix} e_1^H & e_2^H & e_1^F & e_2^F \end{bmatrix}. \tag{2.8}$$

Then, world emissions in our simple model are given by

$$eZ = e(I - A)^{-1} \times Y \tag{2.9}$$

or

$$eZ = eY + eY \times A + eY \times A^2 + eY \times A^3 + eY \times A^4 + \dots \tag{2.10}$$

Now, we have total world emissions decomposed into the emission requirements necessary to produce the goods and services to meet final aggregate consumption in both countries.

Notice that the term $e(I - A)^{-1}$ essentially gives a new vector of emission factors, which have now been adjusted for intermediate goods. Importantly, this addresses the second concern regarding emissions and intermediate goods described above. Given the correction necessary for the intermediate inputs, we can now calculate emissions caused by the home country's final demand. In particular, the consumption measure of emissions is:

$$E^H_{Ic_w} = e(I - A)^{-1} \times \begin{bmatrix} Y_1^{HH} \\ Y_2^{HH} \\ Y_1^{FH} \\ Y_2^{FH} \end{bmatrix} \tag{2.11}$$

where $E^H_{Ic_w}$ denotes the total consumption-based industrial emissions when data are available for the world. The above equation gives the consumption method for calculating CO_2 emissions caused by the home country's consumption of goods and services produced by sectors. This method relies on the availability of a world input-output table, which we have access to.

Additional Consumption Measures

The measure we described above relies only on the data contained in the world input-output tables. However, since we have access to detailed data on Danish firms and sectors we develop additional consumption-based measures of carbon emissions. There are at least two important reasons for developing additional measures: First, additional measures of Danish emissions provides a richer understanding of Danish economic activity and carbon emissions; second, being able to compare different measures of emissions, each relying on different data and assumptions, enhances our understanding of the relationship between data and assumptions in carbon accounting.

Of course, we do not have access to the same level of detail for other counties, so we use measures that take advantage of the full breadth of Danish data. We provide a brief overview of these methodologies using our simple example. Extensive descriptions of the various measures are provided in chapter 5.

- Method 1

Our first measure is simple to calculate but involves a rather strong assumption: The emission rates of industrial output is e_i^A which implies that any intermediate inputs used to produce the output has the same emission rate. However, this method does account for the fact that part of the output produced in a country is used for consumption (and production) in a different country. In order to calculate total industrial emissions, we use the vector of emissions e. In particular, consumption emissions are

$$E^H_{Ic_1} = \sum_{A=H,F} \sum_{i=1,2} e^A_i \sum_{j=1,2} X^{AH}_{i,j} + \sum_{A=H,F} \sum_{i=1,2} e^A_i Y^{AH}_i \tag{2.12}$$

where $E^H_{Ic_1}$ denotes the total consumption-based industrial emissions under Method 1 and where, for example, the emissions rate for sector 1, in the home country is

$$e^H_1 = \frac{\text{Total Emissions produced by sector 1, in country } H}{Z^H_1}. \tag{2.13}$$

Examining equations (2.12) and (2.13) it is easy to see the major drawback of this method (and what distinguishes it from the world I-O method and methods 2 and 3) is its reliance on e^A_i. In chapter 5, we illustrate the effect of this assumption by comparing this measure to measures which makes adjustments for emissions rates of intermediate goods.

- Method 2

In methods 2 and 3, we partially correct the emission factors e by accounting for intermediate goods in the production process.[1] The first step in the calculation is to construct a more accurate measure of emission rates for each sector by accounting for intermediate goods. The idea is to remove from aggregate emissions those emissions which were caused by the use of a sector's output as inputs in other sectors, and include those emissions from other sectors whose output was used in the production process of the sector. In method 2, we do so for only the domestic sectors. So, the adjusted emissions rates for the two sectors in the home country are

$$\bar{e}^H_1 = \frac{e^H_1 Z^H_1 - e^H_1 X^{HH}_{12} + e^H_2 X^{HH}_{21}}{Z^H_1} \tag{2.14}$$

$$\bar{e}^H_2 = \frac{e^H_2 Z^H_2 - e^H_2 X^{HH}_{21} + e^H_1 X^{HH}_{12}}{Z^H_2} \tag{2.15}$$

These per unit emission levels, $\bar{e}^H_i$, are the adjusted emission factors. Now, the task is simply to include those emissions caused by a country's consumption of goods and remove those emissions which were caused by consumption in other countries. So, consumption emissions are given by equation (2.12) which has been revised to include the corrected emission rates:

$$E^H_{Ic_2} = \sum_{A=H,F} \sum_{i=1,2} \bar{e}^A_i \sum_{j=1,2} X^{AH}_{i,j} + \sum_{A=H,F} \sum_{i=1,2} \bar{e}^A_i Y^{AH}_i, \tag{2.16}$$

[1] In the method using the world I-O tables this 'correction' is done by the use of the Leontief inverse matrix $e(I - A)^{-1}$

where $E^H_{Ic_2}$ denotes the total consumption-based industrial emissions under Method 2.

- Method 3

This method improves on method 2 by further accounting for emissions of intermediate goods which are traded across borders. In particular, the revised emissions factors are

$$\hat{e}^H_1 = \frac{e^H_1 Z^H_1 - e^H_1 X^{HH}_{12} - \sum_{j=1,2} e^H_1 X^{HF}_{1j} + e^H_2 X^{HH}_{21} + \sum_{j=1,2} e^F_j X^{FH}_{j1}}{Z^H_1} \tag{2.17}$$

$$\hat{e}^H_2 = \frac{e^H_2 Z^H_2 - e^H_2 X^{HH}_{21} - \sum_{j=1,2} e^H_2 X^{HF}_{2j} + e^H_1 X^{HH}_{12} + \sum_{j=1,2} e^F_j X^{FH}_{j2}}{Z^H_2} \tag{2.18}$$

Similar to the previous methods, we use the new emissions factors in the equation determining aggregate industrial consumption emissions:

$$E^H_{Ic_3} = \sum_{A=H,F} \sum_{i=1,2} \hat{e}^A_i \sum_{j=1,2} X^{AH}_{i,j} + \sum_{A=H,F} \sum_{i=1,2} \hat{e}^A_i Y^{AH}_i, \tag{2.19}$$

where $E^H_{Ic_3}$ denotes the total consumption-based industrial emissions under Method 3.

- Product Based Consumption Method

The emission measures calculated using equations 2.11 to 2.19 share the same principle, which is, sectors, households and governments located in different countries, use products from different sectors located in other countries, to satisfy their demand for consumption. The measures are constructed at the **sector** level. Given the extensive data available on Danish firms, we construct an additional consumption-based measure of emissions based on **product** level emissions. This method is explained in detail in chapter 5.

2.2.2 Household Emissions

Emissions from industrial activities are responsible for a large portion of aggregate emissions of an economy. However, households and government are also responsible for emissions either by directly using fossil fuels (transportation and heating, for example), which produce emissions, or consuming the output of other sectors. The direct use of fossil fuels by these sectors is not included in any of the measures for industrial emissions. We denote these direct emissions as:

- E^H_{Hk} = Household emissions were $k = p, w, c_1, c_2, c_3$;
- E^H_{Gk} = Government emissions were $k = p, w, c_1, c_2, c_3$.

2.2.3 Total Emissions

Aggregate consumption emissions in an economy are simply a sum of the emissions caused by the different sectors of the economy: households, firms and government. The external sector is accounted for by explicitly considering the imports and exports of goods and services either in the production process or in final consumption. Specifically, aggregate consumption emissions for the home country is simply

$$E^H = E^H_{Ik} + E^H_{Ck} + E^H_{Gk} \tag{2.20}$$

were $k = p, w, c_1, c_2, c_3$ index the various measures of carbon emissions. The measure E^H_{Gk} is disregarded in the following as it is equal to zero in the empirical analysis.

Chapter 3

Data

3.1 Introduction

Before moving on to our analyses of the various measures of Denmark's carbon emissions, we first provide a description of the sources of the data we used to calculate our measures of carbon emissions. One way to think about the differences between our measures of carbon emissions is by their data requirements. The measures can essentially be divided into those that depend only on the data provided in the World I-O database and those measures that also rely on access to detailed Danish data of firms and their products. We proceed with the discussion of the data along these lines by first introducing the World I-O database and then discuss the data we use from Statistics Denmark and Danish Register data.

3.2 Methods using only World I-O database

To construct measures of Denmark's consumption-based carbon emissions, we need to track the flows of goods and services across sectors and countries. Recall the importance of tracking the carbon associated with the international trade of intermediate goods described in Chapter 1. The main source of data is the World Input-Output Database (WIOD). The WIOD, which is publicly available at: *www.wiod.org/database/index.htm*, has been used by other studies to examine the effects of globalization on trade patterns (Timmer et al. (2012) and environmental burdens across a wide set of countries (Timmer et al. (2014)). The database consists of world input-output tables for each year since 1995, for 40 countries, including the EU-27 countries as well as 13 other major countries: Australia, Brazil, Canada, China, India, Indonesia, Japan, Mexico, Russia, South Korea, Taiwan, Turkey and the United States. Importantly for our study, these countries represent about 85 percent of Danish imports. Consequently, our measures can account for the carbon content in at least 85 percent Danish imports.

For each country, the WIOD, contains data for 35 industries based on the NACE rev 1 (ISIC rev 2) nomenclature. These industries include agriculture, mining, construction, utilities, 14 manufacturing industries and 17 service industries. The WIOD also reports the total output that was produced by these industries, which we denoted by Z_i^A, and the amount of output that was used in final consumption by households, industries, and governments, in each country, which we denoted by Y_i^A, expressed in millions of current USD.[1] The tables in the database were constructed by combining national input-output tables with bilateral international trade data following the conventions of the System of National Accounts. For more information about the construction of the WIOD, see Dietzenbacher et al. (2013) as well as Timmer et al. (2012).

In addition to tracking transactions across countries and sectors, the WIOD also includes an environmental database consisting of the energy and air emission accounts for each country. This inclusion is invaluable to our study since these data provide a link between economic activities and CO_2 emissions in each country. The main source of information for the energy accounts in the WIOD is the energy balances maintained by the International Energy Agency (see IEA (2011)), which consist of energy inventories using the territorial principle with technology and/or process-based classifications.

We calculated CO_2 emissions, measured in thousand tonnes, from the energy accounts provided in the WIOD. The general approach involved using activity data and technology-specific emissions factors. Data on CO_2 emission factors were obtained from the 2006 IPCC Guidelines for National Greenhouse Gas Inventories as well as from United Nations Framework Convention on Climate Change (UNFCCC) emission reporting where country-specific emission factors are also reported. From the air emission accounts we obtained information on the total emissions embedded in each sector in each country. Based on these data we calculated emissions per unit of total output, which we denoted by (e_i^A), that result from the production in sector i in country A.

3.3 Methods using detailed Danish data

3.3.1 National Accounts

We also used the data residing in the Danish National Accounts obtained directly from Statistics Denmark. The National Accounts contain Danish input-output data broken down by 117 industries based on the NACE rev. 2 (ISIC rev. 4) nomenclature. We combine these data with Danish trade data which was also available from Statistics Denmark. These data contain information concerning the value of imports and exports as well as importing/exporting countries at the 8-digit Combined Nomenclature product-level.

The Danish National Accounts also have data on CO_2 emissions broken down by 117 industries. Similar to the WIOD data, CO_2 emissions in the National Accounts, were calculated by multiplying energy consumption by a technical coefficient that reflects the content of CO_2 per unit of GJ energy consumption. The

[1] The WIOD is available only in current prices. However, since we are calculating a physical quantity, emissions, it does not matter whether we use current or fixed prices: $E_{current} = \frac{E}{Z_{current}} \times Z_{current} = \frac{E}{\frac{Z_{current}}{deflator}} \times \frac{Z_{current}}{deflator} = \frac{E}{Z_{fixed}} \times Z_{fixed} = E_{fixed}$

information on energy consumption comes from Statistics Denmark's energy balances, while the information on emission factors comes from the Danish CORINAIR Database, which is operated by the Danish National Environmental Research Institute (NERI). Additional details are provided by Statistics Denmark (2013). Importantly, we link the Danish industrial data to the international industrial WIOD data by applying the official correspondence tables between the various revisions of the NACE nomenclature (see Eurostat (2013)).

3.3.2 Firm-level data

In addition to the industrial emissions data obtained from the Danish National Accounts, we also have access to firm-level survey data consisting of information on energy consumption and production of goods for the majority of Danish firms in manufacturing industries. We use these data to re-weight the total industrial emissions embedded in imports and exports of goods in order to account for intra-industry variation in emissions, a procedure that we discuss in chapter 5. From the Industrial Commodities Statistics, we have access to information on sales of goods at the 8-digit CN goods-level measured in volume as well as value for all manufacturing firms having at least 10 employees (roughly 93 percent of the total turnover in the manufacturing industries) (Statistics Denmark, 2013). Using unique firm identifiers we linked these data to the Consumption of Energy by Industry, which is a biannual compulsory survey that covers all manufacturing firms having at least 20 employees (approximately 90 percent of the energy consumption by the manufacturing industries) for the years 1996, 1997, 1999, 2001, 2003, 2005, 2007, and 2009. The survey forms part of the energy balances that is used in the National Accounts and are often carried out in cooperation with the Danish Energy Authority, which also uses the results in its statistics. The survey contains information on energy consumption of more or less all energy sources measured in GJ.

From these data we were able to construct a measure of the $\mathrm{CO_2}$ emissions that result from the production of a specific good within a given manufacturing firm. This is done in a number of steps. First, for each firm we allocated total energy consumption of each energy source to each produced good according to the particular good's share of the firm's total output. In order to convert electricity and central heating used to GJ, we used generator level data to calculate the percentage contribution of different fuel types in the production of electricity and central heating. Second, we sum across all energy sources to arrive at a total energy consumption per good. Third, for goods that were produced by multiple firms, we average the energy use across all firms producing the same good. The final step is to convert the total energy consumption into total CO_2 emissions using emission factors similar to the approach taken in the National Accounts. We divided the total CO_2 emissions per good by the total value of that good in order to construct a measure of the per unit emission.

3.3.3 Goods-to-sector linkage

This section describes in detail the goods-to-industries linkage. In order to map the CN goods' codes into National Accounts industries the following crosswalks were applied (see figure 3.1): Starting from the 8-

digit CN goods' codes we remove the last two digits to construct Harmonized System (HS) goods' codes. The HS has undergone three major revisions in the classification of goods over the period of study, which happened in 1996, 2002, and 2007. Using official conversion tables from the United Nations (UN), we convert the HS 1996 and HS 2002 codes into HS 2007 codes UN (2013). Third, we link the HS 2007 codes to the Central Product Classification (CPC) ver. 2 using conversion tables from the UN. Fourth, we link the CPC product codes to the International Standard Industrial Classification (ISIC) rev. 4 (NACE rev. 2) using conversion tables from the UN. As the fourth step, we link the NACE rev.2 to the 117 National Accounts industries using conversion tables obtained from Statistics Denmark. This procedure yielded a few non-unique mappings. Of approximately 5,300 HS goods codes, 209 year 2007 codes (4%) were mapped to multiple National Accounts industries. Likewise, 68 year 2002 codes (1%) and 93 year 1996 codes (2%) were mapped to multiple industries. These codes comprised, for example, different sorts of agricultural products. Furthermore, 102 codes (2%) were not mapped to a sector due to a missing linkage between the CPC and the ISIC. These codes primarily comprised different sorts of waste and scrap from the manufacturing industries. We manually assign industries to goods that either had missing sector linkage or were mapped to multiple industries.

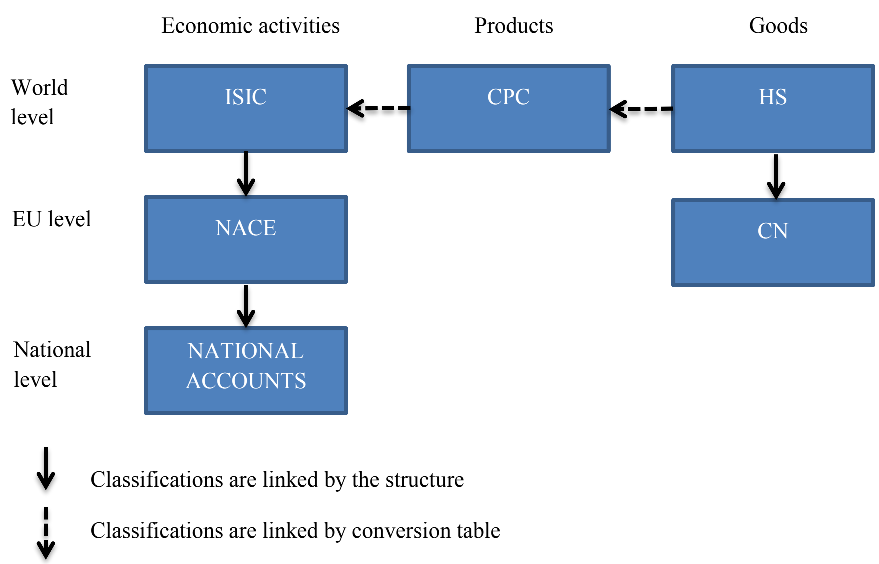

Figure 3.1: International systems of classifications

Chapter 4

Production Emissions

4.1 Production Measure of CO_2

The production based method for calculating carbon emissions is the most widely used measure of carbon emissions. Simply, the production measure is calculated by aggregating total emissions produced by the different sectors of the economy irrespective of their final use. For Denmark, production emissions were calculated using data obtained from the Energy Accounts published by Statistics Denmark. At the most detailed level, the Energy Accounts consist of 40 different fuel types and 117 industries, classified in accordance with DB07 (Danish Industrial Classification of All Economic Activities, 2007). Using these data, Denmark's industrial emissions, denoted by E_{Ip}^{DK} were calculated using

$$E_{Ip}^{DK} = \sum_{j=1}^{117} e_j^{DK} Z_j^{DK} \tag{4.1}$$

where e_j^{DK} is the amount of CO_2 emitted into the atmosphere from producing one unit of a good in industry j and Z_j^{DK} is the total amount of output produced by industry j in Denmark.[1] So, $e_j^{DK} Z_j^{DK}$ is the total emissions produced by industry j. From equation (4.1), it is clear that the main step in calculating the production measure of emissions is to calculate emission rates for each of the 117 industries. That is, we need to calculate e_j^{DK}.

To calculate CO_2 emission rates, we use data on fuel usage obtained from the Danish Energy Accounts as well as use the emission factors for a variety of different fuels which we obtained from the Danish National Environmental Research Institute. The emission factors for each fuel is the amount of pollutant that is emitted into the atmosphere when the specific fuel is used. Emission factors vary across industries (to some extent), fuel-type, and year. The Emission Accounts consist of 117 industries and 40 different types of fuel.

[1] We can also carry out the exercise in monetary terms, which is what we have done to be consistent with the data provided in the WIOD.

Multiplying each industry's fuel usage by the fuel's corresponding emission factor and them summing up over fuels gives each industry's aggregate emissions. Specifically, let F_{ij} be the total amount of fuel i used in industry j (reported in GJ) and denote the emission factor associated with fuel type i used in industry j by t_{ij}. Then the total amount of carbon, resulting from burning fuel i in industry j, emitted into the atmosphere is

$$E_{ij} = F_{ij} \times t_{ij} \tag{4.2}$$

where $i = 1, \ldots, 40$ types of fuels and $j = 1 \ldots 117$ industries. So, E_{ij} is the total amount of carbon emitted by each industry in a given year. Therefore, aggregate emissions for each industry is simply the sum across the different fuel types:

$$e_j^{DK} Z_j^{DK} = \sum_{i=1}^{40} E_{ij}. \tag{4.3}$$

Then, total industrial emissions is the sum over all industrial sectors:

$$E_{Ip}^{DK} = \sum_{j=1}^{117} \sum_{i=1}^{40} E_{ij}. \tag{4.4}$$

Aggregate emissions are then the sum of household and industrial emissions:

$$E_p^{DK} = E_{Ip}^{DK} + E_{Hp}^{DK} \tag{4.5}$$

were E_{Hp}^{DK} are household emissions. Note that we also calculated emissions associated with bunker fuel used in international shipping by ships and planes. However, these emissions are not included in the carbon accounting framework established by the Kyoto Protocol. The results are provided in the appendix.

In table 4.1, we report the amount of CO_2 emitted by Danish industry. There was a steady decline in aggregate emissions between 1996 and 2000. Interestingly, there was not much of a trend post 2000. There were, however, annual fluctuations in emissions with emissions falling to less the 60 million tonnes in 2005 and 2009, but there were also years were emissions surpassed 68 million tonnes. Comparing emissions at the start and end of the series, we find that CO_2 emissions have gone from close to 69 million tonnes in 1996 to 50 million tonnes in 2008, a reduction of almost 28 percent. We also report household emissions in table 4.1. These include emissions directly relating to petrol and diesel for road transport and fuel for heating and cooking etc., but do not include indirect emissions in industries in order to meet household demands. The industries have contributed about 80 percent of all Danish CO_2 emissions, with households making up the remaining 20 percent. The interesting feature of household emissions is that not much of a trend exists. There has not been much change in CO_2 emissions between 1996 and 2009. Emissions are also presented in figure 4.2.

The large annual fluctuations in carbon emissions was due to annual variation in electricity generation.

Table 4.1: Emissions

Year	Industrial (E_{Ip}^{DK})	Household (E_{Hp}^{DK})
1996	68961	12668
1997	60675	12842
1998	56510	12323
1999	53921	12055
2000	49310	11544
2001	51347	11810
2002	50143	12119
2003	55314	12455
2004	50221	12413
2005	47950	12683
2006	56117	12664
2007	52429	13081
2008	49683	12415
2009	47878	12011

[a] CO_2 is measured in 1000 tonnes.

In figure 4.1, we report the emissions for the 4 largest contributing sectors together with industrial emissions. Clearly, electricity generation was the largest emitter of carbon. The amount of carbon contributed by the electricity sector varied annually ranging from around 45 percent to almost 70 percent when generation levels were relatively high. Importantly, there is a strong positive correlation in electricity generation levels and carbon emissions. Of course, this is why policies aimed at reducing carbon emissions have primarily focused on the energy sector.

4.2 Production Emissions

Production emissions (not including fuel bunkering) are reported in figure 4.2. More precisely, the values of E_p^{DK} are reported in the figure. The measures reported do not include emissions from fuel bunkering because we wanted to illustrate trends in industrial and household emissions as well as be consistent with international reporting standards and the Kyoto Agreement. Of course, given that households emit a much smaller amount of carbon compared to industry, aggregate emissions closely tracks industrial emissions. There was a decline in emissions between 1996 and 2000. However, after 2000, there was no clear trend: Emissions fluctuated between 60 million tonnes and 70 million tonnes. Although, emissions in 2009 were the

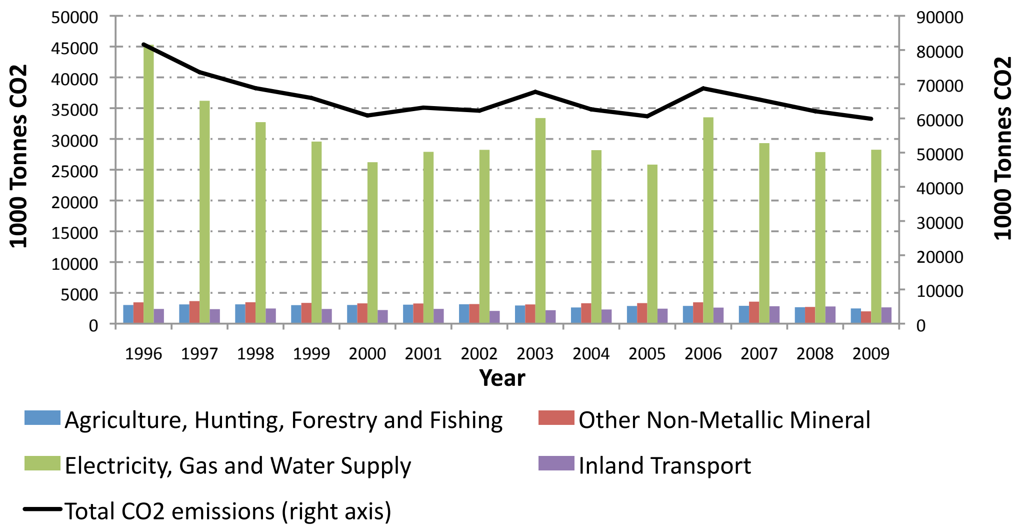

Figure 4.1: Emissions by Sector, 1996-2009

lowest among the 14 years we studied, which coincides with a low electricity production that year in part due to the economic downturn.

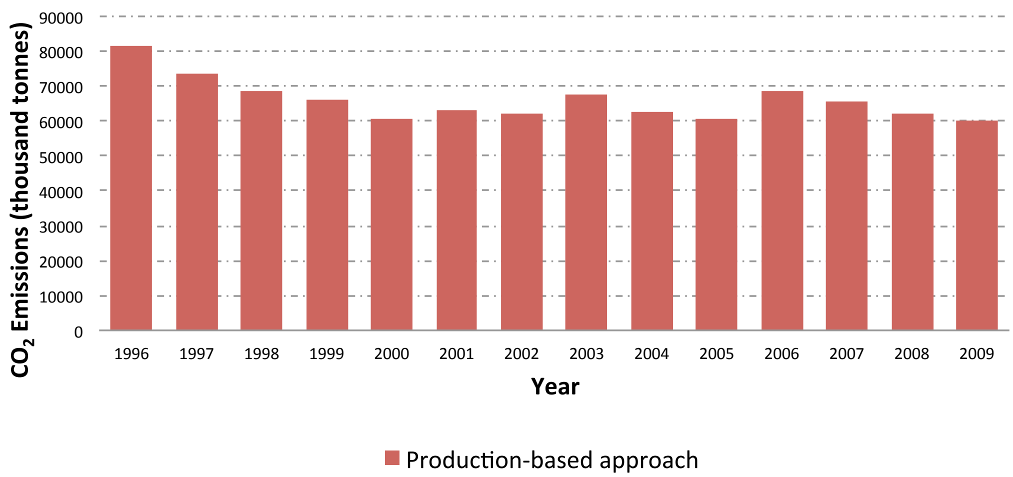

Figure 4.2: Danish CO_2 Production Emissions (E_p^{DK}), 1996-2009

Chapter 5

Consumption Emissions

5.1 Introduction

In this chapter, we construct and report various measures of emissions based on consumption rather than production. We describe each measure and then compare them to the production emissions that we calculated in the previous chapter. We also discuss the differences between the various consumption measures. Each method produces different results which is informative because we get an idea of how different assumptions or types of data used to construct measures can affect results.

We organized our consumption-based measures of emissions into three sections based on the data and corresponding assumptions we used to calculate them. The first section details consumption emissions calculated using only data in the world-IO tables, whereas the second group contains three measures that were calculated using Danish industry data. The final section reports consumption emissions calculated using Danish product-level data.

Note that the results presented in chapter 1 are the consumption emissions calculated using the world-IO tables. We focused on these particular results because the calculations can be replicated for many other countries allowing for cross-country comparisons. In particular, using the world-IO tables enables fairly accurate accounting of emissions embodied in the international trade across 40 countries in a consistent manner. We show in the subsequent sections in this chapter that accounting for emissions embodied in international trade is important.

5.2 Consumption Emissions: World I-O Tables

The world-IO tables contain data for 35 sectors across 40 countries. Using these data, we calculated emissions using a generalized version of equation 2.11. In particular, industrial consumption emissions are

$$E_{Iw}^{DK} = e(I - A)^{-1} \times \begin{bmatrix} Y_1^{DK-DK} \\ \vdots \\ Y_{35}^{DK-DK} \\ Y_1^{1-DK} \\ \vdots \\ Y_{35}^{1-DK} \\ \vdots \\ Y_1^{39-DK} \\ \vdots \\ Y_{35}^{39-DK} \end{bmatrix}, \tag{5.1}$$

recalling that e is a (1×1400) row vector of emissions factors for each of the 35 industries in each of the 40 countries,

$$e = \begin{bmatrix} e_1^{DK} & \dots & e_{35}^{DK} & e_1^1 & \dots & e_{35}^1 & \dots & e_1^{39} & \dots & e_{35}^{39} \end{bmatrix}, \tag{5.2}$$

and A is a 1400×1400 square matrix in which each element, a_{ij}^{AB}, is the share of sector i's aggregate output, located in country A, that is consumed in sector j, located in country B. Note that the numbers 1 to 39 index the 39 other countries besides Denmark. Aggregate emissions are then

$$E_w^{DK} = E_{Iw}^{DK} + E_{Hw}^{DK}. \tag{5.3}$$

Consumption emissions, E_w^{DK}, are reported in figure 5.1. We also report production emissions, E_p^{DK} in the same figure for comparison purposes. Consumption and production emissions were positively correlated in terms of annual fluctuations: Both measures tended to move in the same direction. However, consumption emissions were larger than production emissions and the discrepancy between the two generally got larger over time. The emissions are also reported in table 5.1 below.

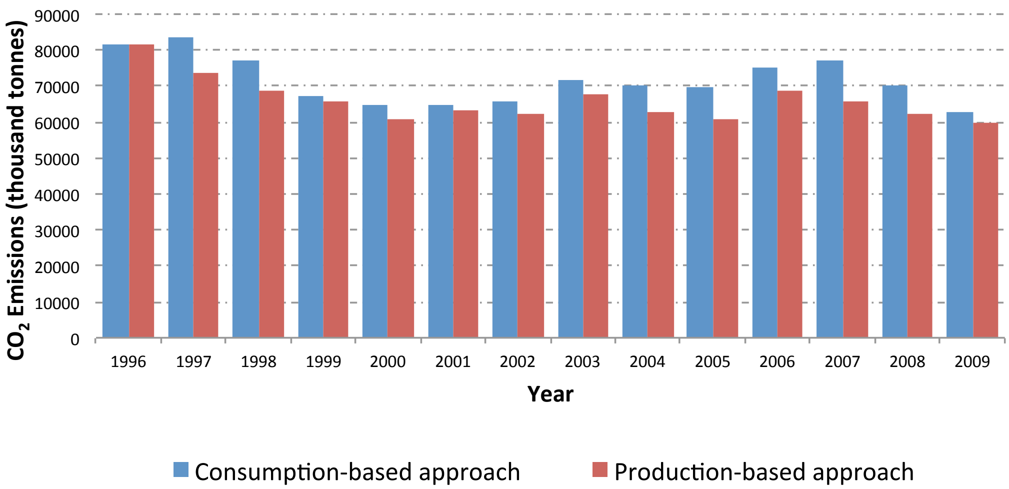

Figure 5.1: Danish CO_2 Emissions, E_w^{DK} and E_p^{DK}, 1996-2009

5.3 Consumption Emissions: Danish Industry Data

In this section we report three different consumption-based measures of emissions. Each differ according to the detail of the data used to calculate the measure as well as the complexity of the measure. These measures were calculated using Danish industry data. Since we want to fully utilize all the information in the data (Danish industry data is more detailed than the world I-O tables), we could not use equation 5.1 to calculate emissions. In particular, the Danish I-O tables consist of 117 sectors, whereas the world-IO tables consist of only 35 sectors.

Since we did not use equation 5.1 to calculate emissions, the Leontief inverse could not be used to adjust emission factors. Therefore, we used alternative adjustments instead. The three measure differ in how we measure the emissions embodied in the international trade of intermediate goods. The first method simply assumes that intermediate goods have the same emissions factors irrespective of where they were produced. The second and third measure use emission factors that vary across intermediate goods.

5.3.1 Method 1, $E_{c_1}^{DK}$

In the first measure, we are only concerned with the emissions embodied in imports without correcting for trade in intermediate goods. In particular, this method does not account for the fact that a sector that produces a certain amount of emissions, within a country, might actually have different emission factors, since the sector might be importing some of its intermediate goods. One reason why this measure is interesting is because it provides some indication of the degree that measures of emissions can be distorted when emission factors are not adjusted to account for international trade in intermediate goods.

Recall the information contained in input-output tables by referring back to table 2.1. However, now we are dealing with 117 Danish industries and 39 other countries. So, emissions are

$$E_{Ic_1}^{DK} = \sum_{i=1}^{117} e_i^{DK} \left(\sum_{j=1}^{117} X_{ij}^{DK-DK} + Y_i^{DK-DK} \right) + \sum_{A=1}^{39} \sum_{i=1}^{35} e_i^A \left(\sum_{j=1}^{117} X_{ij}^{A-DK} + Y_i^{A-DK} \right). \qquad (5.4)$$

The first term consists of emissions produced by consuming Danish produced goods and services including intermediate goods. The second term is a bit more complicated. The sum inside the parentheses aggregates foreign produced intermediate goods consumed in Denmark and final consumption of foreign produced final goods. This sum is multiplied by the emission factor indexed by country and sector. So, the last term measures the carbon embodied in imports. Here we can see how important it is to accurately measure emission factors, e_i^A (see equation 5.5 and the corresponding discussion).

Unfortunately, the Danish Input-Output tables do not contain information about the origin of the imports. Therefore, for each country we constructed its shares of imports, in each sector, using international trade data obtained from Statistics Denmark (StatBank Denmark, 2013). These data contain information about the value of imports and exports at the goods level in current basic prices as well as information about importing/exporting countries.

The last issue to resolve in order to calculate emissions was to construct an estimate of the emission factors, e_i^A. The emission factors used in equation (5.4) were calculated using

$$e_i^A = \frac{\text{Total Emissions produced by sector } i\text{, in country } A}{Z_i^A}. \qquad (5.5)$$

Here we can see that this measure does not account for trade in intermediate goods or equivalently, imported intermediate goods used in the production of final goods have the same emissions rates as the sector that imported them. Again, the main drawback of this measure is its use of the unadjusted emissions factors for each sector. Consequently, this measure suffers from the same criticism levied against the production measure of emissions. Specifically, industries' actual emissions must incorporate their use of "dirty" or "clean" intermediate goods. That is, the emission factors of imported intermediate goods are likely to be different from the emission factors of the sector importing the goods.

Total emissions are

$$E_{c_1}^{DK} = E_{Ic_1}^{DK} + E_{Hc_1}^{DK}. \qquad (5.6)$$

Consumption emissions calculated via this method are reported in figure 5.3. This measure produced emissions levels that are more similar to our production measure. This should not be surprising given that both measures suffer form the same omission. However, the consumption emissions were still consistently higher than production emissions. Consumption emissions measured using method 1, $E_{c_1}^{DK}$, were smaller than the emissions measured using the world-IO tables, E_w^{DK}, which accounted for differences in emission rates for traded intermediate goods (we discuss this comparison in more detail in section 5.3.4).

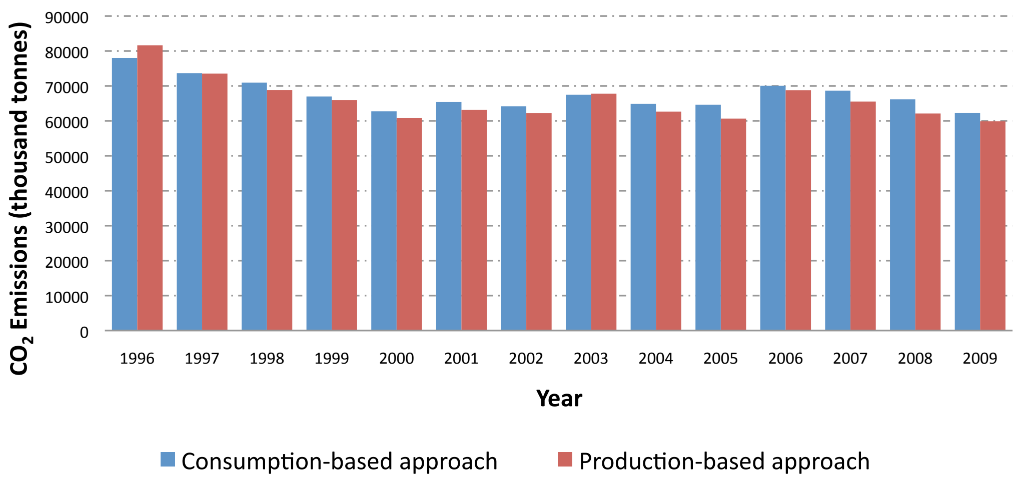

Figure 5.2: Danish CO_2 Emissions (Method 1), $E_{c_1}^{DK}$ and E_p^{DK}, 1996-2009

5.3.2 Method 2, $E_{c_2}^{DK}$

In order to address the main drawback of method 1, methods 2 and 3 try to adjust emission factors by taking emissions of intermediate goods into account. Method 2 does so by accounting for intermediate goods used in Danish sectors. The advantage of first focusing specifically on domestic industries in the calculation of new emission factors is that we can use more detailed data that is available for Danish industrial sectors. A second benefit is that the measure provides yet another comparison in which we can evaluate measures of carbon under different data constraints and assumptions. Specifically, this measure is calculated under the assumption that the emissions from imports are measured as if they were produced in Denmark (this was an important assumption made in Gravgard et al. (2009)). However, we relax this assumption by scaling Danish emission factors by sector and country emission ratios.

The idea of the revised emission rates is to remove from sector i's aggregate emissions, those emissions produced by the use of the sector i's good in another sector, and include the emissions of the intermediate goods produced in other industries and countries in sector i's emissions. Importantly, we use sector specific emissions when including the intermediate goods from other industries (refer back to our example in chapter 2, specifically equations in (2.14)). The new emissions factors, denoted by $\bar{e}_i^A$, are

$$\bar{e}_i^{DK} = \frac{e_i^{DK} Z_i^{DK} - e_i^{DK} \sum_{j \neq i} X_{ij}^{DK-DK} + \sum_{j \neq i} e_j^{DK} X_{ji}^{DK-DK}}{Z_i^{DK-DK}} \tag{5.7}$$

were i and j index the 117 Danish sectors. Therefore, we have calculated 117 emissions rates. The key part of the new emissions factors is the term $\sum_{j \neq i} e_j^{DK} X_{ji}^{DK-DK}$ which shows that we are using the emission rates from sector j to calculate sector i's emission rates when sector i uses sector j's outputs as inputs (intermediate goods). Note also that the equation explicitly illustrates the main assumption with this measure: The sector specific emission rates have DK superscripts indicating that we had to use Danish emission rates because of a lack of international data on all 117 sectors that are available in the Danish data (this is the assumption made in Gravgard et al. (2009)). In order to use all the information on the 117 sectors in the Danish data as well as trade data and relax the assumption that imports have the same emission factors as domestic sectors, we adjusted the emission factors for the 39 foreign countries and denoted these by $\tilde{e}_i^A$. In particular,

$$\tilde{e}_i^A = \bar{e}_i^A \times (s_i^A r_i^A). \tag{5.8}$$

where

- s_i^A = share of imports from sector i that comes from country A;
- r_i^A = emissions per unit output in sector i in country A relative to emissions per unit output in sector i in Denmark. We call these "emission ratios".

Using these revised emission factors, emissions are:

$$E_{Ic_2}^{DK} = \sum_{i=1}^{117} \bar{e}_i^{DK} \left(\sum_{j=1}^{117} X_{ij}^{DK-DK} + Y_i^{DK-DK} \right) + \sum_{A=1}^{39} \sum_{i=1}^{35} \tilde{e}_i^A \left(\sum_{j=1}^{117} X_{ij}^{A-DK} + Y_i^{A-DK} \right) \tag{5.9}$$

The first term in the above equation is the emissions from domestic production of goods and services in Denmark caused by Danish demand for these. The second term is the emissions embodied in imports from other countries.

Because the assumption that intermediate inputs imported into Denmark have the same emission factors is too constraining, we scaled the emissions factors $\bar{e}_i^{DK}$ to take into account relative differences in emissions rates. If we did not scale the emission factors then the total imports (term inside the first parentheses) times Danish emission factor $\bar{e}^{DK}$, measures emissions from imports as if they were produced in Denmark:

$$E_i^{A-DK} = \left(\sum_{j=1}^{117} X_{ij}^{A-DK} + Y_i^{A-DK} \right) \bar{e}_i^{DK} \tag{5.10}$$

where E_i^{A-DK} are the emissions caused by Denmark in country A's sector i (see Gravgard et al. (2009)). Total emissions are

$$E_{c_2}^{DK} = E_{Ic_2}^{DK} + E_{Hc_2}^{DK}. \tag{5.11}$$

Consumption emissions computed using this method are reported in figure 5.3. Once again, consumption emissions are consistently larger the than production emissions and the difference tended to get larger over the period. This result should not come as too much of a surprise since, in this method, we adjusted emission factors, to a degree, by accounting for intermediate goods. In addition, it is interesting to note that

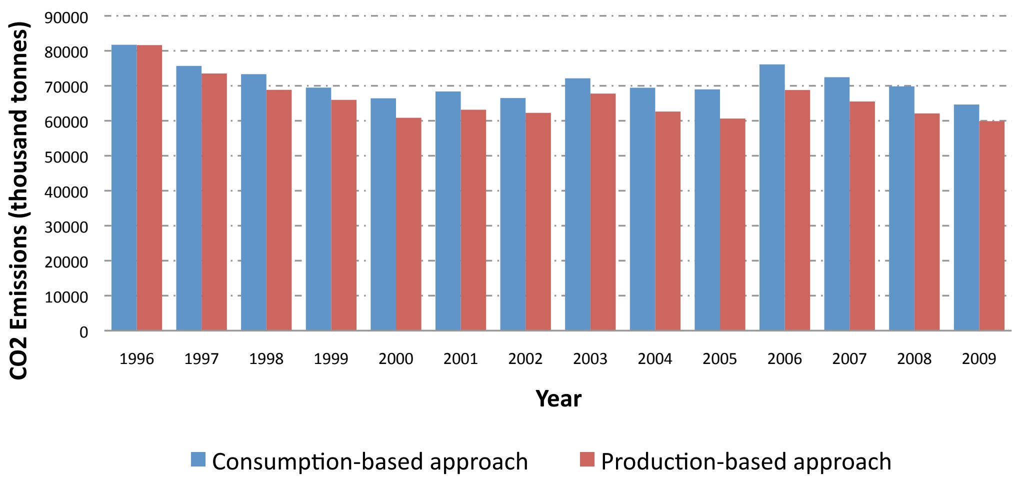

Figure 5.3: Danish CO_2 Emissions (Method 2), $E_{c_2}^{DK}$ and E_p^{DK}, 1996-2009

consumption emissions computed via method 2 are greater than those computed using method 1. Again, not surprising given method 2 includes trade in intermediate goods. We report the value of the measure in table 5.1 below.

5.3.3 Method 3, $E_{c_3}^{DK}$

Method 2 is an improvement on method 1, in terms of providing a more accurate picture of emissions caused by Denmark, by accounting for the intermediate goods effect on emission factors. Method 3 takes this adjustment further by accounting for changes in emission factors due to intermediate goods coming from foreign countries and used in Danish production. Specifically, the emission factors used to calculate consumption emissions are

$$\hat{e}_i^A = \frac{e_i^A Z_i^A - \sum_{j=1}^{35} e_i^A X_{ij}^{AA} - e_i^A \sum_{B=1}^{39} \sum_{j=i}^{35} X_{ij}^{AB} + \sum_{j=i}^{35} e_j^A X_{ji}^{AA} + \sum_{B=1}^{39} \sum_{j=1}^{35} e_j^B X_{ji}^{BA}}{Z_i^A} \tag{5.12}$$

In particular, we calculated new emission factors for 35 sectors in 40 countries, including Denmark (1400 emission factors). The main difference between these emission factors and those calculated in equation (5.7) is the term

$$\sum_{B=1}^{39} \sum_{j=1}^{35} e_j^B X_{ji}^{BA} \tag{5.13}$$

in the numerator. The term shows that rather than using the emissions factors for the sector in the destination country (Denmark), we used the emission factors for the sector in the exporting country. Therefore, we are no longer assuming that imported intermediate goods have the (scaled) emission factors as if they were

Figure 5.4: Danish CO_2 Emissions (Method 3), $E_{c_3}^{DK}$ and E_p^{DK}, 1996-2009

produced in Denmark.

Using these new emission factors, industrial sector emissions are once again

$$E_{Ic_3}^{DK} = \sum_{i=1}^{35} \hat{e}_i^{DK} \left(\sum_{j=1}^{117} X_{ij}^{DK-DK} + Y_i^{DK-DK} \right) + \sum_{A=1}^{39} \sum_{i=1}^{35} \hat{e}_i^{A} \left(\sum_{j=1}^{117} X_{ij}^{A-DK} + Y_i^{A-DK} \right). \tag{5.14}$$

Notice that the sector index only runs to 35 and not 117. This is because we are restricted to the 35 sectors used in the world tables because we are using country and sector specific emission factors. Total emissions are

$$E_{c_3}^{DK} = E_{Ic_3}^{DK} + E_{Hc_3}^{DK}. \tag{5.15}$$

We report the results of this measure in figure 5.4. Once again, we see that consumption emissions are higher than production emissions, but the two measures are positively correlated. Moreover, similar to previous results, the difference between the two measures grew overtime. We report the value of the measure in table 5.1 below.

The difference between the production-based and consumption-based measures is the net amount of CO_2 emissions embodied in international trade. Specifically, the difference equals emissions embodied in exports of goods and services less emissions embodied in imports of goods and services. A positive difference indicates a net export of emissions, whereas a negative difference indicates a net import of emissions. In figure 5.5, we report CO_2 emissions embodied in Danish imports and exports of goods and services. Clearly, Denmark has been a net importer of carbon emissions since 1997. The size of CO_2 emissions embodied in gross flows of imports and exports were significant, both in relative terms and in absolute terms. In relative terms, CO_2 emissions embodied in imports were over 20 percent of production. Therefore, relatively small changes in

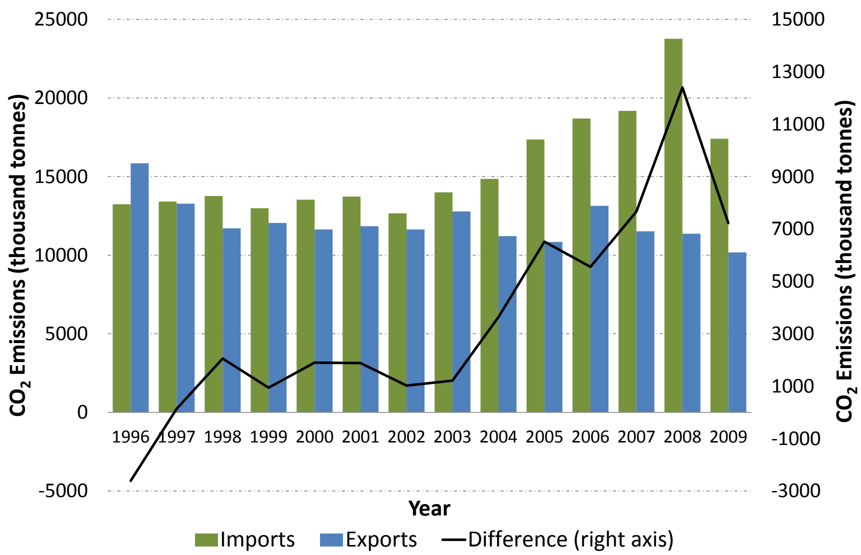

Figure 5.5: CO_2 Emissions Embodied in Danish Imports and Exports, 1996-2009

competitive conditions or relative prices could cause significant changes to net CO_2 balances. In absolute terms, the CO_2 emissions in Danish imports have risen from around 13 Mt in 1996 to 17 Mt in 2009, an increase of over 30 percent. Emission levels peaked in 2008 at 24 Mt, an increase of nearly 80 percent over the emission level in 1996. In general, there has been an upward trend in the amount of CO_2 emissions in imports since 2002, primarily due to more imports coming from emission-intensive emerging markets. At the same time, CO_2 emissions embodied in exports have decreased over time, reflecting in part the relatively low emission-intensity of electricity generation in Denmark. From 1996 to 2009, emissions embodied in Danish exports declined from nearly 16 Mt to 10 Mt, a decrease of 38 percent. Only in 1996, were CO_2 emissions embodied in exports higher than that of imports.

Because the flow of international emissions via trade in goods and services is substantial, production-based accounting measures may overstate the success of environmental policies in Denmark aimed at reducing global CO_2. However, the fact that net imports of CO_2 emissions were increasing is not at odds with the fact that aggregate CO_2 emissions in Denmark declined over the same period. Aggregate CO_2 emissions are composed of emissions from Danish consumption of goods and services produced domestically as well as abroad. The reason that total CO_2 emissions were declining over this period was that emissions produced by domestic sectors were in fact falling.

5.3.4 Comparing Consumption Emissions

We summaries the four measure in figure 5.6 as well as report the computed emissions in table 5.1. Emissions computed using method 1 were consistently lower relative to the other three measures. Recall that in method

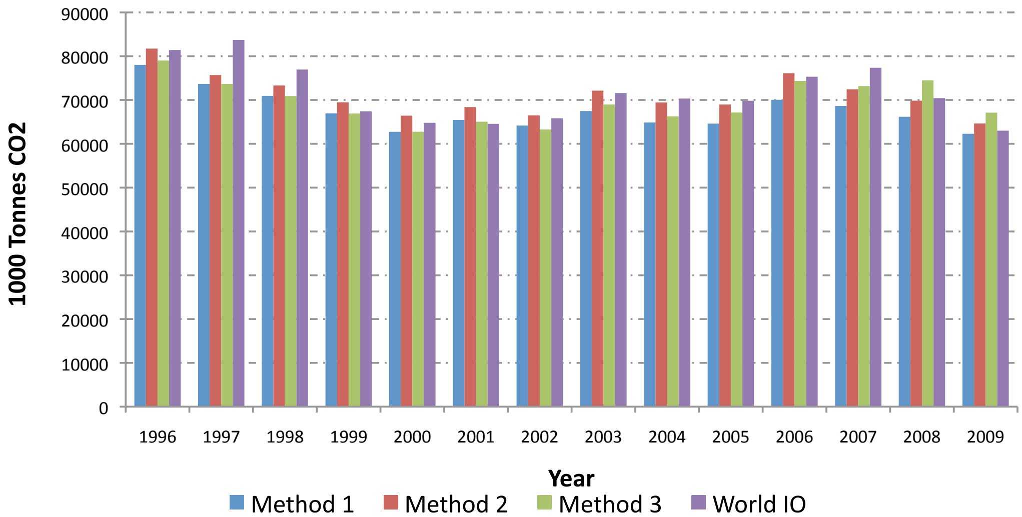

Figure 5.6: Consumptions Emissions, 1996-2009

1, the emission factors were computed by simply dividing the total emissions produced by a sector by the total output of that sector. Therefore, the measure does not account for the emissions produced by intermediate goods. The fact that this measure is consistently lower than the others suggests that intermediate goods are an important source of carbon and should not be omitted from carbon measures. In addition, the difference between the emissions computed using method 1 and the others grew after 2002. This suggests that sectors in Denmark started to import more emission intensive intermediate goods in 2002, and significantly, the first measure did not pick this up.

Method 2 and 3 correct for the omission of intermediate goods. The two measures differ in how the emission factors were adjusted to account for carbon emissions embodied in intermediate goods. Method 2 only accounts for domestic intermediate goods, whereas method 3 accounts for international trade in intermediate goods. The results presented in figure 5.6 show that emissions calculated via method 2 were generally higher than those calculated via method 3 between 1996-2006 and lower post 2007. This may imply that the use of foreign intermediate goods has increased in more recent times and/or the mix of exporting countries has changed such that a higher proportion of intermediate goods were being imported from emission intensive countries.

The reason for developing and implementing four different methodologies of measuring consumption-based emissions was for robustness as well as for assessing the role played by international trade, not just for Denmark, but also for other countries contributing to Denmark's consumption emissions. One way to interpret our measures is that each method adds additional "rounds" by which carbon can travel across borders. Method 1 only accounts for the "first round". That is, the measure only accounts for imports

Table 5.1: Comparison between consumption method methodologies

Year	$E_{c_1}^{DK}$	$E_{c_2}^{DK}$	$E_{c_3}^{DK}$	E_{w}^{DK}
1996	78008	81734	79019	81401
1997	73664	75685	73655	83693
1998	70931	73323	70897	76960
1999	66960	69483	66917	67430
2000	62735	66423	62751	64791
2001	65433	68378	65043	64552
2002	64168	66499	63284	65836
2003	67471	72138	68983	71582
2004	64877	69444	66276	70336
2005	64609	68978	67150	69821
2006	70040	76121	74337	75303
2007	68628	72450	73171	77342
2008	66167	69842	74497	70425
2009	62286	64640	67116	63001

[a] Measured in 1000 tonnes CO2.

and exports and different emission levels across countries. Significantly, the measure does not account for the fact, for example, that even though Denmark might be importing goods from sector 1 in country A, that sector might in turn be producing those goods using goods from other sectors within country A or even sectors in other countries. Our comparisons suggest that carbon measures based on method 1 will underreport emissions levels.

Method 2 accounts for sectors within a country using inputs from other sectors within the same country. Method 3 accounts for sectors within a country using inputs from sectors in other countries as well. In general, these measures are better than Method 1; however, these methods still miss the next level of rounds in the following sense. Suppose Denmark imports cars from Germany which uses inputs from other German industries as well as industries in China. Methods 2 and 3 account for these trades. Suppose, that some of the industries in China actually use some inputs from German industries. This is not accounted for in any of the three methods. The method which uses the world I-O tables accounts for all “rounds”. The difference between method 2 and 3 which uses detailed Danish data and the method using world IO tables is roughly 2 to 3 percent.

5.4 Consumption Emissions: Danish Product Level Data

While the input-output analysis can be used to compute estimates of emissions in a robust way by taking into account all higher order impacts, the analysis is not assumption free. In particular, it assumes homogeneity of prices, outputs and CO_2 emissions within a sector. Therefore, in addition to the aforementioned and explained methodologies comparing consumption measures that differ on how they treat intermediate goods, we also carry out a product level study to investigate intra-sector variation in emissions. To do this, we make use of the Danish register data set VARS, in which firms are registered with a unique CVR-number, as well as information on the products the firms produce (identified by product codes) as well as the volume and the value (revenue) of each product. We linked these register and product data to the survey data "Industrial Energy". These survey data contain information on manufacturing firms' energy consumption, for alternating years, between 1995-2009. Energy consumption reported in the survey is subdivided into electricity (reported in GJ and DKK), heat, LPG, natural gas, city gas, biogas, among others. The energy consumption reported for each fuel in the survey data can be linked to the emission factors for each pollutant obtained from the Danish National Environmental Research Institute. These rich data allows us to determine the extent of intra-sector variation in emissions.

5.4.1 An Example

We begin our analysis by working through an example demonstrating both the calculations as well as the assumption involved with this measure. Let P_{kn} be the percentage of the total value of products produced by firm k for which product n is responsible. Note that n is equal to the product numbers observed in the register data. Table 5.2 is an example of the data we constructed using firms' cvr-numbers. Next, using the survey data "Industrial Energy", we observed that this hypothetical firm used 9658 GJ of electricity in 2007 (note, again, that these are hypothetical values). So, the electricity used in the production of each product n is given by total electricity used multiplied by P_{kn}. An example of this calculation is provided in table 5.3.

The next stage in the computation was to convert the energy used in the production of each product into carbon emissions. We proceeded in four steps.

1. The first step was to ascertain the different types of fuel used to produce electricity in Denmark. We have access to generator level data which allowed us to compute the percentage contribution of the different fuels to aggregate electricity generation. These percentages, which we denote by P_f are given in table 5.4.

Table 5.2: Data from VARS- 2007

CVR-Nr[a]	Sector	Product Nr	Annual Value[b]	P_{kn}
00600XXXXX	233200	6904100000	15,478	45.35
00600XXXXX	233200	6907909100	8,154	23.89
00600XXXXX	233200	6908909100	5,958	17.46
00600XXXXX	233200	6914901000	4,540	13.30

[a] A cvr number is a unique identification number given to each firm in Denmark. Using each firm's cvr number, we can access firm-specific data enabling us to construct the data reported in the table.

[b] Measured in 1000 DKK.

Table 5.3: Product Share of Purchased Electricity

Product-Nr	6904100000	6907909100	6908909100	6914901000
Electricity used	4379,92	2307,39	1685,98	1284,71

[a] Measure in GJ.

Table 5.4: Fuel Shares in Electricity Generation

Fuel	P_f[a]
Coal	42
Natural Gas	19.5
Waste	7
Heavy Fuel Oil	3
Orimulsion	2.5
Straw	2
Wood Pellets	1.2
Wood Chips	1
Biomass Waste	0.8
Bio Gas	0.8
Refinery Gas	0.7
Gas Oil	0.5
Wind	19

[a] Values are percentages.

2. Next, we multiplied P_f with the electricity used in the production of each product to estimate the amount of fuels used to produce each product. Example results are presented in table 5.5.

3. Different fuels cause different levels of emissions. Therefore, we used the emission factors for the different fuels as assessed by Danish National Environmental Research Institute to convert the fuel firms used into emissions, depending on the fuel type. This was done by multiplying each cell in table 5.5 by the emissions factors. Once we have the emissions based on different fuel types, it was a matter of aggregating to get total emissions for each product produced by a firm and then dividing by total value to get emissions per DKK.

4. The final stage was to remove the value of exports.

Table 5.5: Fuel Based Electricity Division in Products

Fuel	6904100000	6907909100	6908909100	6914901000
Coal	1839,56	969,11	708,11	539,58
Natural Gas	854,08	449,94	328,77	250,52
Waste	306,59	161,52	118,02	89,93
Heavy Fuel Oil	131,40	69,22	50,58	38,54
Orimulsion	109,50	57,68	42,15	32,12
Straw	87,60	46,15	33,72	25,69
Wood Pellets	52,56	27,69	20,23	15,42
Wood Chips	43,80	23,07	16,86	12,85
Biomass Waste	35,04	18,46	13,49	10,28
Bio Gas	35,04	18,46	13,49	10,28
Refinery Gas	30,66	16,15	11,80	8,99
Gas Oil	21,90	11,54	8,43	6,42
Wind	832,18	438,40	320,34	244,10

[a] Measured in GJ

This algorithm was also applied to firms' purchases of central heating as well as to firms' use of fuels directly in the production of their goods (not due to electricity). Finally, we averaged the emissions/DKK across all the firms producing the same product, thereby arriving at a per product emission factor $e_{i_k}^{DK}$ where i_k refers to product k from sector i.

5.4.2 Intra-sector Variation in Emissions

The reason for calculating the emissions of each product for each firm was to get at the intra-sector variation in emissions. What we mean by this is that all of our methodologies until now have used data at the aggregate sector level. However, some products which belong to the same sector might have very different emission levels. As such, when calculating the emissions imbedded in imports, since we only use sector level data, we might miss this intra-sector variation. We aim to correct this, and at the same time, measure the importance of intra-sector variation, by analysing the intra-sector variation of emissions across products for Danish sectors and then applying the same variation for goods that were imported. Of course, this can only capture part of the variation since we cannot observe intra-sector variation in sectors located in countries other than Denmark.

It will prove to be useful to first define a few additional variables.

- E_i^{j-DK} = Emissions caused by Denmark in sector i of country j
- $\Phi_{i_k}^{DK} = \frac{e_{i_k}^{DK}}{e_i^{DK}}$ is the share of product k's emissions in sector i.
- $X_{i_k}^{j-DK}$ = Amount (value) of good i_k imported from country j
- X_i^{j-DK} = Total value of goods imported from sector i in country j
- E_I^{DK} = Total industrial emissions caused by Denmark

The emissions embodied in sector i coming from country j (or Denmark) is

$$E_i^{j-DK} = E_i^j \sum_{i_k} \Phi_{i_k}^{DK} \frac{X_{i_k}^{j-DK}}{X_i^{j-DK}}. \tag{5.16}$$

One way to interpret equation (5.16) is that it is a weighted sum of the emissions produced by product k in sector i, where the weights are the share of a product's emission factor in a Danish sector. After accounting for intra-sector variation, total carbon emissions for Denmark were obtained by summing across all industries:

$$E_{Ic_4}^{DK} = \sum_j \sum_i E_i^{j-DK}. \tag{5.17}$$

So, total emissions are

$$E_{c_4}^{DK} = E_{Ic_4}^{DK} + E_{Hc_4}^{DK}. \tag{5.18}$$

The results from this analysis are shown in figure 5.7. From this figure, we can see that the emission levels based on product/firm level data do not change much when compared to the earlier results using sector level data and the world I-O tables. As we stated earlier, this methodology was developed to analyse the intra-sector variation in emission levels for different products. We used the variation in emission levels of products from the Danish economy to scale emission levels from products from other countries. The results

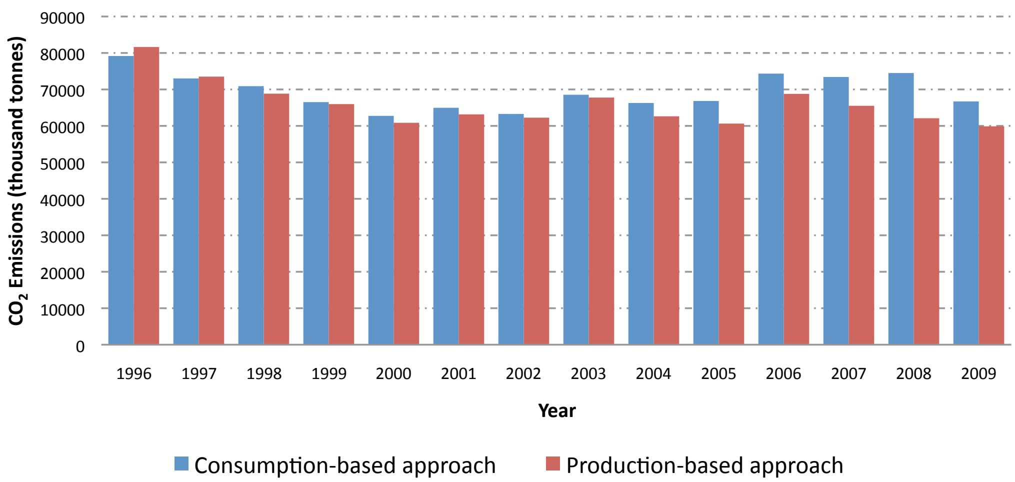

Figure 5.7: Danish CO_2 Emissions (Product-Level), $E_{c_4}^{DK}$ and E_p^{DK},1996-2009

imply that assuming away intra-sector variation in emissions does not distort measures of emissions too much.

However, two caveats are in order here. First, since we do not have access of product level data for countries other than Denmark, it is possible that other countries have intra-sector variation in emission levels of products which is quite different from the variation in Danish industries, which can affect the results. Second, we are only able to match 60 percent of the products in the trade data with product information in the Energy surveys for Danish Manufacturing firms. The flip side of this is that we do not have detailed emission data for 40 percent of the products.

Chapter 6

Counterfactuals and Analysis

6.1 Emission Levels of Danish Imports vs Danish Domestic Production

Some studies, while evaluating the emissions of a country using a consumption-based method, assume that all countries have the same or similar emissions factors. This is a strong assumption: Denmark and China have very different energy sectors, for example, which means they have quite different emission factors across sectors. Differences in emission factors exist for a number of reasons: Countries have different environmental polices, geographies, climates as well as different levels of income. Each of these factors contribute to differences in the structure of the energy sector as well as the industrial and manufacturing sectors. It is not the case that researchers were not aware of the drawback of this type of assumption, rather these types of assumptions were or are typically made because of limitations in the data.

In this section, we exam how these types of assumptions can influence measures of carbon. In particular, we use Method 2 from Chapter 2, i.e., equations (5.9) and (5.8) to see how consumption emissions vary based on how emission factors across countries are treated. Recall the method outlined in section 5.3.2. We calculated new consumption emissions under the assumption that other countries have identical production attributes as Denmark (in terms of producing emissions).[1] These new consumption emissions, which we denote as $E^{DK}_{r=1}$, are compared to emissions calculated using the World I-O tables, E^{DK}_{w}, in figure 6.1. Importantly, under the standard assumption of equal emission factors, consumption emissions are lower than emissions which accounted for differences in emissions intensities across countries. It is clear that emissions caused by Denmark are underestimated if we do not take into account variation in emission factors across countries. Clearly, emissions imbedded in Danish imports are being underestimated. This is primarily because the Danish electricity sector has reduced carbon emissions since 1996.

To emphasize the role of trade for Danish emissions, in table 6.1, we compare the emissions imbedded

[1]This amounts to assuming that $r^A_i = 1$ in equation (5.8).

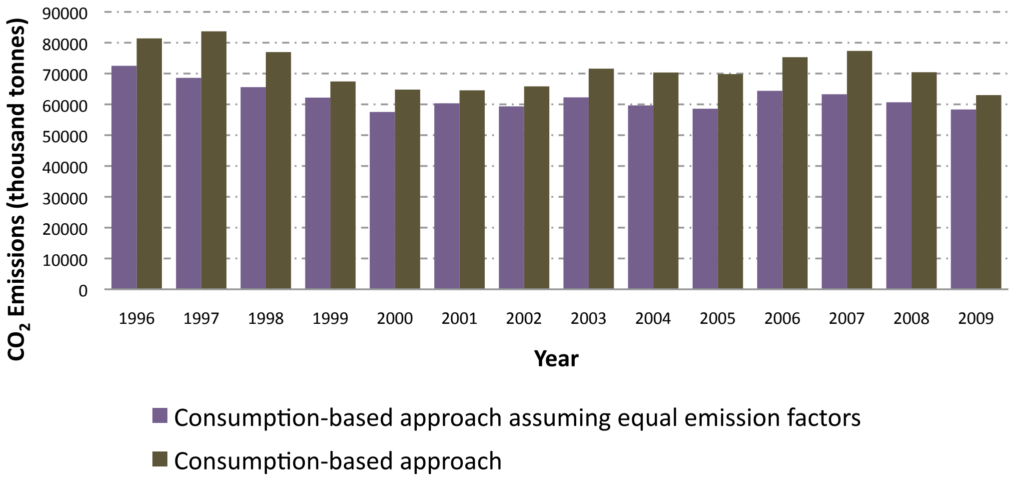

Figure 6.1: Danish CO_2 Emissions,$r_i^A = 1$ and E_w^{DK}, 1996-2009

in imports, assuming other countries have the same emission rates as Denmark, to the actual emissions in Danish imports. Importantly, Denmark is importing goods that produced at least twice the emissions relative to what they would have been emitted if produced in Denmark. Moreover, the ratio has been getting larger over time.

6.2 Trade Balance

An important characteristic of Denmark's trade flows is that it has been importing more emission intensive goods and exporting relatively "cleaner" goods. This feature of Denmark's trade pattern was illustrated in figure 1.7. One way to measure the relative importance of this characteristic on emissions levels is to compute the emissions levels that would obtain assuming balanced trade. That is, to carry out a hypothetical exercise in which Danish imports are constrained to equal Danish exports in terms of value and we compute consumption emissions. Although there is no unique way to impose trade balance, we chose to scale the imports to the level of exports. The results of this exercise are reported in figure 6.2. Assuming trade balance does not affect the results too much. There is a tendency for consumption emissions to be larger than the base case.

Table 6.1: Importing Emissions

Year	Counterfactual ($r_i^A = 1$)	Actual (Y)	Ratio
1996	6176	13240	2.14
1997	6888	13416	1.95
1998	6623	13768	2.08
1999	6304	12990	2.06
2000	6037	13532	2.24
2001	6631	13726	2.07
2002	6841	12663	1.85
2003	6004	13998	2.33
2004	6675	14853	2.22
2005	7234	17359	2.40
2006	7219	18698	2.59
2007	7290	19182	2.63
2008	8278	23770	2.87
2009	6948	17401	2.50

[a] Measured in 1000 tonnes CO2.

6.3 Emissions Using 1996 Levels

By most accounts, the early 1990's was the period when countries around the world started acknowledging the effects of human activities on the environment and specifically the effect of carbon emissions on the atmosphere and rising temperatures. Denmark was amongst the first countries to sign and become part of the Kyoto Protocol. Many other European countries also signed the protocol.

An interesting question is what if countries had gone on with "business-as-usual" and not attempted to curb emissions? To answer this question, we can carry out another hypothetical exercise in which we assume emission factors remained at the 1996 levels. This will illustrate whether governments' policies have had any real effect on carbon emissions, at least in terms of emissions caused by Denmark.

The results of this experiment are reported in figure 6.3. Clearly, if Denmark and the other countries had not responded to the need to cut back emissions, total emissions would have kept on rising for Denmark. The fact that this figure looks very different from the actual emissions, where the latter levels are lower, we can conclude that policies regarding cutting back emissions have worked to some degree.

Figure 6.2: Danish CO_2 Emissions assuming Trade Balance, 1996-2009

6.4 Emission Levels within Danish Imports

Recall from Method 2, i.e., equation (5.10), that the ratio r_i^A is the emissions per unit of output in sector i in country A, relative to emissions per unit of output in sector i in Denmark. In other words, we can use this ratio to study changes in the level of emissions in Danish imports from country A relative to Danish emissions. In particular, we computed country specific ratios r^A by taking the weighted sum of the individual r_i^A where the weights were derived from the amount of imports from sector i to Denmark. We track these ratios over time. The results are presented in figure 6.4 for four of the most important Danish trading partners. Approximately, 28 percent of Danish imports comes directly from Germany and Sweden, hence we study these countries in detail. Also since the USA and China are the biggest players in international trade, it makes sense to consider the emissions embedded in imports from these countries to Denmark.

Consider first Germany and Sweden. It is clear that imports from these countries have not become more emission intensive over time relative to Danish domestic production. Interestingly, the emission intensities in imports from China actually declined relative to Danish domestic production.[2] However, note that the intensities were much higher relative to Denmark's.

[2]It is important to remember that these ratios r^A are weighted by the amount Denmark imports from these countries. They should not be taken to mean that over all emissions in these countries have declined

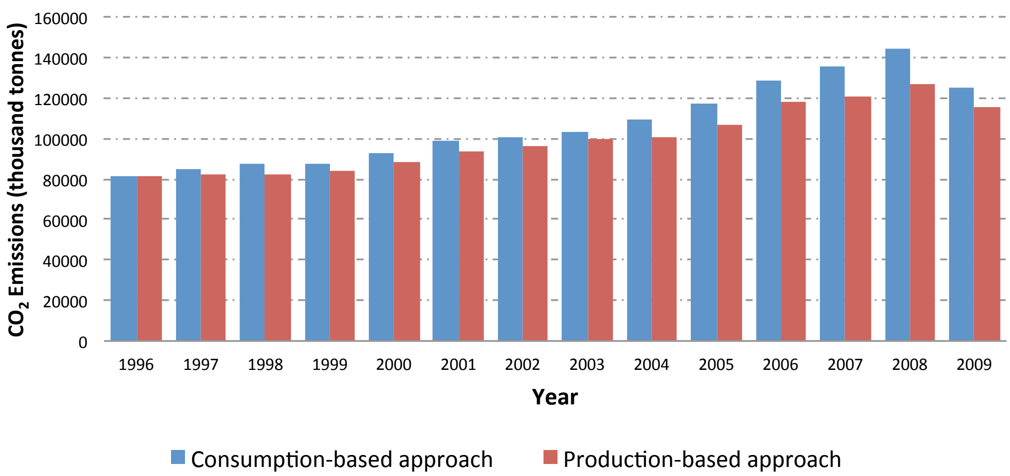

Figure 6.3: Danish CO_2 Emissions assuming 1996 Emission Rates, 1996-2009

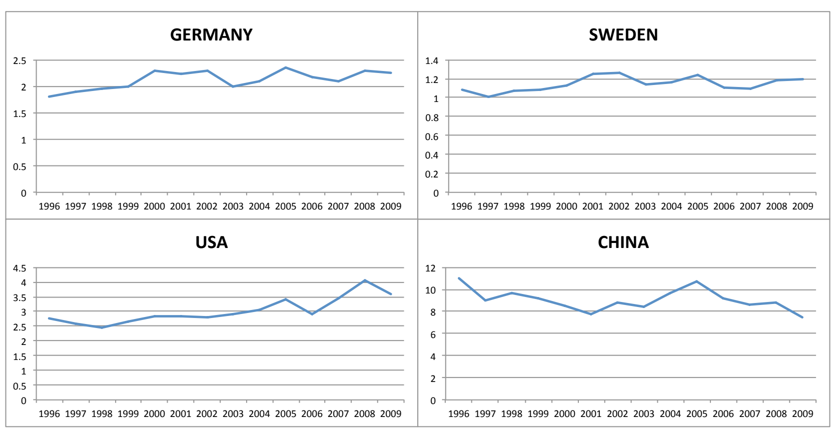

Figure 6.4: r^A, 1996-2009

Bibliography

BASTIANONI, S., F. PULSELLI, AND E. TIEZZI (2004): "The Problem of Assigning Responsibility for Greenhouse Gas Emissions," *Ecological Economics*, 49, 253 – 257.

DANISH ENERGY AGENCY (2012): *Annual Energy Production Statistics.*

DAVIS, S. AND K. CALDEIRA (2010): "Consumption-Based Accounting of CO_2 Emissions," *PNAS*, 107, 5687 – 5692.

DIETZENBACHER, E., B. LOS, R. STEHRER, M. TIMMER, AND G. DE VRIES (2013): "The Construction of World Input-Output Tables in the WIOD-Project," *Economic Systems Research*, 25, 71 – 98.

EUROSTAT (2013): "Correspondence Tables," .

FERNG, J. (2003): "Allocating the Responsibility of CO_2 Emissions From the Perspectives of Benefit Principle and Ecological Deficit," *Ecological Economics*, 46, 121 – 141.

GALEOTTI, M. AND A. LANZA (1999): "Richer and Cleaner? A Study on Carbon Dioxide Emissions in Developing Countries," *Energy Policy*, 27, 565–573, cited By (since 1996)42.

GALEOTTI, M., A. LANZA, AND F. PAULI (2006): "Reassessing the Environmental Kuznets Curve for CO_2 emissions: A Robustness Exercise," *Ecological Economics*, 57, 152 – 163.

GRAVGARD, O., T. OLSEN, AND P. RØRMOSE (2009): "Greenhouse Gas Emissions from the Danish Economy," *Statistics Denmark*.

GROSSMAN, G. AND A. KRUEGER (1995): "Economic Growth and the Environment," *Quarterly Journal of Economics*, 110, 353–377.

HOLTZ-EAKIN, D. AND T. SELDEN (1995): "Stoking the Fires? CO2 Emissions and Economic Growth," *Journal of Public Economics*, 57, 85–101, cited By (since 1996)326.

IEA (2011): "Energy Balances of OECD and Non-OECD Countries, 2011 Edition," .

IPCC (1996): "Guidelines for National Greenhouse Gas Inventories," *Intergovernmental Panel on Climate Change, London*, 1-3.

IPCC (2014): *Climate Change 2013: The Physical Science Basis*, Intergovernmental Panel on Climate Change.

MINISTRY OF CLIMATE, ENERGY AND BUILDING (2011): *Energistrategi 2050 - fra kul, olie og gas til grn energi.*

MINX, J., T. WIEDMANN, R. WOOD, G. PETERS, M. LENZEN, A. OWEN, K. SCOTT, J. BARRETT, K. HUBACEK, G. BAIOCCHI, A. PAUL, E.DAWKINS, J. BRIGGS, D. GUAN, S. SUH, AND F. ACKERMAN (2009): "Input-Output Analysis and Carbon Footprinting: An Overview of Applications," *Economic Systems Research*, 21, 187 – 216.

Munksgaard, J. and K. Pedersen (2001): "CO_2 Accounts for Open Economies: Producer or Consumer Responsibility?" *Energy Policy*, 29, 327 – 334.

Nakano, S., N. Okamura, M. Sakurai, M. Suzuki, Y. Tojo, and N. Yamano (2009): "The Measurement of CO_2 Embodiments in International Trade: Evidence from the Harmonised Input-Output and Bilateral Trade Database," *OECD Science, Technology and Industry Working Papers.*

Peters, G. (2008): "From Production-Based to Consumption-Based National Emission Inventories," *Ecological Economics*, 65, 13 – 23.

Peters, G. and E. Hertwich (2008): "Post-Kyoto Greenhouse Gas Inventories: Production Versus Consumption," *Climate Change*, 86, 51 – 66.

Proops, J. L., G. Atkinson, B. F. Schlotheim, and S. Simon (1999): "International Trade and the Austainability Footprint: A Practical Criterion for its Assessment," *Ecological Economics*, 28, 75 – 97.

Statistics Denmark (2013): "Danish Input-Output Tables and Analysis 2009: Imports, Employment and Environment, 7. Edition," .

Timmer, M., A. Erumban, R. Gouma, B. Los, U. Temurshoev, G. de Vries, I. Arto, V. Genty, F. Neuwahl, M. Rueda-Cantuche, A. Villanueva, J. Francois, O. Pindyuk, J. Pschl, R. Stehrer, and G. Streicher (2012): "The World Input-Output Database (WIOD): Contents, Sources and Methods," *Climate Change.*

Timmer, M., A. Erumban, B. Los, R. Stehrer, and G. de Vries (2014): "Slicing Up Global Value Chains," *Journal of Economic Perspectives*, 28, 99 – 118.

Tucker, M. (1995): "Carbon Dioxide Emissions and Global GDP," *Ecological Economics*, 15, 215–223, cited By (since 1996)39.

UN (2013): "Classification Registry," .

Wiedmann, T. (2009): "A Review of Recent Multi-Region Input-Output Models Used for Consumption-Based Emission and Resource Cccounting," *Econogical Economics*, 69, 211 – 222.

Appendix A

Additional Analysis

In this appendix, we report the results of various other computations. First, we report an aggregate measure of greenhouse gasses. The aggregate measure includes two other Kyoto covered greenhouse gasses: methane, CH_4, as well as nitrous oxide, N_2O. Second, we report the CO_2 emissions associated with fuel bunkering. Standard international reporting of greenhouse gas emissions does not include fuel bunkering. Moreover, recall that the Kyoto Agreement does not cover fuel bunkering. However, we calculated the emissions associated with fuel bunkering and present them in this appendix because shipping is a significant economic activity in Denmark. Finally, we report the emission incidence both across countries and within sectors.

A.1 Aggregate Greenhouse Gas Emissions

Aggregate greenhouse gas emissions are presented in figure A.1. Emissions are reported in units of CO_2 equivalent using a measure called the global warming potential (GWP). GWP is a relative measure of how much heat a greenhouse gas traps in the atmosphere when emitted relative to CO_2. Using GWP provides a way to aggregate greenhouse gas emissions. In particular, the GWP is the warming effect of a mass of a given greenhouse gas relative to the same mass of CO_2. The GWP of CO_2 is normalized to one.

CH_4 is emitted via human activities includes burning of natural gas, leakage from natural gas systems, the burning of biomass and the raising of livestock. The comparative impact of CH_4 on climate change is calculated as being 25 times greater than CO_2 over a 100-year period. N_2O comes naturally from the oceans and from the breaking down of organic material as well as from human activities including various uses in agriculture, the burning of biomass and some industrial activities. The GWP of N_2O is calculated as being 298 times greater than CO_2 over a 100 year period.

Figure A.1 shows that CO_2 is the most prevalent greenhouse gas emitted by Danish consumers (about 82 percent of the Danish GWP). The second most prevalent greenhouse gas is CH_4, which contributes by about 11 percent, while N_2O accounts for about 7 percent of the total Danish global warming potential. Interestingly, consumption of N_2O is marginally lower than the production of N_2O, which is perhaps not surprising given the large Danish agricultural sector.

A.2 International Transportation and Bunkering

The carbon accounting requirements established in the Kyoto Protocol do not include emissions from bunker fuel used in planes and ships. However, bunker fuel is known to be a significant contributor to global carbon emissions. Moreover, accounting for emissions from the use of bunker fuel is particularly important for Denmark because shipping is an important economic activity. So, we calculated carbon emissions from the use of bunker fuel in shipping and report them in table A.1.

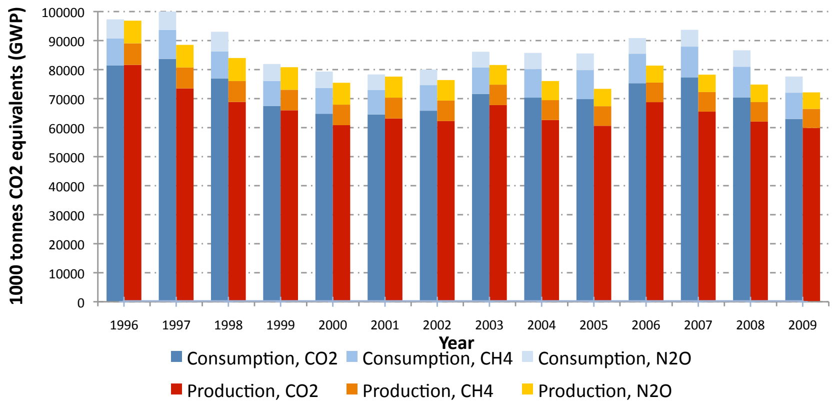

Figure A.1: Aggregate Emissions, CO_2 Equivalent

Emissions from Danish shipping have increased in the more recent years. In 1996, emissions from Danish operated ships in international waters were 11 million tonnes. By 2008 emissions increased to 42 million tonnes. There are likely two reasons for the increase in emissions: First, there has been an increase in international trade requiring ocean transport; and, second, shipping has traditionally been an important economic activity in Denmark.

In table A.2 we report production emissions which now include emissions from bunker fuel. One will notice immediately that when we include emissions from bunker fuel, we get a different picture of Danish production emissions. In particular, Danish emissions between 2005 and 2009 were actually higher than pre-2005 levels. In the last four columns of the table we report the percentage contributed by each sector to aggregate emissions. It is clear from the table that emissions due to shipping has become a significant source of emissions. In 2009, shipping contributed just over 40 percent of aggregate production emissions, whereas industry produced just over 46 percent. There was a modest decline in household emissions after 2005.

Note that production emissions which include international transport are substantially higher than consumption emissions.[1] However, as previously noted fuel bunkering is not part of the Kyoto Agreement and therefore not included in the main results.

[1]By contrast, consumption emissions are relatively invariant to the inclusion of fuel bunkering suggesting that emissions from fuel bunkering related to imports are similar to those related to exports.

Table A.1: Ships and Planes Bunkering CO_2 Emissions, 1990-2000

Year	Planes	Ships	Aggregate
1996	431	10714	11145
1997	538	11811	12349
1998	745	15954	16700
1999	686	15277	15962
2000	514	18951	19466
2001	630	17489	18119
2002	655	19846	20501
2003	664	23514	24178
2004	460	25351	25811
2005	1610	32309	33920
2006	1812	41757	43569
2007	1947	49647	51594
2008	1851	47202	49052
2009	1719	41567	43286

[a] Measured in 1000 tonnes CO_2

Table A.2: Aggregate CO_2 Emissions

Year	CO_2 Emissions[a]	Industrial[b]	Ship Bunkering[b]	Plane Bunk[b]	Household[b]
1996	92775	74.33	11.55	0.46	13.65
1997	85866	70.66	13.75	0.63	14.96
1998	85540	66.06	18.65	0.87	14.41
1999	81939	65.81	18.64	0.84	14.71
2000	80320	61.39	23.59	0.64	14.37
2001	81276	63.18	21.52	0.77	14.53
2002	82763	60.59	23.98	0.79	14.64
2003	91947	60.16	25.57	0.72	13.55
2004	88446	56.78	28.66	0.52	14.03
2005	94553	50.71	34.17	1.70	13.41
2006	112350	49.95	37.17	1.61	11.27
2007	117103	44.77	42.40	1.66	11.17
2008	111150	44.70	42.47	1.66	11.17
2009	103176	46.40	40.29	1.67	11.64

[a] Measured in 1000 tonnes.

[b] Percentage of aggregate CO_2 emissions.

A.3 Emission Incidence: By Country and Sector

In equation 5.1, we saw how emissions caused by Danish consumption can be calculated using data from an input-output matrix. Using this equation, we can also disaggregate emissions by country as well as by sector. By disaggregating the emissions, we can identify in which countries Danish consumption is causing emissions as well as in which sectors.

From the world input-output tables we have 35 industries and 40 countries. This implies that $\bar{e} = e(I-A)^{-1}$ is 1×1400 row vector. We can think of $\bar{e}$ as a row of corrected emission factors. We used equation (A.1) to disaggregate aggregate Danish consumption emissions into those emissions caused in each country. Recall that the first 35 elements in the Y vector in equation 5.1 pertain to Denmark. We did not include them in this calculation because we want to know the emissions caused in other countries:

$$E^{j-DK} = [\bar{e}_{35\times j+1} \dots \bar{e}_{35.j+35}] \times \begin{bmatrix} Y_1^{j-DK} \\ \vdots \\ Y_{35}^{j-DK} \end{bmatrix} \text{ where } j = 1 \dots 35 \quad \text{(A.1)}$$

Similarly, in order to disaggregate total emissions into each sector, we collected all the emissions caused in different countries, including Denmark, but within the same sector. In particular,

$$E_i^{DK} = [\bar{e}_i, \bar{e}_{i+35}, \bar{e}_{i+70} \dots \bar{e}_{35+40\times35}] \times \begin{bmatrix} Y_i^{DK-DK} \\ Y_i^{1-DK} \\ \vdots \\ Y_i^{39-DK} \end{bmatrix} \text{ where } j = 1 \dots 35 \tag{A.2}$$

The results of the computation are reported in table A.4 as well as in table A.5.

Table A.3: Countries

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

[a]

Table A.4: Countries

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
AUS	46[a]	240	84	32	33	39	40	43	54	57	58	56	57	61
	(0,1)[b]	(0,4)	(0,2)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,2)
AUT	73	170	93	104	104	100	111	112	112	111	112	116	107	81
	(0,2)	(0,3)	(0,2)	(0,2)	(0,2)	(0,2)	(0,3)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)
BEL	507	523	525	541	498	455	505	493	548	488	504	512	546	464
	(0,8)	(0,8)	(0,9)	(1)	(1)	(0,9)	(1)	(0,9)	(1)	(0,9)	(0,9)	(0,8)	(1)	(1)
BRA	11	93	10	11	12	27	18	20	23	32	37	40	94	43
	(0,1)	(0,2)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,2)	(0,1)
BGR	50	978	36	34	22	19	19	18	18	25	28	17	17	15
	(0,1)	(1,4)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)
CAN	91	273	94	139	186	127	221	116	140	123	140	231	243	181
	(0,2)	(0,4)	(0,2)	(0,3)	(0,4)	(0,3)	(0,5)	(0,2)	(0,3)	(0,3)	(0,3)	(0,4)	(0,5)	(0,4)
CHN	1542	1248	1204	1282	1014	916	910	1348	1804	2339	2783	3127	3159	2726
	(2,3)	(1,8)	(1,9)	(2,4)	(2)	(1,8)	(1,7)	(2,3)	(3,2)	(4,1)	(4,5)	(4,9)	(5,5)	(5,4)
CYP	2	56	5	4	4	3	5	4	2	4	3	4	7	5
	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)
CZE	121	387	107	109	85	94	88	87	139	183	248	258	223	184
	(0,2)	(0,6)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,3)	(0,4)	(0,4)	(0,5)	(0,4)	(0,4)
DNK	56440	53557	51551	41946	39950	40858	40508	45638	42708	41534	44483	46190	39734	35935
	(82,2)	(75,6)	(79,8)	(75,8)	(75,1)	(77,5)	(75,5)	(77,2)	(73,8)	(72,7)	(71,1)	(71,9)	(68,5)	(70,5)
EST	76	248	116	145	146	114	147	105	97	87	90	78	95	96
	(0,2)	(0,4)	(0,2)	(0,3)	(0,3)	(0,3)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)
FIN	194	308	204	331	288	271	328	250	239	287	300	284	341	206
	(0,3)	(0,5)	(0,4)	(0,6)	(0,6)	(0,6)	(0,7)	(0,5)	(0,5)	(0,6)	(0,5)	(0,5)	(0,6)	(0,5)
FRA	633	516	740	696	581	618	755	493	500	489	532	489	417	323
	(1)	(0,8)	(1,2)	(1,3)	(1,1)	(1,2)	(1,5)	(0,9)	(0,9)	(0,9)	(0,9)	(0,8)	(0,8)	(0,7)
DEU	2131	1373	2465	2517	2569	2492	2577	2618	2644	2829	3384	3376	3149	2626
	(3,2)	(2)	(3,9)	(4,6)	(4,9)	(4,8)	(4,8)	(4,5)	(4,6)	(5)	(5,5)	(5,3)	(5,5)	(5,2)
GRC	21	65	34	26	31	30	31	31	34	64	78	48	38	46
	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,2)	(0,2)	(0,1)	(0,1)	(0,1)	(0,1)
HUN	24	219	30	33	34	37	42	48	62	90	100	163	156	116
	(0,1)	(0,4)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,2)	(0,2)	(0,2)	(0,3)	(0,3)	(0,3)
IND	308	715	288	285	294	252	237	244	343	486	476	511	538	454
	(0,5)	(1,1)	(0,5)	(0,6)	(0,6)	(0,5)	(0,5)	(0,5)	(0,6)	(0,9)	(0,8)	(0,8)	(1)	(0,9)
IDN	70	203	122	109	110	115	93	93	122	96	100	100	112	107
	(0,2)	(0,3)	(0,2)	(0,2)	(0,3)	(0,3)	(0,2)	(0,2)	(0,3)	(0,2)	(0,2)	(0,2)	(0,2)	(0,3)

[a] Measured in 1000 tonnes.

[b] Percentage of aggregate CO_2 emissions caused by Danish consumption.

Table A.4: Countries (continued)

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
IRL	222	230	151	154	169	147	135	126	139	156	177	160	139	112
	(0,4)	(0,4)	(0,3)	(0,3)	(0,4)	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)
ITA	546	379	638	612	556	559	524	491	513	572	587	628	537	379
	(0,8)	(0,6)	(1)	(1,2)	(1,1)	(1,1)	(1)	(0,9)	(0,9)	(1,1)	(1)	(1)	(1)	(0,8)
JPN	179	120	198	192	126	121	136	92	115	187	215	222	235	93
	(0,3)	(0,2)	(0,4)	(0,4)	(0,3)	(0,3)	(0,3)	(0,2)	(0,2)	(0,4)	(0,4)	(0,4)	(0,5)	(0,2)
KOR	283	340	531	209	604	347	104	681	1134	476	448	221	196	948
	(0,5)	(0,5)	(0,9)	(0,4)	(1,2)	(0,7)	(0,2)	(1,2)	(2)	(0,9)	(0,8)	(0,4)	(0,4)	(1,9)
LVA	47	110	70	60	53	53	49	47	54	61	66	60	56	56
	(0,1)	(0,2)	(0,2)	(0,2)	(0,1)	(0,2)	(0,1)	(0,1)	(0,1)	(0,2)	(0,2)	(0,1)	(0,1)	(0,2)
LTU	80	167	68	103	145	130	239	169	112	84	78	90	260	86
	(0,2)	(0,3)	(0,2)	(0,2)	(0,3)	(0,3)	(0,5)	(0,3)	(0,2)	(0,2)	(0,2)	(0,2)	(0,5)	(0,2)
LUX	7	84	8	9	8	7	10	9	13	14	17	12	22	23
	(0,1)	(0,2)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)
MLT	0	27	0	1	1	1	0	1	1	1	2	2	5	8
	(0)	(0,1)	(0)	(0,1)	(0,1)	(0,1)	(0)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)
MEX	31	174	31	32	93	80	90	100	122	71	88	55	96	48
	(0,1)	(0,3)	(0,1)	(0,1)	(0,2)	(0,2)	(0,2)	(0,2)	(0,3)	(0,2)	(0,2)	(0,1)	(0,2)	(0,1)
NLD	903	1111	1052	1069	1348	1043	1077	1313	1451	952	1040	1041	1211	1001
	(1,4)	(1,6)	(1,7)	(2)	(2,6)	(2)	(2,1)	(2,3)	(2,6)	(1,7)	(1,7)	(1,7)	(2,1)	(2)
POL	933	1102	747	756	778	657	838	692	789	791	888	829	842	586
	(1,4)	(1,6)	(1,2)	(1,4)	(1,5)	(1,3)	(1,6)	(1,2)	(1,4)	(1,4)	(1,5)	(1,3)	(1,5)	(1,2)
PRT	141	198	152	140	107	98	80	68	63	61	65	54	55	44
	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,2)	(0,1)	(0,1)	(0,1)
ROU	22	498	20	17	23	19	16	16	14	18	20	14	27	24
	(0,1)	(0,8)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)
RUS	181	1883	223	383	416	281	449	430	388	485	693	400	501	189
	(0,3)	(2,7)	(0,4)	(0,7)	(0,8)	(0,6)	(0,9)	(0,8)	(0,7)	(0,9)	(1,2)	(0,7)	(0,9)	(0,4)
SVK	24	393	15	20	26	29	32	37	44	51	68	100	114	73
	(0,1)	(0,6)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,2)	(0,2)	(0,2)	(0,2)
SVN	15	150	23	23	24	26	26	29	35	46	70	65	45	34
	(0,1)	(0,3)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,1)	(0,2)	(0,2)	(0,1)	(0,1)
ESP	169	293	241	227	214	206	219	212	268	298	350	323	227	174
	(0,3)	(0,5)	(0,4)	(0,5)	(0,5)	(0,4)	(0,5)	(0,4)	(0,5)	(0,6)	(0,6)	(0,6)	(0,4)	(0,4)

Table A.4: Countries (continued)

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
SWE	893	858	1015	1173	1004	977	1439	1413	1543	1797	2329	2389	2101	1523
	(1,3)	(1,3)	(1,6)	(2,2)	(1,9)	(1,9)	(2,7)	(2,4)	(2,7)	(3,2)	(3,8)	(3,8)	(3,7)	(3)
TWN	162	273	167	195	237	134	179	190	228	230	216	245	193	142
	(0,3)	(0,4)	(0,3)	(0,4)	(0,5)	(0,3)	(0,4)	(0,4)	(0,4)	(0,5)	(0,4)	(0,4)	(0,4)	(0,3)
TUR	107	304	124	156	133	138	158	161	184	216	203	234	212	157
	(0,2)	(0,5)	(0,2)	(0,3)	(0,3)	(0,3)	(0,3)	(0,3)	(0,4)	(0,4)	(0,4)	(0,4)	(0,4)	(0,4)
GBR	923	603	884	906	822	760	840	727	656	672	771	691	909	826
	(1,4)	(0,9)	(1,4)	(1,7)	(1,6)	(1,5)	(1,6)	(1,3)	(1,2)	(1,2)	(1,3)	(1,1)	(1,6)	(1,7)
USA	528	376	563	593	402	363	443	364	468	574	794	829	995	797
	(0,8)	(0,6)	(0,9)	(1,1)	(0,8)	(0,7)	(0,9)	(0,7)	(0,9)	(1,1)	(1,3)	(1,3)	(1,8)	(1,6)

Table A.5: Sectors

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Agriculture, Hunting, Forestry and Fishing	1363	1460	1443	1313	1274	1191	1189	1262	1302	1308	1142	1374	1380	1244
	(2.0)	(2.1)	(2.2)	(2.4)	(2.4)	(2.3)	(2.2)	(2.1)	(2.2)	(2.3)	(1.8)	(2.1)	(2.4)	(2.4)
Mining and Quarrying	300	610	588	439	76	94	79	101	76	31	43	194	154	-62
	(0.4)	(0.9)	(0.9)	(0.8)	(0.1)	(0.2)	(0.1)	(0.2)	(0.1)	(0.1)	(0.1)	(0.3)	(0.3)	(-0.1)
Food, Beverages and Tobacco	3332	3575	3392	2676	2702	2630	2724	2902	2873	3020	2851	2897	2793	2442
	(4.8)	(5.0)	(5.2)	(4.8)	(5.1)	(5.0)	(5.1)	(4.9)	(5.0)	(5.3)	(4.6)	(4.5)	(4.8)	(4.8)
Textiles and Textile Products	1884	898	1461	1511	1326	1204	1100	1163	1193	1242	1257	1242	1048	788
	(2.7)	(1.3)	(2.3)	(2.7)	(2.5)	(2.3)	(2.0)	(2.0)	(2.1)	(2.2)	(2.0)	(1.9)	(1.8)	(1.5)
Leather, Leather and Footwear	219	8	181	159	158	160	106	112	120	132	135	151	115	76
	(0.3)	(0.0)	(0.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.2)	(0.1)
Wood and Products of Wood and Cork	138	143	152	129	136	118	139	143	161	145	162	166	131	85
	(0.2)	(0.2)	(0.2)	(0.2)	(0.3)	(0.2)	(0.3)	(0.2)	(0.3)	(0.3)	(0.3)	(0.3)	(0.2)	(0.2)
Pulp, Paper, Printing and Publishing	643	634	641	553	514	510	522	571	581	606	616	551	476	426
	(0.9)	(0.9)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.0)	(1.1)	(1.0)	(0.9)	(0.8)	(0.8)
Coke, Refined Petroleum and Nuclear Fuel	3172	1513	2070	2014	2113	2226	2459	2303	2013	2565	2681	2273	3072	2296
	(4.6)	(2.1)	(3.2)	(3.6)	(4.0)	(4.2)	(4.6)	(3.9)	(3.5)	(4.5)	(4.3)	(3.5)	(5.3)	(4.5)
Chemicals and Chemical Products	1075	1398	1171	1132	1116	1070	1101	1159	1264	1277	1352	1357	1420	1117
	(1.6)	(2.0)	(1.8)	(2.0)	(2.1)	(2.0)	(2.0)	(2.0)	(2.2)	(2.2)	(2.2)	(2.1)	(2.4)	(2.2)
Rubber and Plastics	272	275	288	248	241	235	245	263	320	337	353	380	346	262
	(0.4)	(0.4)	(0.4)	(0.4)	(0.5)	(0.4)	(0.5)	(0.4)	(0.6)	(0.6)	(0.6)	(0.6)	(0.6)	(0.5)
Other Non-Metallic Mineral	633	604	690	623	544	522	564	450	525	577	574	800	642	412
	(0.9)	(0.9)	(1.1)	(1.1)	(1.0)	(1.0)	(1.0)	(0.8)	(0.9)	(1.0)	(0.9)	(1.2)	(1.1)	(0.8)
Basic Metals and Fabricated Metal	663	1136	877	727	916	728	762	830	971	924	832	871	786	442
	(1.0)	(1.6)	(1.4)	(1.3)	(1.7)	(1.4)	(1.4)	(1.4)	(1.7)	(1.6)	(1.3)	(1.4)	(1.4)	(0.9)
Machinery, Nec	1257	3316	1434	1289	1293	1195	1213	1351	1437	1565	1888	2145	2166	1529
	(1.8)	(4.7)	(2.2)	(2.3)	(2.4)	(2.3)	(2.3)	(2.3)	(2.5)	(2.7)	(3.0)	(3.3)	(3.7)	(3.0)
Electrical and Optical Equipment	1556	2473	1362	1399	1374	1285	1320	1346	1683	1765	2270	2562	2228	1829
	(2.3)	(3.5)	(2.1)	(2.5)	(2.6)	(2.4)	(2.5)	(2.3)	(2.9)	(3.1)	(3.6)	(4.0)	(3.8)	(3.6)
Transport Equipment	2374	3698	2680	2128	2430	2070	2079	2278	3028	2670	3033	3315	3417	3267
	(3.5)	(5.2)	(4.1)	(3.8)	(4.6)	(3.9)	(3.9)	(3.9)	(5.2)	(4.7)	(4.8)	(5.2)	(5.9)	(6.4)

[a] Measured in 1000 tonnes.

[b] Percentage of aggregate CO_2 emissions caused by Danish consumption.

Table A.5: Sectors (continued)

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Manufacturing, Nec; Recycling	772	727	968	821	791	765	689	771	811	859	1019	1025	845	683
	(1.1)	(1.0)	(1.5)	(1.5)	(1.5)	(1.5)	(1.3)	(1.3)	(1.4)	(1.5)	(1.6)	(1.6)	(1.5)	(1.3)
Electricity, Gas and Water Supply	22404	18902	16955	14004	13034	13730	13538	15595	12745	10822	12569	11077	10006	10666
	(32.6)	(26.7)	(26.2)	(25.3)	(24.5)	(26.0)	(25.2)	(26.4)	(22.0)	(18.9)	(20.1)	(17.2)	(17.3)	(20.9)
Construction	6804	7825	7284	6381	6239	6206	5988	6734	6879	7048	8234	8464	7101	5523
	(9.9)	(11.0)	(11.3)	(11.5)	(11.7)	(11.8)	(11.1)	(11.4)	(11.9)	(12.3)	(13.1)	(13.2)	(12.2)	(10.8)
Sale, Repair of Mtr v's; Ret. Sale of Fuel	722	889	743	704	655	627	695	739	794	799	892	914	727	596
	(1.1)	(1.3)	(1.1)	(1.3)	(1.2)	(1.2)	(1.3)	(1.2)	(1.4)	(1.4)	(1.4)	(1.4)	(1.3)	(1.2)
Wholesale and Commission Trade (Except Mtr v's)	2933	3444	3275	2854	2504	2481	2748	2956	3042	3263	3447	4081	3137	2250
	(4.3)	(4.9)	(5.1)	(5.2)	(4.7)	(4.7)	(5.1)	(5.0)	(5.3)	(5.7)	(5.5)	(6.4)	(5.4)	(4.4)
Retail Trade (Except Mtr v's)	1042	1072	954	810	773	779	866	1002	959	884	982	990	964	828
	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.5)	(1.6)	(1.7)	(1.7)	(1.5)	(1.6)	(1.5)	(1.7)	(1.6)
Hotels and Restaurants	1006	965	932	825	762	758	761	801	799	822	885	911	857	735
	(1.5)	(1.4)	(1.4)	(1.5)	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)	(1.4)	(1.5)	(1.4)
Inland Transport	1081	1273	1227	710	839	802	806	859	956	986	974	1195	925	828
	(1.6)	(1.8)	(1.9)	(1.3)	(1.6)	(1.5)	(1.5)	(1.5)	(1.7)	(1.7)	(1.6)	(1.9)	(1.6)	(1.6)
Water Transport	383	816	853	221	433	359	445	422	501	616	522	711	246	26
	(0.6)	(1.2)	(1.3)	(0.4)	(0.8)	(0.7)	(0.8)	(0.7)	(0.9)	(1.1)	(0.8)	(1.1)	(0.4)	(0.1)
Air Transport	174	257	300	289	175	155	161	208	142	136	164	182	116	173
	(0.3)	(0.4)	(0.5)	(0.5)	(0.3)	(0.3)	(0.3)	(0.4)	(0.2)	(0.2)	(0.3)	(0.3)	(0.2)	(0.3)
Supporting and Auxiliary Transport Activities	861	834	803	824	663	540	625	673	698	745	783	790	754	840
	(1.3)	(1.2)	(1.2)	(1.5)	(1.2)	(1.0)	(1.2)	(1.1)	(1.2)	(1.3)	(1.3)	(1.2)	(1.3)	(1.6)

Table A.5: Sectors (continued)

Sector	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Post and Telecommunications	231	326	336	304	381	339	334	393	415	485	500	522	394	363
	(0.3)	(0.5)	(0.5)	(0.5)	(0.7)	(0.6)	(0.6)	(0.7)	(0.7)	(0.8)	(0.8)	(0.8)	(0.7)	(0.7)
Financial Intermediation	336	368	378	348	470	454	458	523	499	503	542	555	504	465
	(0.5)	(0.5)	(0.6)	(0.6)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)	(0.9)
Real Estate Activities	1322	1585	1513	1344	1201	1231	1324	1495	1508	1496	1733	1878	1584	1384
	(1.9)	(2.2)	(2.3)	(2.4)	(2.3)	(2.3)	(2.5)	(2.5)	(2.6)	(2.6)	(2.8)	(2.9)	(2.7)	(2.7)
Renting Mn. and Aq; Other Business Activities	632	692	727	674	648	672	788	841	919	993	1108	1208	1097	875
	(0.9)	(1.0)	(1.1)	(1.2)	(1.2)	(1.3)	(1.5)	(1.4)	(1.6)	(1.7)	(1.8)	(1.9)	(1.9)	(1.7)
Public Admin, Defence; Social Security	2367	2424	2364	2078	1955	1985	1930	2142	2356	2369	2363	2540	2156	2228
	(3.4)	(3.4)	(3.7)	(3.8)	(3.7)	(3.8)	(3.6)	(3.6)	(4.1)	(4.1)	(3.8)	(4.0)	(3.7)	(4.4)
Education	2013	1900	1903	1645	1507	1480	1566	1797	1642	1580	1704	1664	1514	1542
	(2.9)	(2.7)	(2.9)	(3.0)	(2.8)	(2.8)	(2.9)	(3.0)	(2.8)	(2.8)	(2.7)	(2.6)	(2.6)	(3.0)
Health and Social Work	3132	3130	3077	2818	2775	2850	3074	3502	3266	3300	3638	3859	3624	3601
	(4.6)	(4.4)	(4.8)	(5.1)	(5.2)	(5.4)	(5.7)	(5.9)	(5.6)	(5.8)	(5.8)	(6.0)	(6.2)	(7.1)
Other Community, Social and Personal Services	1638	1683	1609	1379	1227	1290	1320	1441	1450	1267	1390	1421	1280	1236
	(2.4)	(2.4)	(2.5)	(2.5)	(2.3)	(2.4)	(2.5)	(2.4)	(2.5)	(2.2)	(2.2)	(2.2)	(2.2)	(2.4)

Measuring Denmark's CO_2 Emissions

Denmark has committed to ambitious goals to reduce greenhouse gas emissions. In agreement with conventions and international practice, these goals only deal with CO_2 emissions originating from production activity in Danish national territory.

However, CO_2 emissions embodied in internationally traded goods and services are likely to play an important role in total CO_2 emissions related to economic activities in small open economies like Denmark.

With research funding from the Rockwool Foundation, Centre for Economic and Business Research (CEBR) at Copenhagen Business School has produced an emission inventory of the Danish economy, which accounts for the international trade of CO_2 emissions through imports and exports of goods and services.

Using the most recent data available, the analysis finds that total Danish annual CO_2 emissions have exceeded conventional CO_2 accounts by up to 18 percent in the period from 1996 to 2009.

The Rockwool Foundation

Kronprinsessegade 54, 2. tv
DK – 1306 Copenhagen K
Denmark

Tel	**+45 46 56 03 00**
Fax	**+45 46 59 10 92**
E-mail	**rockwool.fonden@rockwool.org**
Web	**rockwoolfoundation.org**